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Collaborative Cloud Land Surveying: A VGI-Based Approach to Practice and Education in Surveying Engineering

by Ioannis Sofos

supervisor
prof. Vassilios Vescoukis

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Ιωάννη Δ. Σοφού
Διπλωματούχου Αγρονόμου Τοπογράφου Μηχανικού ΕΜΠ, MBA, MSc

Η διατριβή υποβλήθηκε στη Σχολή Αγρονόμων Τοπογράφων Μηχανικών του Εθνικού Μετσόβιου Πολυτεχνείου προς εκπλήρωση των προϋποθέσεων του τίτλου του Διδάκτορος Μηχανικού.

Τριμελής Συμβουλευτική Επιτροπή

Β. Βεσκούκης, Αν.Καθ. ΕΜΠ

Μ. Τσακίρη, Αν.Καθ. ΕΜΠ

Μ. Κάβουρας, Καθ. ΕΜΠ

Επταμελής Εξεταστική Επιτροπή

Βεσκούκης Β, Αν.Καθ. ΕΜΠ

Γκίκας Β, Αν.Καθ. ΕΜΠ

Δουλάμης Ν, Επικ.Καθ. ΕΜΠ

Κάβουρας Μ, Καθ. ΕΜΠ

Μπούτουρα Χ, Καθ. ΑΠΘ

Πανταζής Γ, Αν.Καθ. ΕΜΠ

Τσακίρη Μ, Αν.Καθ. ΕΜΠ

Αθήνα, Μάρτιος 2017

Ιωάννης Δ. Σοφός

Υπ. Διδάκτωρ Σχολής Αγρονόμων Τοπογράφων Μηχανικών Ε.Μ.Π

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Prologue

Surveying Engineering attempts to freeze time, trap reality, understand it, abstract and release time again; just like a photographer takes a snapsot and abstracts three dimensional - full light spectrum reflecting space to a two dimensional human visible representation. It is in this context that I spent a big part of my life studying initially and researching on the sequence, the fundamental concepts of space and time. At the end, it is all about the best finite representation of an infinite reality, that we call a good “Measurement”.

This work is about measurement and only measurement. The most valuable, hard to get, expensive and irreplaceable asset of every Land Surveying process, but also strangely enough the first to be ignored in the end. Starting from modeling and following the route from data collection to final dissemination, the writer will explore several aspects of an alternative measurement ecosystem.

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…it is all about the best finite representation of an infinite reality

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Abbreviations

ACSM	American Congress on Surveying and Mapping
API	Application Program Interface
CCLS	Collaborative Cloud Land Surveying
CP	Control Point
DBMS	Database Management System
ENAEE	Network for Accreditation of Engineering Education
FIG	International Federation of Surveyors
GCP	Ground Control Point
GGRS 87	Greek Geodetic Reference System 1897
GI	Geographic Information
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
HEPOS	Hellenic Positioning System
HMGS	Hellenic Military Geographical Service
HOCS	Higher Order Cognitive Skills
INSPIRE	Infrastructure for Spatial Information in the EU
IS	Information Sharing
LADM	Land Administration Domain Model
LOCS	Lower Order Cognitive Skills
MBGIS	Measurement-Based Geographical Information System
NGRS	National Geodetic Reference System
O&M	Observations and Measurements
OGC	Open Geospatial Consortium
PPK	Post Processing Kinematic
RINEX	Receiver Independent Exchange Format
RTK	Real Time Kinematic
SAS	Sensor Alert Service
SML	Sensor Model Language
SOS	Sensor Observation Service
SPS	Planning Service
SWE	Sensor Web Enablement
TML	Transducer Model Language
TPS	Total Station Positioning System
TS	Total Station
VGI	Volunteer Geographic Information
WMS	Web Map Service
WNS	Web Notification Services
XML	eXtensible Markup Language

Abstract

Volunteered Geographic Information (VGI) has enabled many innovative applications in various scientific fields. This paper introduces a new framework called "Collaborative Cloud-Based Land Surveying - CCLS" that uses VGI principles for data sharing among surveyor engineers to boost the productivity and improve the quality of their applications. A cloud-based spatio-temporal data repository is presented, aiming to facilitate the sharing of VGI among surveyor engineers. In this context, an OGC compatible, aligned to 'Observation and Measurements' standard, model for land surveying observations has been developed and discussed.

Additionally, a fully-functional distributed software application has been developed and used to apply CCLS in a large-scale land surveying project, which involves the mapping of the historic centre of Athens. Results from the data analysis of hundreds of measurements indicate a substantial (30% to 60%) error reduction and also a significant productivity raise (~22%).

Moreover, a novel educational methodology that implements Collaborative Cloud Land Surveying (CCLS) and presents Bloom's taxonomy theory with respect to Land Surveying educational context is discussed. It analyses the transition from lower three taxonomy levels, usually achieved by typical learning approaches, to higher knowledge levels through the application of the proposed methodology. Finally, a case study that demonstrates the efficiency of the introduced educational frame is described to analyse how students pass from the simple evaluation of assigned projects, to assessment and understanding of the learning objectives.

Εκτεταμένη Περίληψη

Οι τοπογραφικές παρατηρήσεις αποτελούν πρωτογενή πηγή πληροφορίας κάθε χωρικής μελέτης απαιτήσεων υψηλής ακριβείας, ενώ επιπλέον έχουν κάποια ιδιαίτερα χαρακτηριστικά τα οποίακαθιστούν μοναδικό το κάθε σύνολο δεδομένων που προκύπτει από μετρήσεις πεδίου, με σημαντικότερα τα παρακάτω:

- Η διαδικασία τοπογραφικής αποτύπωσης καταγράφει γεωμετρικά μεγέθη σε δεδομένο χρόνο, αποτυπώνοντας ένα στιγμιότυπο ενός συνεχώς μεταβαλλόμενου περιβάλλοντος. Οι ίδιες παρατηρήσεις δεν μπορούν να επαναληφθούν καθώς το περιβάλλον ενδεχομένως έχει μεταβληθεί.

- Σύνολα δεδομένων που αναφέρονται στο ίδιο μετρούμενο μέγεθος, παρατηρούμενα από διαφορετικά συστήματα ‘οργάνου-παρατηρητή-συνθηκών’ είναι απαραίτητα για την εκτίμηση της ακριβούς τιμής.Στην επίτευξη του παραπάνω μπορεί να βοηθήσει η επαναχρησιμοποίηση μετρήσεων υπό συνθήκες που πρέπει να καθοριστούν.

- Η συλλογή παρατηρήσεων πεδίου αποτελεί την πλέον απαιτητική σε πόρους φάση μιας διαδικασίας Τοπογραφικών μετρήσεων.

Τα παραπάνω τεκμηριώνουντη σπουδαιότητα της πρωτογενούς μετρητικής πληροφορίας και θεμελιώνουν την ανάγκη διερεύνησης και ανάπτυξης ενός νέου πλαισίου διαχείρισης, διάθεσης και επαναχρησιμοποίησης των τοπογραφικών μετρήσεων. Στο πλαίσιο αυτό, η παρούσα διατριβή πραγματεύεται την προδιαγραφή, πρότυπη υλοποίηση και αξιολόγηση μιας νέας προσέγγισης στον τρόπο διαχείρησης αλλά και αξιοποίησης των τοπογραφικών παρατηρήσεων, περιγράφοντας ένα κεντρικό σύστημα στο οποίο αποθηκεύονται οι πρωτογενείς μετρήσεις και παραμένουν διαθέσιμες και αξιοποιήσιμες για μελλοντική χρήση. Η προτεινόμενη μεθοδολογία που εισάγεται από την διατριβή εξετάζει ένα σύνολο από ζητήματα όπως:

i. τη διερεύνηση των προκλήσεων για τη μετάβαση στη συλλογικότητα και το διαμοιρασμό των πρωτογενών μετρήσεων(«εθελοντικά μοιραζόμενη γεωγραφική πληροφορία» - VGI: Volunteered Geographic Information)

ii. την καταγραφή των πλεονεκτημάτων που συνεπάγεται η εν λόγω προσέγγιση

iii. τον καθορισμό του απαραίτητου μεθοδολογικού πλαισίου σε εννοιολογικό (περιγραφή και μοντελοποίηση μετρητικών οντοτήτων και διαδικασιών), λειτουργικό (διερεύνηση και προδιαγραφή υπηρεσιών και υποσυστημάτων) και τεχνικό επίπεδο (περιγραφή στοιχείων λογισμικού και υλικού, ανάπτυξη πιλοτικού συστήματος)

iv. τη περιγραφή των διαφορετικών εφαρμογών - περιπτώσεων χρήσης πουεξελίσσουν -βελτιστοποιούν υπάρχουσες διαδικασίες,καθώς και αυτών που εισάγει το προτεινόμενο σύστημα.

Στο πλαίσιο αυτό, η διατριβή καταπιάστηκε με ζητήματα προτυποποίησης των παρατηρούμενων μεγεθών κατά τα διεθνή πρότυπα και ανέπτυξε ένα μοντέλο παρατηρήσεων το οποίο και εφάρμοσε στις διάφορες μελέτες περιπτώσεων. Κατά την διαδικασία ανάτπυξης του μοντέλου διαπιστώθηκαν και συζητήθηκαν ζητήματα που απαιτούν ιδιαίτερο χειρισμό (σε σχέση με τις τυπικές περιπτώσεις μοντέλων παρατήρησης), λόγω της φύσης των τοπογραφικών μετρήσεων, και συγκεκριμένα:

i. ο διανυσματικός χαρακτήρας του φορέα παρατήρησης, με δεδομένο ότι ως αντικείμενο παρατήρησης αναγνωρίζεται ο διανυσματικός φορέας κέντρου παρατήρησης - στόχου.

ii. η ιδιότητα του χωρικά μη εκ των προτέρων προσδιορισμένου (δεν ξέρουμε τις συντεταγμένες στις οποίες αναφέρεται), που όμως φέρει την πληροφορία που απαιτείται για να γίνει εκ των υστέρων υπολογισμός.

Για τον έλεγχο της προτεινόμενης προσέγγισης, έγινε υλοποίηση ενός πρότυπου συστήματος, ώστε να γίνει δυνατή η περαιτέρω διερεύνηση τωναπαιτουμένων στοιχείων αρχιτεκτονικής, καθώς και η αξιολόγηση της λειτουργικότητας και αποτελεσματικότητας σε πραγματικές συνθήκες. Η πιλοτική εφαρμογή επεκτάθηκε σε τρεις περιπτώσεις χρήσης, συγκεκριμένα (i)εφαρμογή μοντέλου και ανάπτυξη πρότυπων service διαχείρισης δεδομένων όπως αυτά ορίζονται από το Open

Geospatial Consortium (OGC) με το πρότυπο Sensor Observation System (SOS), (ii)αποτύπωση μεγάλων εκτάσεων και μεγάλου όγκου παρατηρήσεων (Αρχαιολογικό Κτηματολόγιο) και (iii)χρήση στην εκπαίδευση (ανάπτυξη δεξιοτήτων ανώτερων γνωστικών επιπέδων κατά την ταξινομία Bloom). Η χρήση σε πραγματικές συνθήκες ανέδειξε αύξηση των επιπέδων ακρίβειας και της παραγωγικότητας, ενώ η ανάπτυξη και διερεύνηση εκπαιδευτικών σεναρίων με βάση την προτεινόμενη μεθοδολογία καλλιεργεί γνωστικές λειτουργίες ανάλυσης, εφαρμογής και αξιολόγησης.

Κατά την ανάπτυξη του πιλοτικού συστήματος, αντιμετωπίστηκαν ζητήματα αρχιτεκτονικής λογισμικού αλλά και προέκυψαν νέες απαιτήσεις με βάση την εμπειρία κατά τη χρήση, η ικανοποίηση των οποίων διεύρυνε το πεδίο συμβολής της διατριβής. Συγκεκριμένα αντιμετωπίστηκαν τα ακόλουθα:

- Ζητήματα συγχρονισμού μετρητικών δεδομένων. Η Βάση Δεδομένων που φιλοξενεί τις τοπογραφικές παρατηρήσεις δέχεται συνεχώς νέες εγγραφές. Ο χρήστης του συστήματος πρέπει να έχει γνώση όλων των στοιχείων που είναι διαθέσιμα στην περιοχή μελέτης του. Έτσι είναι απαραίτητος ο συγχρονισμός των εγγραφών της εφαρμογής πελάτη (μονάδα πεδίου) με το κεντρικό αποθετήριο, είτε κατά το χρόνο της μέτρησης με χρήση δικτύων κινητής τηλεφωνίας, είτε με ενημέρωση πριν την έξοδο στο πεδίο για την περίπτωση που δεν είναι διαθέσιμη πρόσβαση στο διαδίκτυο κατά τη λήψη μετρήσεων.

- Κατ' επιλογή χρήση πολλαπλών επιπέδων χωρικής πληροφορίας. Ανάμεσα στις λειτουργίες που έχουν προδιαγραφεί, είναι η αξιολόγηση των μετρήσεων κατά τη λήψη (εντοπισμός χονδροειδών σφαλμάτων), η γνώση πληρότητας η μη των συλεχθέντων παρατηρήσεων αλλά και η επίβλεψη της προόδου των εργασιών με βάση προυπάρχουσες μελέτες και σχέδια. Το πιλοτικό σύστημα αναπτύχθηκε ώστε να υποστηρίζει πολλαπλά επίπεδα πληροφορίας (ορθοφωτοχάρτες κτηματολογίου, διανυσματικά αρχεία, προυπάρχουσες μετρήσεις, ληψη φωτογραφιών) τα οποία μπορούσε ο χρήστης να επιθέσει ή απενεργοποιήσει κατά τη διάρκεια των εργασιών.

- Ανάπτυξη αλγορίθμου επίλυσης σε σχεδόν πραγματικό χρόνο. Η συνεχόμενη εισροή νέων εγγραφών από το συγχρονισμό με τη Βάση Δεδομένων και τη διαδικασία συλλογής μετρήσεων, καθώς και η απαίτηση για αξιολόγηση των μετρήσεων κατά το χρόνο λήψης, προϋποθέτει διαρκή επανάληψη της επίλυσης του δικτύου (μία νέα μέτρηση μπορεί να επηρεάσει τη γεωμετρία όλου του δικτύου). Για την κάλυψη αυτής της απαίτησης αναπτύχθηκε αναδρομικός αλγόριθμος μη επιβλεπόμενης επίλυσης του δικτύου που δίνει έμφαση στην ελαχιστοποίηση του χρόνου εκτέλεσης. Ο παραπάνω αλγόριθμος δεν έχει στόχο την τελική επίλυση με χρήση προχωρημένων στατιστικών τεχνικών αλλά την ανίχνευση χονδροειδών σφλμάτωνπου υποδεικνύονται σε χρόνο μέτρησης αλλά και την απεικόνιση των μετρήσεων με αυτόπαραγόμενο σχέδιο.

- Περιγραφή διαδικασιών αξιολόγησης των παρατηρήσεων. Ένα ιδιάιτερης σημασίας ζήτημα αποτελεί η προδιαγραφή των διαδικασιών αξιολόγησης των παρατηρήσεων. Η παρούσα διατριβή εξετάζει την παραπάνω απαίτηση με χρήση τριών επιπέδων αξιολόγησης (καταχώρηση προδιαγραφών εξοπλισμού – βαθμονόμηση, μεγέθη κλεισίματος σφάλματος κατά τις επιλύσεις, πλήθος περιπτώσεων χρήσης μέτρησης από το χρήστη).

- Ανίχνευση πιθανών σφαλμάτων κατά τη στιγμή της μέτρησης. Μια από τις επιθυμητές λειτουργίες είναι η δυνατότητα εντοπισμού μετρήσεων που είτε περιέχουν χονδροειδές σφάλμα είτε είναι κάτω από το επιθυμητό επίπεδο ακριβείας. Το πιλοτικό σύστημα με χρήση του υλοποιημένου αλγορίθμου επίλυσης και σύγκριση με τις υπάρχουσες μετρήσεις, υποδεικνύει την ενδεχόμενη εσφαλμένη μέτρηση ώστε ο χρήστης να μπορεί να επαναλάβει και να αξιολογήσει το πρόβλημα.

Σε επίπεδο υλοποίησης, η αρχιτεκτονική τριών επιπέδων (3 tier-layerarchitecture) κατέληξε σε (i)Σύστημα Διαχείρησης Βάσης Δεδομένων (ΣΔΒΔ)Postgres, PostGis, filesystem (datalayer), (ii)Php, geoserver (application layer) και (iii)web interface, androidapplication (presentation layer) για το πιλοτικό σύστημα με κώδικα που αναπτύχθηκε κατά περίπτωση στην πλατφόρμα που υλοποιήθηκε.

Εν κατακλείδι, ηδιατριβή ασχολήθηκε με τα ακόλουθα θέματα:

1. Οριοθέτηση του πεδίου έρευνας, ανάλυση παρούσας κατάστασης και περιγραφή των απαιτήσεων του γενικού πλαισίου μιας νέας μεθοδολογίας.

2. Ανάπτυξη κλάσεων μοντελοποίησης των τοπογραφικών παρατηρήσεων κατά τα διεθνή πρότυπα με επέκταση του προτύπου ‘OGC Observation&Measurement’. Διερεύνηση ιδιαιτέρων απαιτήσεων μοντέλου και περιγραφή αντιμετώπισης αυτών με παράλληλη εφαρμογή σε πλατφόρμα υλοποίησης ‘SOS 2.0’.

3. Ανάπτυξη ενός νέου αλγορίθμου μη επιβλεπόμενης επίλυσης τοπογραφικού δικτύου με απαίτηση την εκτέλεση και ολοκλήρωση για μεγάλα σύνολα δεδομένων που περιλαμβάνουν δεδομένα VGI, σε ‘near real-time’. Πιλοτική εφαρμογή σε φορητή επεξεργαστική μονάδα για αξιολόγηση ταχύτητας.

4. Ανάπτυξη της αρχιτεκτονικής ενός προτεινόμενου πλαισίου εφαρμογήςτου αλγορίθμου, καθώς και διαφορετικών περιπτώσεων χρήσης με μεταβλητό προσανατολισμό εφαρμογής (ταχύτητα, κόστος, ακρίβεια, αξιολόγηση).

5. Ανάπτυξη ενός πιλοτικού συστήματος για τη διερεύνηση των δυνατοτήτων, των απαιτήσεων και την εφαρμογή σε μελέτες περιπτώσεων με σκοπό την a posteriori ποιοτική και ποσοτική αξιολόγηση της μεθόδου.

6. Χρήση σε πραγματικές συνθήκες στο πλαίσιο του έργου ‘Αρχαιολογικό Κτηματολόγιο’ κατά τη διαδικασία αποτύπωσης του ιστορικού κέντρου της Αθήνας παράλληλα με συμβατική διαδικασία αποτύπωσης. Συγκριτική αξιολόγηση των δύο προσεγγίσεων και παρουσίαση αποτελεσμάτων.

7. Ανάπτυξη εκπαιδευτικών σεναρίων και πιλοτική εφαρμογή με έμφαση στην προσωποποιημένη υποστήριξη και την επίτευξη ανάπτυξης γνωστικών λειτουργιών ανώτερου επιπέδου. Παρουσίαση και ανάλυση ταξονομίας Bloom στον χώρο της Τοπογραφίας και τέλος αξιολόγηση αποτελεσμάτων της προτεινόμενης προσέγγισης.

1. Introduction

Topography science focuses in determining the position of features in a specified coordinate system. These features can be either natural or man-made, on or below the surface of the earth [1]. The American Congress on Surveying and Mapping (ACSM), defines Surveying as "*the science and art of making all essential measurements to determine the relative position of points and/or physical and cultural details above, on, or beneath the surface of the Earth, and to depict them in a usable form, or to establish the position of points and/or details*". Land Surveying is the detailed study or inspection, as by gathering information through observations, measurements in the field, questionnaires, or research of legal instruments, and data analysis in the support of planning, designing, and establishing of property boundaries. It involves the re-establishment of cadastral surveys and land boundaries based on documents of record and historical evidence, as well as certifying surveys (as required by statute or local ordinance) of subdivision plats/maps, registered land surveys, judicial surveys, and space delineation. Land surveying can include associated services such as mapping and related data accumulation, construction layout surveys, precision measurements of length, angle, elevation, area, and volume, as well as horizontal and vertical control surveys, and the analysis and utilization of land survey data [2].

In order to accomplish the above objective, measurements have to be acquired in a systematic methodology frame so that environment is geometrically defined. The method that is applied in each case, determines the kind of required observations and also the proper scientific equipment to be used. The typical measured quantity is the distance between points of interest but also the direction these define, given a coordinate frame system. Furthermore, advanced reality description models presume measurements of time, gravity field, aerial photos, satellite images, satellite observations, earth tide, electromagnetic waves or even direction to stars, depending on the method to be used in each case (Classical Land Surveying, Physical geodesy, Photogrammetry, Satellite geodesy).

A major objective of surveying equipment industry is the achievement of continuously better quality of information. Research and development departments scout towards that direction while hardware meets higher and higher quality specifications, eliminating actually the error component that is associated to it. The error component that is based on observer's fault can be detained using statistical tests that are based on repeated measurements and by having multiple "observer-equipment" combinations, so that appropriate processing models can minimize random and systematic errors. At the same time, research in science fields that examines natural phenomena, invention and evolution of mathematical models that describe environment structure and the huge increase in available processing power, make possible the achievement of even better, in terms of precision, results.

The above discussion describes an abstract frame of surveying engineering scientific field, which is the wider environment into which this research is referred. This first chapter aims to initially describe some blind spots of the land surveying procedure, emphasize concerns of major importance, introduce data management policies - agreements and highlight benefits of incorporating new technology protocols, standards and working patterns as modules of a novel approach. In this context, basic procedures and fundamental concepts are discussed so that a list of considerations finally forms the frame of the proposed methodology.

1.1. Surveying Engineering base concepts

During a Land Surveying project, a two basic step workflow is followed. The first part of this procedure is the acquisition of measurements on the field. Ensuring that the dataset built by these measurements is complete is of essential importance. The second phase is about processing collected data, where the appropriate algorithms are applied so that the final product is delivered. If it happens to note later in the office out of specification data or even worse, information missing, on field procedure is repeated and further processing of additional information applied. The following paragraphs discuss different aspects of these procedures and highlight fundament concepts and critical parameters that are later used to outline this research's objective.

1.1.1. Measurement - Uncertainty

The international vocabulary of metrology [3], provides the following definitions in the context of metrology science.

- ☐ *Quantity*: property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference
- ☐ *Quantity value*: number and reference together expressing magnitude of a quantity.
- ☐ *Measured quantity value*: quantity value representing a measurement result.
- ☐ *Measurant* quantity intended to be measured.

"Measurement" is defined as the process of "*experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity"* [3]. On field measurement procedure provides the primary data for every topography related project. Both quality and integrity of every measured quantity is of essential importance for the outcome of processing procedure. In order to effectively describe the above, true and expected values are defined. The *true value* is the quantity value that is consistent with the definition of a quantity and is considered to be unique and in practice unknowable**.** Instead of it, the *expected value* is used, that is he average that would ensue from an infinite number of replicate measurements of the same measurand. Also *measurement error* is defined as the measured quantity value minus a reference quantity value. Considering the above definition schema, every quantity value is described by its measurement value and an error.

$$Quantity\ Value = \ Measured\ quantity\ value \pm Measurement\ error \tag{eq. 1.1}$$

“Measurement error” refers to uncertainty introduced by measuring system, operating procedure and a set of conditions related to measurement procedure. Errors are grouped in three categories: *gross errors*, *systematic* and *random*. By gross error (known also as production error or mistake) surveying defines those that due to operator carelessness and can be easily detected by measurement repeating. Systematic error refers to the error component that in replicate measurements remains constant or varies in a predictable manner while random error refers to the component that varies in an unpredictable manner and can be managed using statistic distributions and tools.

In order to be able to create tools that estimate acquired data quality, measurement precision and accuracy has been introduced. *Measurement precision* is defined as the closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions. These conditions include the same measurement procedure, same operators, same measuring system and operating conditions. On the other hand, *measurement accuracy* refers to the closeness of agreement between a measured quantity value and a true quantity value of a measurant.

“Measurement trueness” refers to the closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value. It is known that in order to estimate the true value, measurement values must be provided by different operating conditions (operator, equipment and other environmental parameters). This fact remains up to now one of the most challenging problems to overcome as it has impact on project completion time and overall cost.

If *X* is defined as the true value, and x_i if the result of one measurement, free of gross and systematic error, the true error ε_i is:

$$\varepsilon_i = x_i - X \quad \textbf{(eq. 1.2)}$$

Due to the fact that X is not known and cannot be estimated, true error cannot be computed. As a result, *expected value* (μ) is used, that is populated by a series of measurements giving the same value in an infinite measurement population.

$$\mu = \lim_{n\to\infty}\frac{\sum x_i}{n} \qquad \textbf{(eq. 1.3)}$$

The difference $u_i = x_i - \mu$ is defined as *random error* and it has been proven that both measured quantity value and random error follow normal distribution (Gauss), having a probability density function:

$$y = f(x) = f(u) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-\mu)^2}{2\sigma^2}} = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{u^2}{2\sigma^2}} \qquad \textbf{(eq. 1.4)}$$

and *standard deviation*

$$\sigma = \pm\sqrt{\frac{\sum_i (x_i-\mu)^2}{n-1}} \qquad \textbf{(eq. 1.5)}$$

By Integrating $f(u)$ between –σ and σ, the probability of error found in this range is provided:

$$P(-\sigma < u < \sigma) = 68.3\ \% \quad \text{(eq. 1.6)}$$

If range is expanded, it is possible to get corresponding probability:

$$P(-2\sigma < u < 2\sigma) = 95.4\ \% \qquad \textbf{(eq. 1.7)}$$

$$P(-3\sigma < u < 3\sigma) = 99.7\ \% \qquad \textbf{(eq. 1.8)}$$

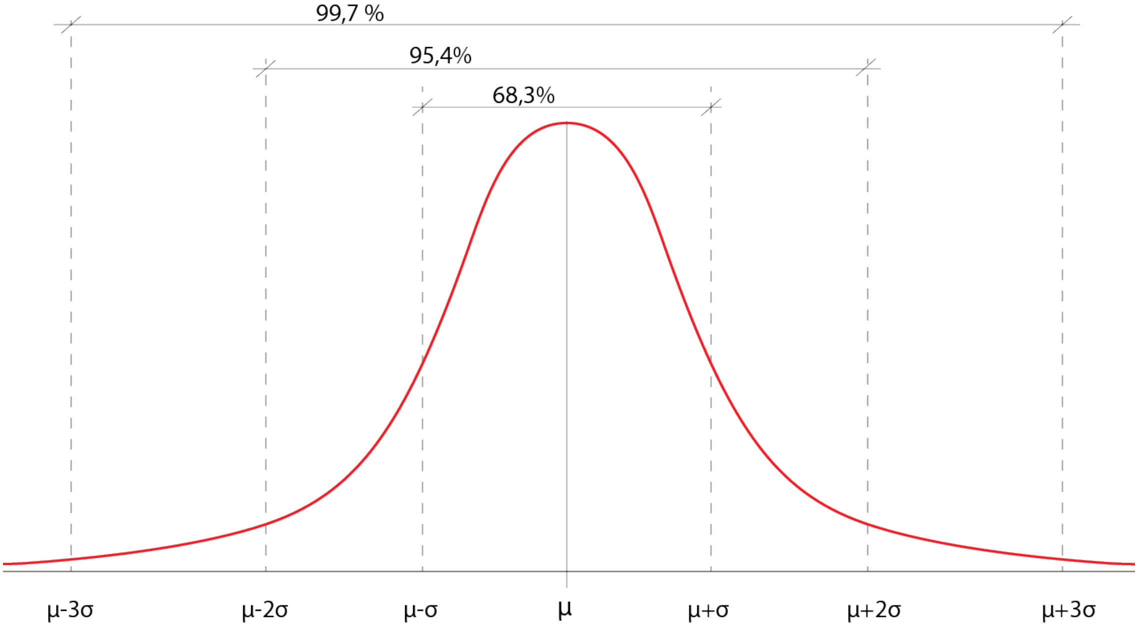


Figure 1.1 Normal distribution, standard deviation probability graph.

Every measurement set collected under the same operating conditions (operator, equipment, environmental parameters) is managed in a common procedure. Due to the fact that it is not possible to collect an infinite number of measurements so that the *expected value* is determined, available measurements provide the mean value to be used instead as an "*estimator*".

$$\hat{x} = \overline{x} = \frac{1}{n}\sum_{1}^{n} x_i \qquad \textbf{(eq. 1.9)}$$

The difference $v_i = x_i - \hat{x}$ is knows as possible error or remaining (or residual).

Since observations are considered to be of same weight, they are all of the same precision. Supposing a series of measurements $x_1, x_2, \ldots\ldots, x_n$ having σ as precision for each observation, the *mean value* is:

$$\overline{x} = \frac{1}{n}\sum_{1}^{n} x_i \qquad \textbf{(eq. 1.10)}$$

By applying error propagation with dependent variables it is possible to determine the standard deviation of the mean value (*standard error*).

$$\sigma_{\overline{x}}^2 = \frac{1}{n^2}\sigma_{x1}^2 + \frac{1}{n^2}\sigma_{x2}^2 + \cdots + \frac{1}{n^2}\sigma_{xn}^2 = \frac{1}{n^2}\sigma^2 + \frac{1}{n^2}\sigma^2 + \cdots + \frac{1}{n^2}\sigma^2 = \frac{n}{n^2}\sigma^2$$

$$\sigma_{\overline{x}}^2 = \frac{\sigma^2}{n} \qquad \textbf{(eq. 1.11)}$$

The more observations available, the more $\hat{x}$ converges to μ ($\sigma_{\overline{x}}^2$ is inversely proportional to the population) and remaining behave (statistically) like random errors. This fact, makes redundant observations of essential importance in the context of statistical model and high precision level achievement.

1.1.2. Data collection

The field data collection is a time consuming and demanding procedure. Depending on the project's special requirements, different methodologies can be used in order to collect the necessary dataset that will provide the input to the appropriate processing schema. In the vast majority and in a very abstract way of classifying, measurements come down to angle, distance, time and electromagnetic wave observations, between established points and features of interest. These information collections (i) meet high precision specifications, (ii) come along with the corresponding meta data and (iii) are used to model reality within a geometrical context. Typical land surveying procedures that use *"Global Navigation Satellite Systems"* (GNNS) and/or Total Station (TS or TPS) equipment are briefly discussed in the following paragraphs.

GNSS use known orbit satellite vehicles that transmit data, in order to define the position of point on earth surface. Receivers record transmitted signal and apply processing algorithms so that coordinates are computed. There are basically two process flows that this methodology applies to.

The first one is known as "*static post processing"* and is used when very high accuracy requirements are specified (~mm). Two GNSS receivers are set, with one over a ground control point (GCP) that is a point of known position, and the second one over the point to be defined. Both stations record satellite transmitted signal information at the same time, given a minimum duration that depends on distance between stations, receiver specifications, receiver to sky visibility and satellite sky coverage. On the sequel (office time), post processing of acquired observations and satellite metadata provide the coordinates of point to be defined. The above procedure is applied to determine the position of one single point and requires considerable resources (on field time, equipment, operators).

The second methodology applies in cases where a lot of points have to be defined and there is a moving receiver (*Kinematic*), in real time (*Real Time Kinematic – RTK*) or post processed (*Post Processing Kinematic*), impacting this way in corresponding accuracy (~cm). The principle is that a base station is set over a GCP, and a mobile receiver goes through points of interest for a short time period (few seconds or minutes). The final computation can take place in real time, provided the two receivers are linked, or in later time. In order to reduce required resources (time, equipment, operators) for both of the above, there are GNSS observation providers that sell information of base stations that record 24 hours a day. This way only one receiver (and one operator) is required, where this work model is applicable. In projects where GNSS methods apply, the result data can be of various forms. There can be files that contain plain coordinates in text form (.csv, .txt. xml), typical drawing files (.dxf, .dwg), pseudo-distance information in RINEX or manufacturer specific format. Fortunately the RINEX standard is usually provided thus users can exchange data in a global open file structure.

The typical and most used procedure, involves Total Station equipment for land surveying data collection. After the station is set and initialized (tripod set, leveling, centering), angles and distances are recorded to points of interest. Each measurement record is consisted of horizontal angle, vertical angle, distance and target height (from ground). The same fact of file format scattering (each Total Station constructor uses its own data structure) and there is no specific file format established (as GNSS RINEX format is) so that data exchange can apply without technical considerations. Modern surveying equipment provides some on field computation functionality. Given the appropriate parameters set, coordinates can be computed and exported in real time, instead of raw measurement recording. Nevertheless, this approach in not usually applied due to the fact that there is no way to mix collected data with other available thus process using statistical models and complex error correction algorithms.

The above data collection procedures are usually applied in typical land surveying projects. Table 1.1 summarizes collected measurements' type, other information acquired on field and metadata (operating conditions: operator, equipment and other environmental parameters) that describe each observation period. Every set of information collected over each equipment settlement by an operator is defined as "*observation period*".

Information Objective	**Information type- attributes**		**Data storage media**
Operator	-		
Equipment	Type	(GNSS receiver, Total station)	
	Model Specifications	(mm ± ppm, grad ± ppm) Calibration	
Observation Period	[Environmental conditions]	Instrument Height Start time End time (temperature, pressure, humidity)	
Observation - measurement	GNSS	Signal phase – Pseudodistance Coordinates Target height	RINEX .txt, .dxf
	Total Station	Horizontal angle Vertical angle Distance Target height	Various file formats
	Measuring tape Laser	Distance	documents
	Photograph	Raster [Position] [Orientation]	file
Observation metadata	Time ID Description [Photograph]		
Generic	Draft sketch Photographs		Documents Raster

Table 1.1 Measurement objectives, types, attribute – storage media.

Besides field measurements, surveying engineers collect other type of data that are necessary in order to complete successfully land mapping projects. These range from administrative documents and law articles to geometric data coming from authorities or other available sources. Typical example of the latter is the construction restrictions applied to area of interest which is mandatory to include in most cases. These are provided by urban planning authorities in various forms (maps, coordinates, documents) both digital and analog.

Other information can be maps indicating past land state, GCP coordinates, land distribution maps, aerial photographs, archaeological land zones, law restrictions on land usage and other type of relevant information. Usually these are maintained by public authorities like Hellenic Military Geographical Service (HMGS), urban planning ministry, ministry of Culture, Greek Cadastre, forest management authorities, ministry of agriculture. Depending on the case, the procedure of acquiring this information can be really straight forward and have the necessary documents even from internet, or it could be a long procedure that depends in authorities' minimum response time (for example, getting an aerial photo by Greek Cadastre Authority, currently takes 20 working days).

It comes out of the above discussion, that this procedure is overall time consuming and without standardize in the form of the content provided, not even among authorities of the same ministry. In some cases, the required time is not manageable and as a result some processes can be blocked or deadlines not met.

1.1.3. Typical workflow

Applied workflow in the procedure of field observation collection, is defined by both the methodology to use and a priori data availability. Although it is a project depended process to consider, there are some basic procedures that surveying engineers follow.

The first consideration of the surveyor is getting familiar with the project area. In order to be able to fully describe - model the physical environment topography and human interventions, it is required to form a generic picture of the study area. Afterwards, a reference network (traverse or triangular) is to be defined that is used as the base for determining the position of every other feature. The reference network is consisted of nodes (stations) that will be used as Control Points (CPs). The measurements acquired to define CP position, require observations of high accuracy because any error introduced will be propagated in all other points. The primary condition of CP selection is to ensure mutual visibility, as measuring equipment is settled over them (GNSS, Total Station), but also visibility of the total set of mapped features. CP related observations aim to define the geometry of the reference network but also adjust it to a higher order network and coordinate system (e.g. GGRS 87’).

In order to define the geometry structure and metrics, observations that describe the CP network take place. Both distance and angle measurements are required. Each of the quantities to be defined presumes multiple observations (two positions for each observation period, multiple observation periods) so that statistical processing can provide the best estimation of expected value.

The incorporation into the National Geodetic Reference System (NGRS) can be achieved through multiple approaches. The minimum requirement is to define the absolute position of one CP in the NGRS and one direction. Instead of the direction, usually a second CP is defined. The absolute positioning of these CPs can be achieved either by using preexisting points or by acquiring measurements to and from them. Registry of known CPs is maintained by authorities like HMGS or Greek Cadastre, and is a commercially provided. Alternatively, CP position of wide horizon visibility is set, and GNSS observations are recorded (about 30min per CP).

In the post processing procedure, required data are bought from commercial providers that record continuously fixed station received signal (HEPOS), so that CP positions can be determined after processing. It is important to emphasize, that there is a very high probability to detect CPs in the wider area of interest that were defined in the context of previously assigned projects. Unfortunately, there is no way to access corresponding information as there is no service to maintain such precious data that could be used as a way to reduce required resources (time, cost). National Geodetic Reference System (NGRS) incorporation translates to additional cost either because of the CP coordinates or GNNS measurements cost.

After the reference network definition and GNNS measurement record, Total Station is set over CPs so that measurements referring to the network itself but also the features of interest are acquired. At the same time, a draft of the area is sketched, where every feature observation and metadata is written down (point, type, line, id, etc). Furthermore, photographs on site are taken so that surveyor can use as source of any other not recorded information. Avoiding returning on the study area for complementary information is of essential importance.

1.1.4. Authorities - Community

The need to standardize the structure and services of surveying engineering related information, has made its appearance from the last decade. Both public authorities and private companies have been assigned to collect and maintain such datasets but also provide the corresponding management services. HMGS has established and maintained the national reference network stations having the fist measurements collected since its foundation in 1889. Hellenic Cadastre is in posses of a registry of CPs in areas of its authority and also provides GNSS HEPOS observations. Local municipalities often try to concentrate, standardize and create systems containing construction restrictions. Furthermore, large projects like Archaeological cadastre and forest maps are in progress. All the above are high cost initiatives, a fact that indicates or even proves the need to standardize high accuracy spatial data and create corresponding services.

The above ascertainment recognizes the need of a central management model for high quality spatial information, observed, provided, processed and produced by surveyor engineers. Additionally to the latter, the need to standardize and thus create the infrastructure for systems interoperability is globally defined by directives. In the European context, the above requirement has been implemented by INSPIRE directive [4]. More specifically, it has been determined that:

- ☐ Data should be collected only once and kept where it can be maintained most effectively.
- ☐ It should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications.
- ☐ It should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes.
- ☐ Geographic information needed for good governance at all levels should be readily and transparently available.
- ☐ Easy to find what geographic information is available, how it can be used to meet a particular need, and under which conditions it can be acquired and used.

Aligned to the above way of thinking, there is hardly a few hundreds of spatial engineering specialist working over these requirements. In organization structures or private sector assignments, expertise is provided in the context of various projects that most of the times overlap partly, sometimes conflict and often lack in numbers. On the other hand there is the community of spatial information industry. The Technical Chamber of Greece reports 6,070 [5] surveying engineering members registered. If we add 29,030 Civil engineers and 18,362 Architects (spatial oriented professions that also work on land surveying projects), it comes out that the community of engineers that observe, provide, process and produce high quality spatial information sums to several thousands. Activating such a data productive force by providing standards, services, data and motivation would rapidly result to a huge, high quality spatial infrastructure.

1.2. Current state

Currently applied data management scheme on collected information does not follow any particular standardized structure or provide services that support information reuse. As a result, observations and other processed data are mostly typical "*hard to collect – use once"* cases. Every surveying engineer maintains a personal, non-structured, file repository. File formats vary in favor of equipment available, personal methodology strategies and project parameters. This fact does not satisfy the minimum requirements of information reuse that would promote resource economy thus minimize cost – benefit ratio, that data sharing principles guarantee.

In order to examine the cost (or loss of potential benefit) it is required to discuss typical use cases. Every land surveying project collects information of a wider than the study area field. So if a property is to be mapped, it is certain that observations of boundary properties will be recorded. According to laws 4014/2011, 4178/2013 and previously, every property transaction contract comes with land surveying plans. The latter ensures that every property has been mapped at least once. Moreover, 4178/13 imposes that the construction license plans should include every boundary property fully charted, accompanied by building block contour. That translates to at least four measurement information sets collected for each property. The same applies to pre 4178/13 cases, without the obligation of all properties mapped fully but partially.

It is obvious that non urban areas have been mapped for each generation at least twice. Urban areas, due to the construction related obligations, are processed four times fully or partially. Figure 1.2 is the product of a typical land surveying project. It is obvious that the information collected and processed is a superset of direct property features. Also CPs established for this project form a network of 11 nodes that could be used in every project related to closely located properties. All this high quality and resource cost information is 'use once' case.

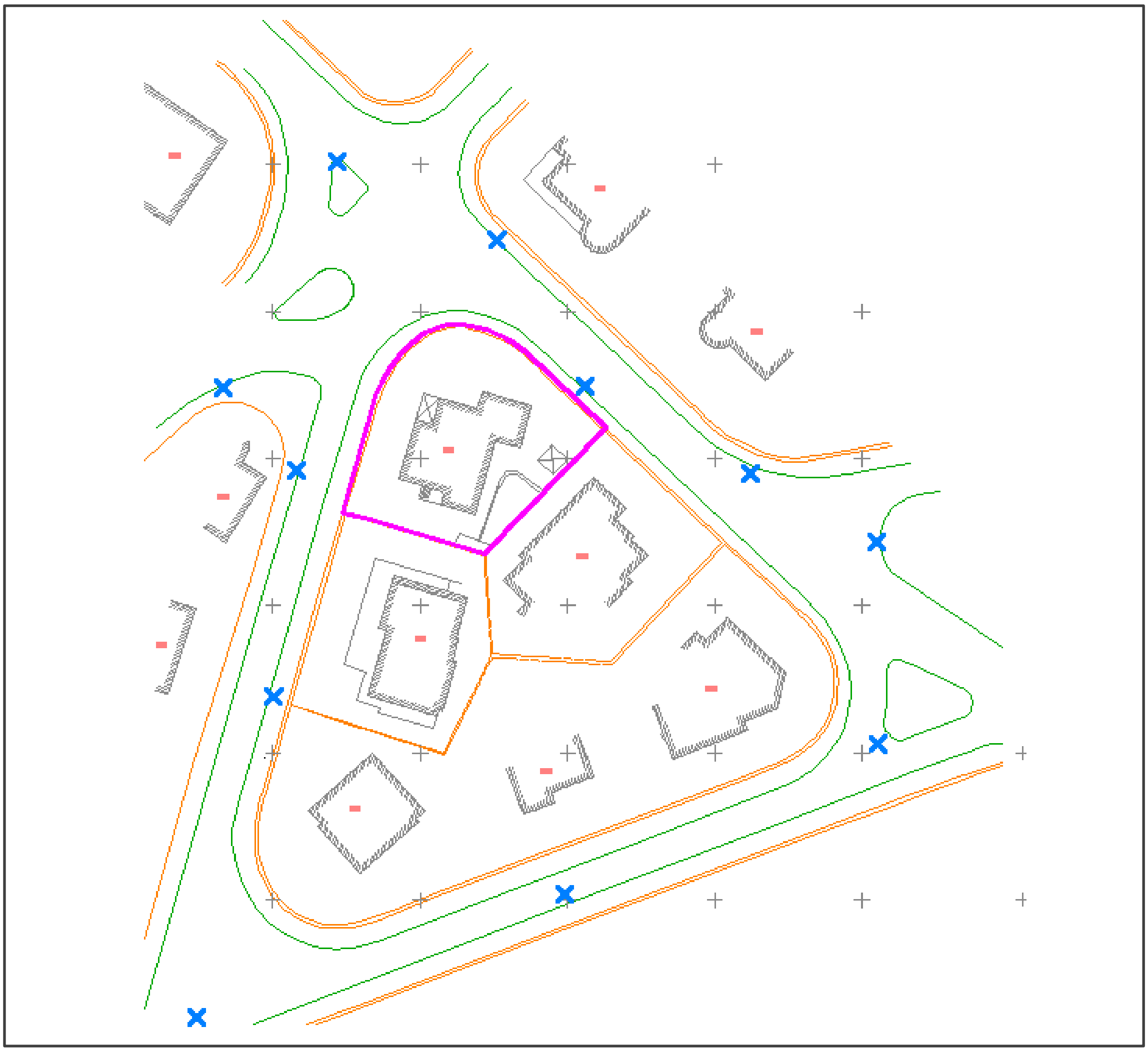


Figure 1.2 Typical Land Surveying product.

The above multiplicity is the source of multiple reference network establishments along with measurements in order to be incorporated to the National Reference Network. Multiplicity order of CPs is aligned the latter meaning that 4N CPs have been set for N unique nodes. Depending on the factor to examine, it comes out that it is possible to have up to:

- ☐ 75% less time spent on field
- ☐ $\sigma' = \frac{\sigma}{\sqrt{4}} = \frac{\sigma}{2}$ standard deviation, thus increased precision
- ☐ 75% less resources (== cost) spent

1.3. Problem statement - Goal and scope of the research

The above discussion and review of fundamental concepts, methodologies, policies and working flow processes that surveying Engineers apply, highlight some critical considerations. Depending on the aspect one examines these parameters, a list of weak spots, non efficient data management habits, potential information quality improvements and reduce of resource spending, arise. The community of engineers that observe, provide, process and produce high quality spatial information consists of several thousands of experts that altogether work on massive amount of spatial information, observations and product data. A big part of these data have corresponding measurements stored by other engineers, meaning that resources are spent more than required. Problems like the lack of

☐ applied standards in corresponding data structure
☐ services for information management
☐ tools to bind available data processing to field procedures
☐ motive and sharing mentality

do not promote or enable more cooperative workflow models that would provide benefits on every aspect to be discussed. Strict mathematical modeling, research field, data management policies, information recycling resource management, are aspects that could potentially benefit from a novel approach providing:

☐ Minimize time consuming processes
☐ Minimize cost
☐ Maximize product quality by incorporating multiple user measurements
☐ Overlapping projects alignment
☐ Directives incorporation
☐ Spatial infrastructure rapid development.

The first step of every science improvement effort is to examine the current environment and detect parameters that interfere with the efficiency of process flows. The above statements outline a set of restrictions, problems, potential benefits and considerations that define the starting point of the current discussion and form the actual goal and scope of the proposed research approach.

This study defines "*Collaborative Cloud Land Surveying*" (CCLS) as a targeted, specialized methodology framework to implement the concept of Volunteer Geographic Information (VGI) in Surveying Engineering applications. The objective CCLS discusses in this study is a methodology, and specialized VGI data processing framework to achieve all of the above that has been first introduced in 2015 by the author [6]. A framework to meet the needs for surveying engineering applications and accuracy requirements will be proposed, to facilitate the sharing of VGI information among Surveying Engineers. In order to effectively describe the Land Surveying measurement entity, an OGC compliant model will be discussed [7]. Total Station (TS) networking and measurement processing will be described, using data casting technologies and portable processing units along with integrated Web-GIS services, as a new methodology for land surveying that can largely benefit from applying the above concepts which combine on-the-field measurements, processing, sharing and validation in real-time.

2. Methodology

2.1. Introduction

2.1.1. Information Sharing

Information Sharing (IS) refers to the exchange of information among multiple participants, allowing them to access data collected by other users. Internet has provided the necessary technical tools, prototypes and services that has made possible to largely revolutionize many activities ranging from research to daily life activities over the past few years [8], [9]. Some government agencies and academic archives have made available for decades, massive sets of geographical, demographic, health and economic data. Data-sharing projects prove to be increasingly important, whether referring to public or private organizations. Known, popular examples vary from social network implementations like YouTube, to private sector projects (Google Maps), while even the whole of the information that is freely routed through web could be considered as the ultimate data sharing project. Educational, scientific and economical benefits are clearly thought to be substantial, considering the mechanisms that supports such attempts. Metadata standards are created with the intention of assisting all possible users and uses of data [10]. Established policies (e.g. INSPIRE directive) clearly promote open data access and contribute to the spread of sharing concepts (European Parliament established the Infrastructure for Spatial Information in the European Union (INSPIRE) frame, requesting that data should be collected once and reused [11]). Data sharing benefits had been considered to be very promising many years ago and have been used as study objective. The following list summarizes these benefits [12]:

- ☐ re-inforcement of open scientific inquiry
- ☐ verification, refutation, or refinement of original results
- ☐ promotion of new research through existing data
- ☐ encouraging more appropriate use of empirical data in policy formulation

☐ improvements of measurement and data collection methods

☐ development of theoretical knowledge and knowledge of analytic technique

☐ encouragement of multiple perspectives

☐ provision of resources for training in research

☐ protection against faulty data

☐ climate in which scientific research confronts decision making

Since then, the value of these concepts have proven to keep growing and researchers more and more discuss additional outcomes, such as better quality data and greater accountability [13]. Sharing in science is considered to be of great importance, not only because of the advantage of multiple sources information access thus more data available, but also because of the different approach that different scientist provide. Fischer & Zigmond discuss in depth and justify the most importan advatages of sharing [14]:

Sharing permits research to progress faster and further because it:

☐ provides a foundation in knowledge

☐ broadens score of research

☐ diversifies perspectives

Sharing allows resources to be used more efficiently because it:

☐ Reduces costs – both money and effort

☐ Maximizes use of data

☐ Corrects error of analysis

☐ Increases impact of findings

☐ Reduces subject burden

☐ Facilitates resource development

Sharing enhances the climate of scientific community because it:

☐ Discourages fraud and enhances confidence

☐ Promotes creativity

“Sharing grows little by little, as [we] develop the ability to see things from another person’s point of view and to trust that what they share will be given back.” – Fred Rogers (2004)

2.1.2. Volunteered Geographic Information - VGI

Geographic Information (GI) has proven to be of critical importance in decision making in public, private and non-government sectors [15]. Strategies built on GI process and evaluation, ranging from business growth policy to public transportation infrastructure definition, indicates the economic and social value of spatial data. Craglia and Novak identified three main types of social-political benefits associated with authoritative GI use [16]:

- ☐ Benefits to citizens through greater access to information and more transparent and accountable governance, improved empowerment and participation, customer/citizen goodwill and quality of life
- ☐ Benefits to government that arise from improved collaboration with other stakeholders within and outside government, greater political legitimacy, improved decision making, enhanced service delivery (e.g. health services) and better management and planning of land use change, environmental issues and sustainable development
- ☐ Benefits to business related to increased innovation and knowledge, new business opportunities and applications, and job creation.

Due to the increasingly high demand for such datasets, user generated content began to be considered of high value. The implementation of Information Sharing concept in GI context provided the framework that combined IS benefits to spatial data usage. In 2007, "*Volunteered Geographic Information*” (VGI) was introduced by Goodchild as “a special case of the more general Web phenomenon of user-generated content” [17]. Since then, user contribution has found its way to the development of successful and popular projects that rely on VGI, like OpenStreetMap (OSM) and WikiMapia. The idea that has been successfully implemented in these projects is that mass data coming from various sources, collected and assessed heterogeneously, are aggregated in geographic data collections that one can access and process in order to deliver new geo-spatial products or services (OSM counts over 3.2 million users and 5.4 billion GPS points uploaded at the time of writing [18]). Global geo-spatial applications motivate the development of communities that share all kinds of geographic information, organized in national or even global data collections [19].

On the other hand, there are concerns about data heterogeneity problems, given the fusion of amateur, expert and professional participation [20] [21]. “As a data source, the lack of expert oversight, the absence of professional standards, and the inherent heterogeneity of VGI across thematic, media, and spatial dimensions were identified as key contributors to the complexity of valuing VGI data” [22]. For example, Common VGI data coming from citizens without appropriate knowledge have not yet proven to meet the standards of topographic base projects [23]. Over this discussion, Coleman categorizes contributors into five overlapping classes along a spectrum, ranging from users that have no background to those that have high expertise in a subject [24].

☐ "*Neophyte*" -- someone with no formal background in a subject, but possessing the interest, time, and willingness to offer an opinion on a subject;

☐ "*Interested Amateur*" -- someone who has "discovered" their interest in a subject, begun reading the background literature, consulted with other colleagues and experts about specific issues, is experimenting with its application, and is gaining experience in appreciating the subject;

☐ "*Expert Amateur*" -- someone who may know a great deal about a subject, practices it passionately on occasion, but still does not rely on it for a living;

☐ "*Expert Professional*" -- someone who has studied & practices a subject, relies on that knowledge for a living, and may be sued if their products, opinions and/or recommendations are proven inadequate, incorrect orlibelous;

☐ "*Expert Authority*" -- someone who has widely studied and long practiced a subject to the point where he or she is recognized to possess

> an established record of providing high-quality products and services and/or well-informed opinions -- and stands to lose that reputation and perhaps their livelihood if that credibility is lost even temporarily.

Doing so, Coleman has set the basis to evaluate the quality of VGI project‘s datasets, as contributor’s capacity defines the potential usage of geographic data collections. Latest studies indicate that crowdsourcing and VGI differ by information clarity, purposes, abilities to control collection and reusability with VGI referred as geographic information collected with the knowledge and explicit decision of a person [25]. While crowdsourcing was initially used as a synonym to VGI, due to their common “sharing” property, it is clear that VGI projects that refer to participants who belong to the three “Expert” categories, provide a huge quality advantage over crowdsourcing, where participants do not have any specific expertise [26]. In line with this distinction and towards a professional-wize VGI concept, ESRI hosts the Community Maps Program [27], providing the means to geographic Information creators to share their Authoritative Content With the Global GIS Community while still retaining their intellectual property.

VGI seems to be evolving through time in order to meet the requirements of Geographic Information demand whether is Market, Social Network of Governmental driven [24]. It was initially considered as a crowdsourcing synonym but it is currently transforming to find its place in professional communities workspace, while retaining the sharing element along with its benefits intact. This thesis’ objective, explores the perspective of such a VGI concept, as an implementation in Land Surveying Science field. A community made by Surveying Engineers and generally spatial related scientists, that would contribute their data to a well defined, standardized VGI system, combines previously mentioned sharing benefits with high quality field collected measurements and produced geographic data.

2.1.3. On field processing

Projects that require measurements to be acquired, usually follow a three step workflow. The first step is to determine the details of required field tasks, in order to collect a complete and fully sufficient dataset. During this procedure, user should carefully examine every aspect of the project to be executed, including preexisting available datasets, available resources (equipment, methods, staff) and final product minimum specifications. Subsequently, measurement procedure takes place, using available equipment and chosen methodology so that all necessary data get collected. After measurement procedure is completed, the analysis of data takes place and final results and conclusions are produced. In case results do not meet predefined specifications or dataset collected proves to be incomplete or faulty, measurement procedure should be repeated (at least partially). Surveying Engineering is a science field that applies inline to the above protocol. Due to the fact that measurements take place on exterior environment, usually referred as "*on field work*", it is the part of the project that consumes most of available resources. This fact makes even more essential the need to minimize on field work in order to achieve the optimal cost-benefit ratio (BCR). Surveying Engineers have realized that long ago and have tried to limit as possible filed work in two ways.

The first approach is to develop methods that have limited demand on land measurements, such as photogrammetry or laser scanning. This approach uses equipment that collects massive amount of data (photons in photographs or laser point cloud in laser scanning) and only a few Ground Control Point (GCP) land measurements. The processing procedure uses complex models and needs huge processing power, while necessary equipment (photogrammetric station, metric cameras, drones, laser scanners) is of high cost. A drawback of such methods is that land surveying needs to output a abstact version of reality while mass cloud point data is delivering an over-sampled one that makes extremely difficult to simplify. Over the last years it has been proven that this approach is not sufficient for projects that handle common surveying use cases, while can perform great on special projects like development of monument 3d model.

The second option is to integrate processing procedure on field, so that checking collected data integrity in real time is possible and also measurement error detection along with quality estimation are provided on field. This approach ensures that the most difficult and complex issues are managed on site, while at the same time, the possibility of the need to revisit field gets minimized. Topographic equipment industry has tried to implement the above idea, as portable processing features are provided by technology evolution. The following options describe such implementations:

- ☐ GPS real time processing. Real Time Kinematics (RTK) technique along with GNSS hardware make use of advanced satellite based position computation algorithms, data communication channels (radio, GSM) and portable processing units in order to deliver on field real time position computation along with respective accuracy estimation. The Invention was introduced by Trimble in 1992 (US Patent Number: 5148179) [28] and since then there has been remarkable progress in system's reliability and provided features. The drawback of this technology is that open sky visibility is required in order to acquire desired position. Near buildings, under trees, near communication antennas, are some of the cases where GNSS RTK is not efficient to be used. Open sky areas are ideal cases for application but projects in high density urban areas prove to make only limited use of this technology, requiring the use of classical Total Station equipment.
- ☐ Field processing features have been introduced into Total Stations that implement basic coordinate transformation. The option to work on Cartesian coordinates instead of polar (angles and distances) has been available given the position of the station and one known azimuth. This mode is not preferred, as a possible error would create domino error effect to related data, while the correction is not manageable missing the actually measured quantities. As technology evolves, Total Station Industry develops more sophisticated field high end hardware and software solutions [29], [30] that make use of portable processing devices adding visualization, image overlay and field data file sharing from office.

The second approach has been gaining ground more and more, having Positioning Industry investing in research and development but also scientific community looking towards on field processing [31]. This fact indicates clearly that the need to unify measuring and processing on field, as much as this could be achieved, shows the way to future research objectives, as there are many related difficulties to overcome in such implementations.

Processing models is one of the most crucial discussion subjects, as simple transformations are not sufficient to manage collected and previously available measurement data in real time so that desired quality review is possible. In order to have complete control over measurement procedure, statistical models that normally apply in office, like least square processing, have to be implemented and have available dataset evaluated on measure trigger. Such an approach demands continuous reprocessing of the available information using appropriate algorithms to indicate outliers, out of specification measurements or missing data combining information coming from various sources. Data heterogeneity on the other hand, is a factor that has to be limited so that available information integration is succeeded. In fact, this is one of the main reasons that systems developed by different manufactures do not provide interoperability. The only way to overcome this drawback is to define global standards on information structure, so that data exchange and implementation on multiple platforms and different use cases is possible. Information standards are discussed in detail later on.

Finally, the specifications of appropriate equipment are of great importance. Visualization, processing and information routing through communication channels, are functions delivered currently by high cost Total Stations. Existing equipment that meets specification standards able to achieve high precision measurements acquisition, should be equipped with additional modules in order to provide previously mentioned functions. Such attempts usually implement portable devices that manage information routing, processing and visualization [31]. This thesis’ prototype, uses a low end Total station equipped with a Bluetooth module for data sending/receiving and a android tabled that uses GSM network for data communication, along with developed software. This approach minimizes the required additional investment, allowing existing Total Stations to be upgraded.

2.1.4. Data importance

The data collection process is the most resource demanding part of the full project workflow as it is applied in common land surveying – mapping projects. Resources of different types are required, namely time, human, equipment that on the whole in most cases define the total cost of the final product. The working group is consisted of two or three people minimum that work in the field in order to collect the observation data. The data collection process takes place on site, so transportation to the area of interest is mandatory, which in many cases can be located in long distance (islands, mountains, etc). It terms of time, the observation process requires usually a minimum of one working day and can scale up to months depending on the project size and specifications. Also there is the need of high accuracy, high cost equipment that can be either be bought or rent. All the above mentioned requirements set the observation collection procedure as the most resource intensive part in the context of land surveying mapping projects.

Another restrictive attribute of the observation process is the requirement for a complete of measurements dataset. The collected information that will be processed in a second phase, is geometrically self descriptive given that all necessary observations that describe the geometry model have been collected. In case of lacking observations, the dataset cannot be processed and the missing measurements are required to be collected by revisiting the field. The completeness requirement character of the land surveying, set the observation collection process as one of critical importance, as any missing observation would require a partial repeat of the measurement process and thus add a big overhead to the total of the resources spent.

Given the fact that the environment is a non spatially static system, every collection process produces a geometry descriptive dataset that is a snapshot at a specific time stamp. The surface of the earth is a moving system and human interventions modify the physical and technical environment through time. This is why every observation process cannot be repeated over time and provide the same results (the dataset refers to a modified geometry). In this sense, every collection process that generates an observation dataset, is a unique and non repeatable process, meaning that it is not possible to be confident that the observed features define the same geometry in another time snapshot.

All the above arguments set the process of observation collection as the most critical part of land surveying work flow. The fact that observations are first class "data - citizens" provides a major reason for concentrating and storing this information. As surveying science evolves, new algorithms, techniques and uses of measurements are developed, that would greatly benefit from temporary spatial.

2.2. Data model

In the above mentioned context, research has been done regarding systems that manage measurement data in the scientific field of Surveying Engineering. Buyond et al [32] analyzed the concept of measurement based cadastral systems and Goodchild [33] discussed the differences between coordinate-based and measurement-based GIS. Navratil et al [34] worked on ESRI ArcGIS product test case, in the generic frame of measurement-based GIS and Leung et al [35] proposed a general framework for error analysis in measurement-based geographical information systems (MBGIS). Although there is yet no widely accepted implementation developed, researchers put effort in defining and creating necessary building blocks of measurement driven systems.

The above concept implementation in Land Surveying is yet another promising field of research. Measurements collected for this purpose (angles, distances, coordinates), would provide, if shared effectively, benefits regarding aspects of working procedures [36] such as:

☐ more efficient preparation for subsequent land surveys
☐ faster data processing
☐ exchange of land survey data between different parties
☐ resolving of land disputes, etc.

In order to provide sharing services among users and different systems, it is important to focus on standardizing geodetic measurements representation and also methods to access modeled information. For this purpose, Open Geospatial Consortium (OGC) has developed a number of standards to meet the above requirement. In the context of Sensor Web Enablement (SWE), OGC has developed the ISO: 19156:2011 standards on Observations and Measurements (O&M) that describes a framework and encoding for measurements and observations. The O&M standard has been widely used and implemented in other representation packages as parts or extensions. Land Administration Domain Model (LADM [37] [38]; previously called the Core Cadastral Domain Model), has been designed by the International Federation of Surveyors (FIG) in order to model Land Administration information. Its last edition became an international standard (ISO 19152:2012) that itself integrates among others the 'OM_Observation' definition from the ISO: 19156:2011. Also, information policy makers officially require the establishment of sharing components in infrastructure for spatial information. In EU, for example, the Inspire directive [4] has issued specific implementation guidelines regarding O&M standard [39] that partially extend the model.

In regard to the requirement for services that provide system interoperability, OGC has developed the Sensor Observation Service (SOS) standard. The SOS standard defines web services to search, filter and retrieve observational data and sensor information [40] [41]. Research in Land Surveying domain, regarding both measurement models and interoperability services, reveals very promising results and constantly increasing interest. Oosterom et al [42] discussed among other issues the Spatial Unit (LADM), 'LA_Source' (LADM) and 'OM_Observation' class (ISO 19156). Kandawasvika [43] discussed a general framework implementing OGC standards for geodetic sensors in the context of landsite monitoring. Finally, Vranic et al [36], worked on Land Surveying data and developed a model for GNSS measurement systems, based on 'OM_Observation' standard.

In this section the conception and implementation of an OGC O&M standard compliant, Land Surveying measurement model is described. This work has originated within the Collaborative Cloud Land Survey (CCLS) [6] research context as a backbone system layer of introduced architecture. The core of the O&M encoding is presented and also the OGC Sensor Observation Service (SOS) and Sensor Modeling Language (SensorML) is discussed. Later on, a case study is discussed where a SOS web service is utilized, XML/JSON Request documents are developed, and WMS visualization modes are demonstrated in order to explore application requirements, restrictions and potentional benefits.

2.2.1. OGC – Sensor Web Enablement initiative

The Open Geospatial Consortium (OGC) is an international not for profit organization committed to making quality open standards for the global geospatial community. These standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data [44]. The organization preexists as Geographic Resources Analysis Support System (GRASS) Foundation from 1992. In 1994 GRASS renamed to Open GIS Consortium and since 2004 it is officially known as Open Geospatial Consortium (OGC) [45]. Currently OGC has over 500 members (Companies, Universities, Non Profit Organizations, government agencies, research organizations) that contribute in to the development of publicly available standards [46].

OGC standards are technical documents that detail interfaces or encodings. These documents, known as Abstract Specifications, define the common information protocol guidelines, applied by developers in order to create open interfaces and encodings to their product and services. Currently (December, 2016), over 40 standards have been developed that constitute the base of interoperability development in spatial information and services domain. GML, KML, WMS, WFS are recognized standards in every web enabled, commercial or open source, GIS implementation as their utilization provides major operational advantages over other arbitrary solutions regarding systems interoperability.

2.2.1.1. Sensor Web Enablement (SWE)

In order to enable developers to make sensors and sensor data repositories discoverable, accessible and useable via the Web, OGC has specified interoperability interfaces and metadata encodings facilitating integration of heterogeneous sensor webs into the information infrastructure [47]. Sensor Web Enablement (SWE) standards have been developed by OGC to define the specifications for creating applications, platforms, and products involving Web-connected devices. Each of the following OGC standards has been developed to address different requirements of the SWE framework initiative.

- ☐ Observations & Measurements (O&M) defines models and XML Schema for encoding sensor observations and measurements (section 2.2).

- ☐ Sensor Model Language (SensorML) (currently v2.0) provides the framework to describe characteristics and capabilities of sensors and systems, associated with the measurement and post-measurement transformation. The standard has been defined by OGC in order to describe the information model and provide the appropriate XML specification context. By adopting SML, the developer can define models and XML schemas to describe any process (sensor system measurement or post-measurement processing), though it is best suited to sensor systems and processes of sensor observations. In the context of this paper, SML is discussed as the information provider about sensor characteristics and process of observation acquisition. In general it can be used to also support processing and analysis of observations, provide quality characteristics; describe system components, data flows or transformation functions.

- ☐ Sensor Observations Service (SOS) is a standard to define web service interface for requesting, filtering, and retrieving observations and sensor system information (section 2.3).

Furthermore, SWE is also consisted of Transducer Model Language (TML), Sensor Planning Service (SPS), Sensor Alert Service (SAS) and Web Notification Services (WNS) standards [48] that refer to concepts and functions not to be discussed in the context of this thesis.

2.2.1.2. ISO 19156:2011 – Observations and Measurements (O&M) standard

OGC Observation and Measurement standard, published as ISO 19156:2011, originating in the work of OGC's Sensor Web Enablement (SWE) activity, as previously discussed. In the context of SWE, O&M standard defines models and XML schema for encoding sensor observations and measurements.

"*Measurement*" has been defined as the process of 'experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity′ [3]. Observation is the 'act of observing a property, having goal of an observation may be to measure or otherwise determine the value of a property' [ISO/DIS 19156:2010]. Both of these closely related concepts incorporate the action (process), the subject (feature of interest), the property to measure and the result of the process. This abstract approach has been adopted by O&M standards definition so that the final model can be applicable across a wide variety of application domains. O&M standard [49] defines as key properties of an Observation the 'featureOfInterest', the 'observedProperty', the 'procedure' and the 'result'.

The 'procedure' element, referenced as 'OM_Process' class, defines the description of a process used to generate the observation result. An instance of 'OM_Process' is often an instrument or sensor, but may be a human observer, a simulator, or a process or algorithm applied to more primitive results used as inputs [50]. As defined in the context of O&M standard, it is abstract; it has no attributes, operations or associations, and must be extended in order to become suitable for the observed property.

The ‘featureOfInterest’ is a feature of any type (ISO 19109, ISO 19101) [51] [52], which is a representation of the real-world object, regarding which the observation is made. The phenomenon that is observed by the model is referenced by the ‘observedProperty’ element and it can be a single scalar value or a composite multi-component phenomenon descriptor. It may optionally be modeled as a property in an application schema that defines the feature of interest and should be conceptually associated with it. Finally, the ‘result’ element contains the value generated by the procedure. The type of the observation result must be consistent with the observed property, and the scale or scope for the value must be consistent with the quantity or category type. Figure 2.1 illustrates the core class diagram of O&M conceptual model that is aligned to the above classification schema.

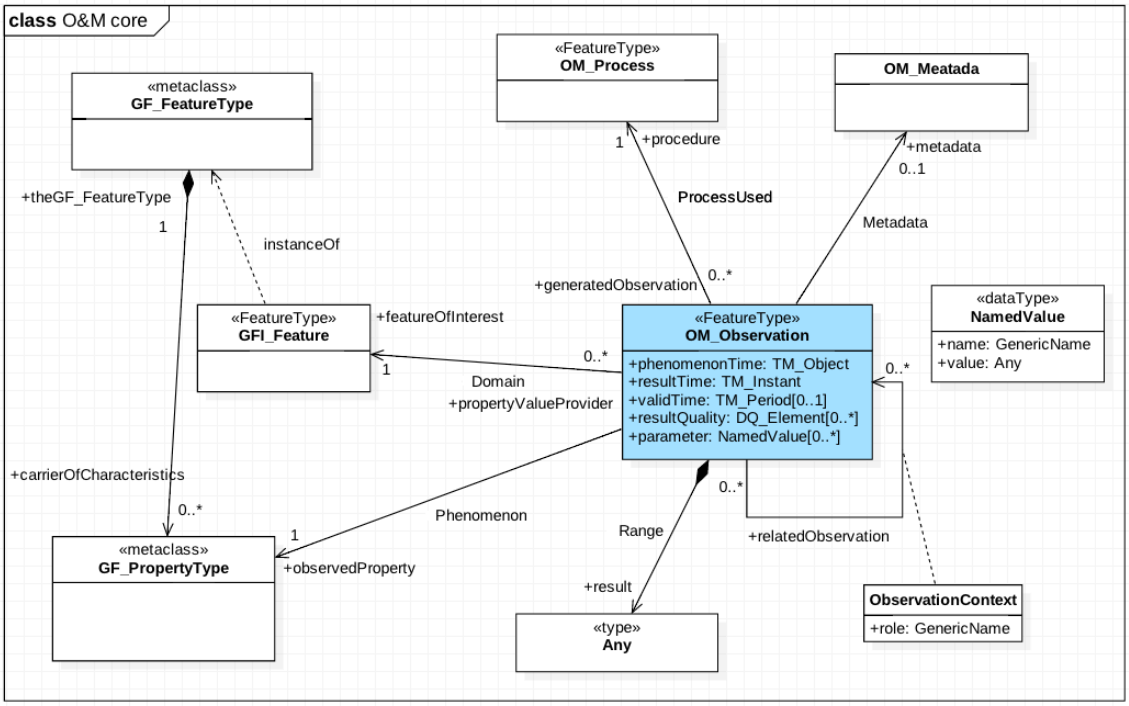


Figure 2.1 Core class diagram of O&M conceptual model.

2.2.1.3. Sensor Observation Service (SOS)

OGC defines Sensor Observation Service (SOS) (from now this paper refers to SOS 2.0 specifications), it is as standard that ‘provides an API for managing deployed sensors and retrieving sensor data and specifically “observation” data’ [41]. The goal of SOS is to provide access to observations from sensors and sensor systems in a standard way that is consistent for all sensor systems. In order to be consistent with its definition, SOS specifies a set of operations that can be used to request available data (operations for sensor data consumer) or to publish information (operations for sensor data publisher). These are classified into the Core operations and three extensions.

The SOS ‘Core’ requirements class defines three operations for retrieving data from the repository. ‘GetCapabilities’ allows clients to access service metadata of a specific service instance. ‘DescribeSensor’ is designed to request detailed sensor descriptive information. Usually, Sensor Model Language (SensorML) or Transducer Markup Language (TML) is used to encode the response to this request. Finally, ‘GetObservation’ operation retrieves observation data structured according to the Observation and Measurement specification, filtered by spatial, temporal and thematic properties. The above three operations of the Core profile of the SOS are mandatory and have to be offered by every SOS implementation.

The ‘Transactional Extension’ refers to three operations that allow user to register new data and sensors into the SOS and also inserting new observations. ‘InsertSensor’ request sends a SensorML or TML description of the sensor to be added. The response returns the assigned sensor id that can be used as a parameter of ‘InsertObservation’ operation to add new observations. ‘DeleteSensor’ operation allows the deletion of registered sensors and all their associated observations. The above operations are defined as optionally implemented into SOS systems.

2.2.2. Implementations - extensions

O&M standards have been implemented as needed in a wide range of projects, standards and guidelines that refer to modeling of observation procedure [53], [54], [55]. This paper examines concepts in the frame of Land Surveying information management and implementation, thus three cases relevant to the Surveying Engineering context shall be mentioned namely Inspire Guidelines for O&M and SWE use, FIG Land Administration Standardization with focus on Surveying and Spatial Representations and Vranic et al O&M GNSS implementation.

European Commission established the Infrastructure for Spatial Information in the European Union (INSPIRE) frame, requesting that data should be collected once and reused. In the context of this initiative, a special document that refers to Observation and Measurements and Sensor Web Enablement Standards has been developed. Due to the fact that O&M standard provides a generic framework for the provision of measurement data, there are many ways of utilizing the core structures. The provided guidelines ensure compatibility across INSPIRE applications, thus should be taken in to account in all INSPIRE themes integrating or referencing to the O&M standard [39]. The developed document discusses fundamental concepts of O&M standard along with case specific application paradigms.

The International Federation of Surveyors (FIG) has developed the Land Administration Domain Model. Primarily it was named as 'Core Cadastral Domain Model' and finally it evolved to ISO 19152:2012 Geographic information - Land Administration Domain Model (LADM) [37].. The main objective of this work was to define a conceptual model related to parties, ownership rights, spatial units, spatial sources (surveying), and spatial representations (geometry and topology). The modeling of spatial sources is made by developing the described 'LA_SpatialSource' Class that represents an integral part of the land administration system. The definition of the above class implements the OM_Observation and OM_Process of O&M standard, indicating this way the strong conceptual relation between land surveying measurement data and discussed concepts. Van Oosterom et al [56] discussed further the use of the above model in the context of Land Administration and provided land surveying measurement level examples.

Finally, Vranic et al [36] discussed the use of O&M OGC model in the context of Land Surveying. More specifically, an implementation of the standard was introduced and a model for GNSS measurements was developed. This work discussed the use of the model in the context of Croatian Surveying Community, providing use concepts and benefits of O&M implementation on Land Surveying data. Figure 2.2 shows the developed GNSS model.

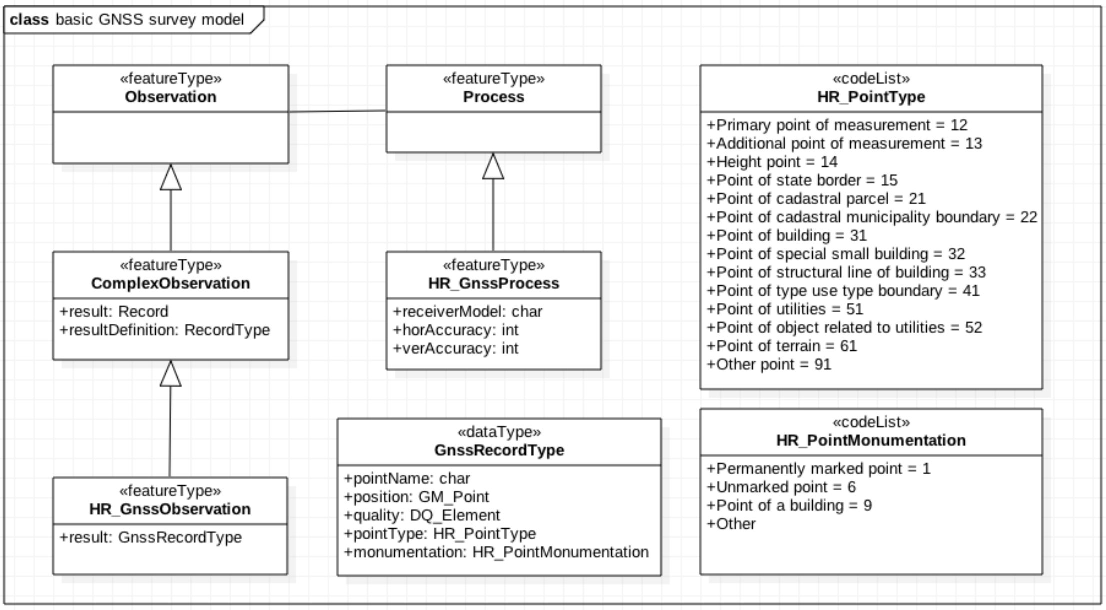


Figure 2.2 Core class diagram of 'HR_GNSS' O&M conceptual model.

The above approach, considers the point of measure to be the feature of interest while the process is described by the specification and the model of the receiver. The result is a set of information that contains the name, position, measurement quality, point type and point monumentation.

2.2.3. Definition of Model

Based on reviewed literature and relevant work, a model that refers to Land Surveying measurements will be discussed and the corresponding classes that define the model will be developed. By using OGC O&M conceptual model, land survey observations can be modeled and be used as source for measurement driven data management systems, analysis tools that benefit from raw data and global observation exchange platforms. The following analysis is structured according to the fundamental "*feature of interest - observed property - process - result*" discussion pattern.

2.2.3.1. Feature of interest

The first consideration to be made in the process of creating a model that refers to Land Surveying measurements is to clearly define the "*feature of interest*" concept. According to ISO 19109, it should be a representation of the observation target, being the real-world object regarding which the observation is made. Land surveying measurement process is about obtaining data describing the relation between two points in space. The first one acts as an observation base and the other as the remote object. While it is easy to understand that the feature of interest is not the base point, it should be remarked that neither the remote object is. Total stations and GNSS equipment are used to measure quantities such as:

- ☐ Slope distance from set point to remote target
- ☐ Horizontal direction from set point to remote target
- ☐ Vertical angle from set point to remote target
- ☐ Time or carrier phase that refer to signal received from set base and transmitted from space vehicle.

The above considerations make it clear that this kind of observations refer to a three dimensional vector. In the context of this paper, the model's feature of interest is the physical instance of base - target vector representation, called from now on as observable vector (Figure 2.3).

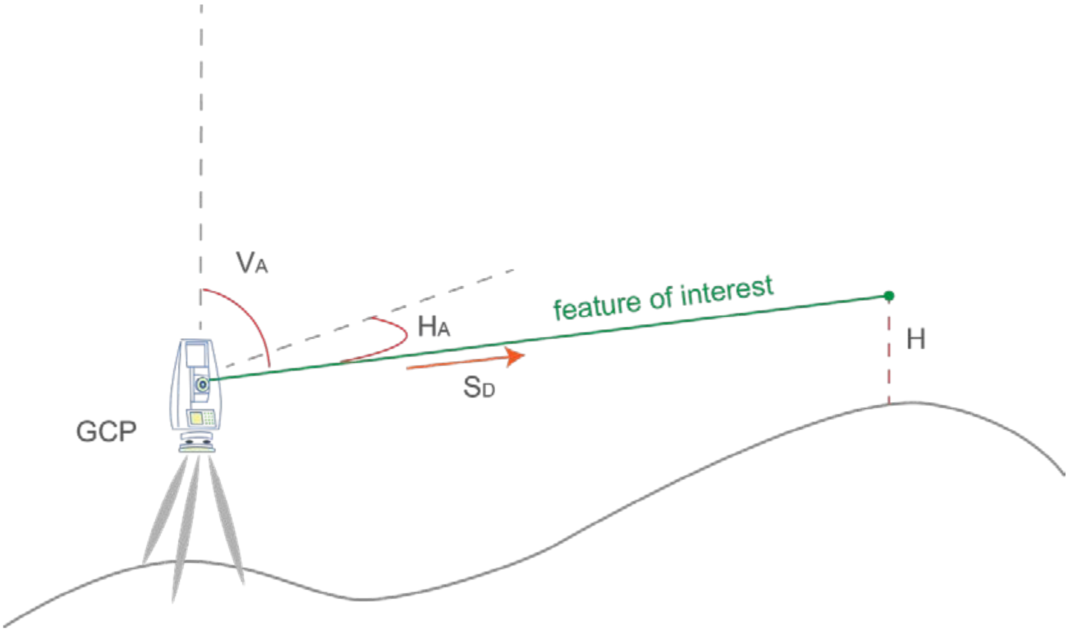


Figure 2.3 Observable quantities of feature of interest.

2.2.3.2. Process

After defining the feature of interest it is necessary to describe the observation acquisition procedure. In order to determine the structure of the 'process' class, it is required to identify the attributes that uniquely define the model. In land surveying, the measurement acquisition procedure is strongly related to the equipment initialization. Whenever a Total Station is set over a base point, there are specific parameters that are set and fixed, which remain unchanged until the next base point setup. This information not only is it required during the data processing but also contains metadata that allow the evaluation of the collected measurements, the final result and the process itself. More specifically in the context of this paper the following attributes are addressed to describe the 'process' class.

The equipment used is an object to be described. Information that refers to accuracy is required in order to evaluate collected observations or compare different set of measurements. The identification structure of the total station is consisted of the manufacturer, the instrument model and date of last calibration. Furthermore, the accuracy specifications are required regarding all types of measurement available, which are angular observation accuracy (separately horizontal and vertical if available) and distance observation accuracy.

As mentioned above, every measurement process starts with the initialization of the total station over an established control point. Data that refer to the base setup are required to the computation procedure and should be implemented in the definition of the model. This is consisted of information regarding the identification of the control point that is a description attribute, filed notes and type of monumentation. Additionally, the equipment setup height, over the control point, provides necessary information in order to extract the third dimension (height) for all of our observed points.

Finally, data referring to the operator can provide information to estimate or evaluate measurement quality. Furthermore, the operator - equipment system can provide, given further statistical analysis, the detection of systematic error patterns thus increase the accuracy of estimated quantities. Based on the latter, contact information, experience in land surveying and field of expertise are integrated into the developed model.

2.2.3.3. Observed property - Result

As stated above, each measurement provides one or more quantity values that refer to the geometric instance of the observable vector. These can be the distance between set point and remote target, the horizontal direction that refers to a random - but fixed for each measurement set - origin or the vertical angle defined as the angle defined by zenith and observable vector. The above are the core observation data that a surveyor engineer collects on the field.

Nevertheless these values are to be provided with other information that is required to define the vector but also relevant observation metadata. Height of remote target is a required attribute for extracting the third dimension from field measurements. Also descriptive information should be recorder both in non-structured (description notes) and structured (point type, observation type) attributes.

2.2.3.4. Class diagram

The above discussion provides the necessary knowledge of Land Surveying work and data context for exploring this paper's model requirements. Based on this knowledge, an extension of the core O&M model has been developed, which is aligned to the specific requirements of Land Surveying previously described. The classes of this model have been prefixed as 'LS_' standing for Land Surveying.

Figure 2.4 shows the 'LS_Process' class that is an extension of 'OM_Process' class of O&M OGC standard. Each of the previously discussed attributes are implemented so that the 'LS_Process' object can effectively describe the actual Land Surveying process. Additionally, Figure 2.5 depicts the 'LS_Observation' class deriving from 'OM_Complex_Observation' class. LS_Operator, LS_TotalStation, LS_Accuracy and

LS_Point are introduced to define and integrate into the model the above discussed entities of operator, total station, accuracy and ground point instance.

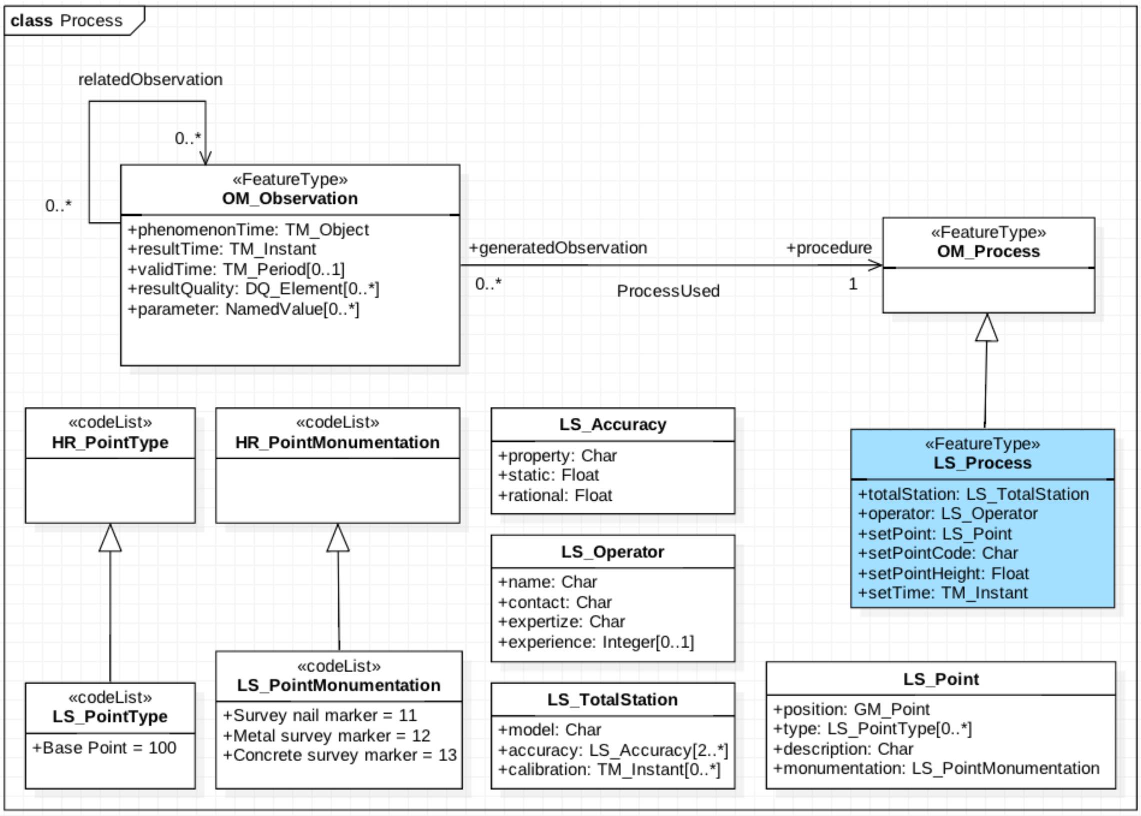


Figure 2.4 'LS_Process' Core class diagram.

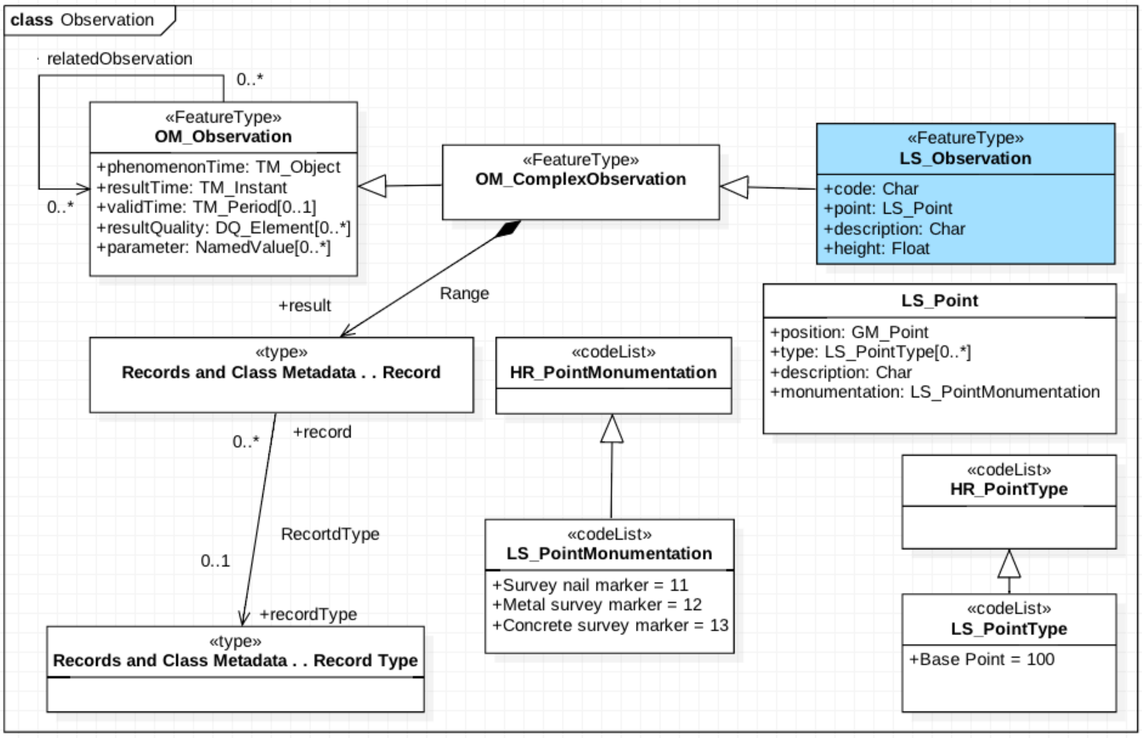


Figure 2.5 'LS_ Observation' Core class diagram.

2.3. System Architecture

The objective of CCLS is to provide a methodology, and specialized VGI data processing framework to achieve all of the above discussed specifications. To meet the needs for surveying engineering applications and accuracy requirements a data structure has been proposed, to facilitate the sharing of VGI information among Surveying Engineers. TS networking and measurement processing using data casting technologies and portable processing units along with integrated Web-GIS services is exploited, as a new methodology for land surveying that can largely benefit from applying the above concepts which combine on-the-field measurements, processing, sharing and validation in real-time. The core of the proposed approach is found in the VGI behaviour concept for geo-data sharing and exchange.

Manufacturers of surveying equipment such as TS work integrating on-the-field computational tools. Most of these implementations are currently limited in off-the shelf TS providing mainly transformations of coordinate reference systems and visualizations of points of interest. Lately, efforts are made in integrating connected portable devices with TSs in order to upgrade their capabilities at a minimum cost adding visualization, image overlay and field data file sharing from office. Clearly, there is a need to unify measuring and processing tasks on the field. The drawback is that every commercial product of this category follows its own standards and do not target or allow creating a community that would share measurements and GI in general out of individual or company context. The evolution of cloud computing enables the creation of a system for sharing surveying measurement data for engineering applications. The ability to share data over the internet provides many advantages, such as real-time measurement and processing synchronization and dynamic interaction, on-the-field accuracy estimation and erroneous observation detection, and access to online shared data both for downloading and uploading measurements. Also, multiple synchronized TSs sharing data can speed up the on-field measurement progress and collaboratively achieve the detection of critical measurements that are missing. Important aspects are also the on-the-field metadata collection and sharing, visualizations of the processed data and real-time progress monitoring and dynamic work reorganization.

The proposed method aims to integrate the acquisition and processing of surveying-accuracy data, and also to provide access to shared data captured by other Surveying Engineers. The synchronization of raw measurements allows for real-time data flows from and to any connected TS, while project overview and progress indicators are also available to authorized clients. There are two main types of actors: “Data collector” that refers to all types of activities that capture measurement data on-the-field, and “data manager”, that allows users to process collected data. After discussing these entities, a database schema for storing all data is presented; finally the main on-the-field functions are reviewed. Figure 2.6 illustrates an overview of the proposed architecture. The system components are further analysed in the following paragraphs.

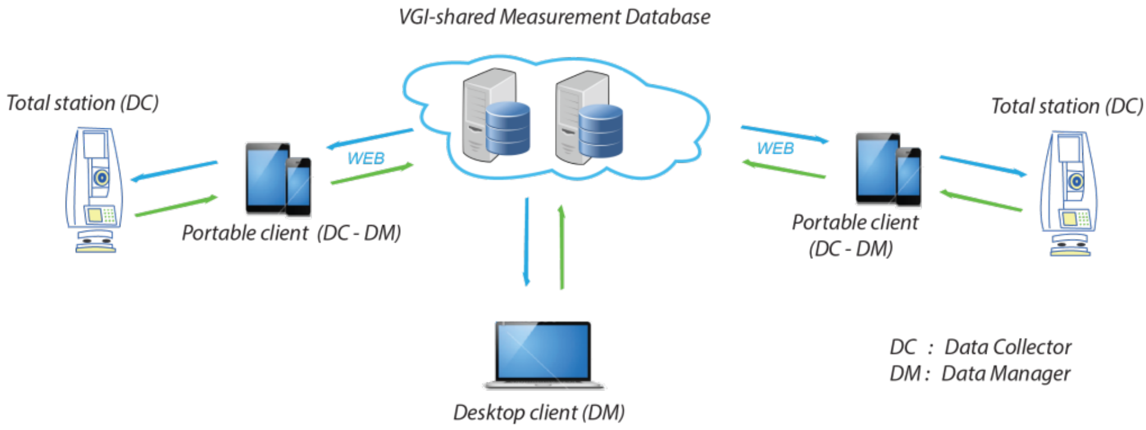


Figure 2.6 Networked measurement stations, VGI database and data consumers.

2.3.1. Data collection

Every device that is used to acquire data on-the-field is referred to as a data collector. The essential data collector is a TS with data communications functionality and network access. Every record of data contains the following fields: slope distance, horizontal angle, vertical angle, target height. By using as a reference the TS position coordinates, along with the above information, the position of any point can be determined. Notably, except from models that natively support wireless communications, most TSs that allow serial communications for data and command processing can be used together with some aftermarket serial-to-wireless adaptor.

Total stations for routine surveying applications do not allow network and visualization functions, nor do they offer any programming framework in order to develop the software required. On the other hand, powerful handheld portable devices provide processing abilities at very low cost, especially since the introduction of the Android ecosystem. Therefore, any android tablet or Smartphone doubles as a great tool for data management. In the case study to be discussed in the sequel, a Nexus 10 tablet (10' screen, 2core 1.7GHz CPU, 2GB ram) and LG G2 mobile phone (5.2' screen, 4core 2.2GHz, 2GB ram) have been used, connected via Bluetooth to a TS. The software that has been developed uses the Bluetooth connection to send the appropriate commands and waits for measurement data to be received back (slope distance (sd), horizontal angle (hz), vertical angle (vz)). Thus, the software takes over the handling of the measurements. The TS receives the commands and responds by supplying the measurement data (i.e. angles hz, vz and slope distances sd) as seen in Figure 2.7.

Additionally, other portable units can be configured to capture attributes of objects, metadata, tagged photos and further manage network data flows. Given that TSs with limited programming capabilities can also be used, the portable devices become the mediator for routing data to a cloud-hosted geo-database, via a mobile data network.

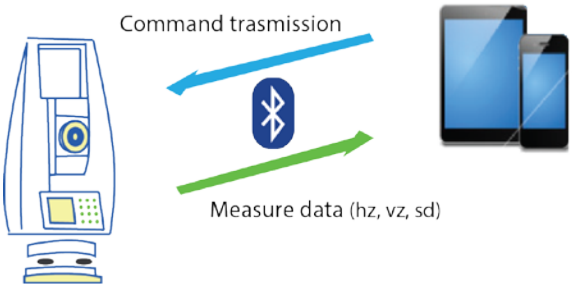


Figure 2.7 Portable device Total Station Communication.

"*Control Points*" (CP) i.e., points on the earth's surface with known location, are the main entities that are used to put the observation set in a reference framework. They form networks (reference networks) and are used as the basis for computing all other points' positions. In a national level, CPs are managed usually by authorities responsible to maintain and provide information about their position. Such authorities are "Hellenic Military Geographical Service" and "National Cadastre" for Greece. These CPs form a network of a points, but these are just for reference (usually 1-2 as accessible) and the surveyor has to use more to form his local network. The majority of surveying applications usually require that such a network is already established. However, lack of access to past data while on-the-field, makes the established CPs useless. The goal is to make the established CPs reusable, which means that anybody can have access to their data. A CP has the following attributes: description, feature (location, accuracy), time, and creator. Every time a TS is set over a CP for measuring purposes, the recorded raw measurements are grouped into sets of data that share similar properties. This is achieved using the object “Measurement_Set” which is the core entity. As the raw data come from the TS, an instance of measurement class is created. Basic attributes include the horizontal and vertical angles, slope distance, target height and meta-data.

The above objects are the minimum required to define the model. Additionally, timestamps and other relevant metadata that refer to spatial resources’ description extension [57] could be used in order to define an ontology-based approach to describe each point [58] [59]. The proposed data model has implemented these attributes as discussed in section 2.2.

As the position of measured features on the earth’s surface could change over time (e.g. sidewalk reconstruction, building move after earthquake, infrastructure network reform), the proposed approach allows for temporal management of measurements to track phenomena of such nature. Figure 2.8 describes different cases of determining the position of the same Control Point (CP0). There are approaches like multi spatial (when CP0 is determined by different CPs), multi user (when different users determine the position of CP0) and multi epoch (when CP0 position is determined over different timeframes). This fact allows for the determination of the accuracy of user equipment as well as for the detection of time-based changes.

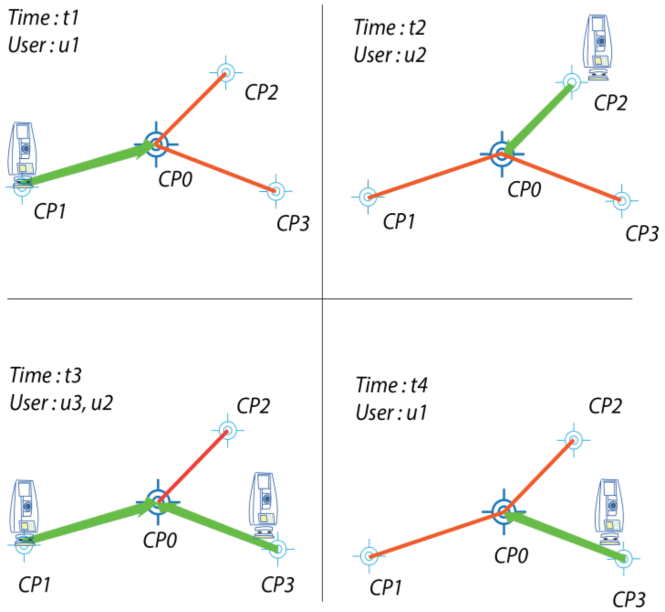


Figure 2.8 Multi user - time position CP definition.

2.3.2. Data management and process

Data management and processing are procedures that both must be executed in real-time, to allow access to all available information on-the-field as well as in the office. This approach examines two types of system clients, namely portable (on-the-field) and desktop (office). Each client type receives and offers distinct functionalities using appropriate tools and functions which will be discussed in the following sections.

2.3.2.1. Portable client

The portable devices interact with the TS, in order to receive raw measurement data. Together with the data collection, the devices are employed for three more important tasks: data routing, data processing and information visualization. Appropriate prototype software for this project has been developed in Android OS that enables all the above operations to be executed.

Data routing. The portable clients perform the data routing, since TSs have limited functionality. The first step is the control of the TS over Bluetooth, which is followed by the measurement data response. The developed software gathers the raw measurement data which may be enriched with other types of data (e.g. photos, metadata, spatial attributes) essential to extent geometry and enhance potential usability [60] [61]; these data are stored locally in order to have offline access, and are also sent to the system server over a wireless internet connection. The final goal is to achieve data synchronization both on user request and real time when possible.

Data processing. One of the main advantages of the proposed architecture is the real-time data processing during data collection on-the-field. This allows the surveyor to validate the collected measurements, detect erroneous observations, verify the integrity of measurements by eliminating a possible lack of measurements - as the real-time processing can detect missing information, and integrate all available data. In order to make this possible, computations of the reference network are triggered to compute the positions of the entire CP network upon any new measurement data entry. This way, whenever the local device or any connected network device provides new data, the network CPs positions are updated (if the user selects to integrate all measurements available) so that the user can constantly evaluate the full dataset easily by having any conflicting measurements highlighted, prompting for a review.

Data visualization. Portable devices are equipped with high definition flat panel displays capable of providing an advanced visualization experience. The developed software displays both raster maps and vector generated data. Geo-referenced maps, web map service (WMS) - tiles and orthophotos of the area of interest are pre-loaded on the device and used as a background of overlaid vector data. In the project described in this work, orthophotos provided by the National Greek Cadastre Service are used as a background, providing 20 cm accuracy level over urban areas, allowing for gross error detection – removal (every measurement that contributes in over 20 cm position error of measured point, is immediately recognized).

Regarding vector information, there are multiple cases of spatial data usage. Preloaded vector files can be projected over the project workspace, in order to be compared with the collected data (*.kml files have been used for our case study). Every time the system recalculates a feature's position, it gets drawn over the raster images and the available layers containing the vector information. As mentioned above, this results in the detection of erroneous observations, which are highlighted on the screen. Figure

2.9 and Figure 2.10 give examples of visualization modes as developed and used in the current implementation.

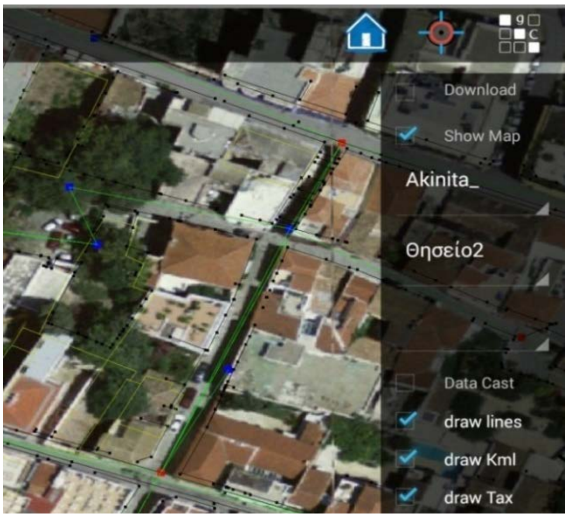


Figure 2.9 Portable client WMS visualization.

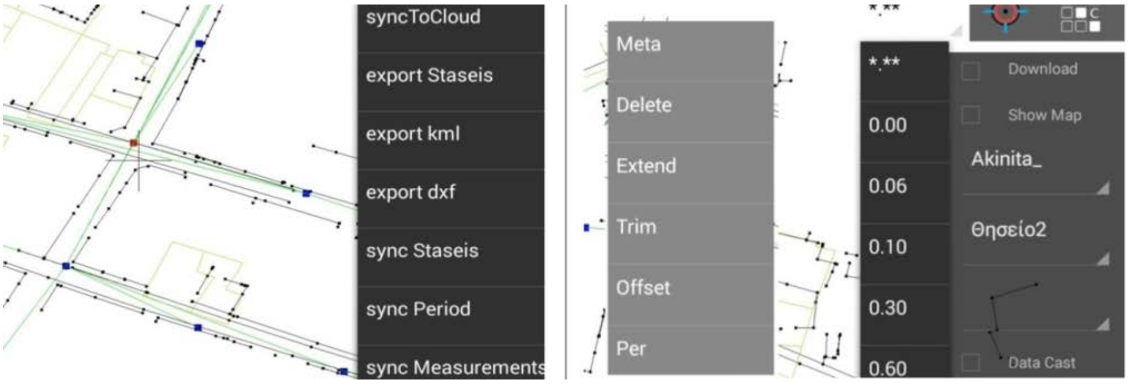


Figure 2.10 Portable client vector visualization.

2.3.2.2. Desktop client

The Project administration - overview (including the field work monitoring), is also possible via dedicated software. The Desktop client developed for this project runs on a web browser environment, enabling the project management and granting administrative rights (project creation, global variable setting, grant user access, set available layers, etc). Also there are several functions provided additionally to those of the portable clients, such the project creation, project edit, progress overview, computations finalization, report export and quantitative tools for the purposes of this research. Moreover, as the web application has been developed in JavaScript, HTML, and PHP programming languages, it is possible to hand out the system functionality through an application program interface (API), which will allow further extensions by the community, according to the current trend in platform-independent collaborative software development.

2.3.3. Client – Server architecture

Centralized data management requires a database for maintaining data. Through the selected Database Management System (DBMS), the developed software can implement data management functions such as input, storage and retrieval, while ensuring both data integrity and security. The use case prototype implementation has used MySQL and Postgres with PostGis which are open software DBM Systems. The proposed approach is the three-tier architecture implementation of multi-tier architecture. This architecture pattern seperates the system logic in three well defined layers namely, Data tier, Application tier and presentation tier.

The "*data layer*" includes the information management (entry, retrieve, etc) mechanisms and the API that exposes the service methods that manage the access to the database and thus the access to the data. As descripbed in section 2.2, the data schema has been developed according to OM Observation and Measurement standard. A relational DBMS such as Postgres with PostGis handle the low level functions and expose higher level methods by OGC SOS implementation (52N used in case study) as described in section 2.2.1.3 (GetCapabilities, DescribeSensor, GetObservation, InsertSensor, InsertObservation, DeleteSensor, etc).

The "*application layer*" includes all the processing functionality that uses original measurements to produce or extract requested information. Geometry transformation functions, error managemend, statistical model application, visual information adjustment, information access and land surveying algorithms are implemented and provided as a separate layer in two basic forms. Mainly as data process web services that can execute requested operations but also as part of system clients (desktop or mobile) to apply operations that will not stress the server and will also be available offline.

The "*presentation layer*" includes all the operations and modules that produce visual information data structures that can be used and discussed by the system user. These can be 3rd party available maps (WMS), produced vector maps, 3d models, graphs, data tables and other visualization schemas that enchance the user experience and the overall data interpretation. The presentation layer features are part of the client architecture side as it has to benefit from desktop or mobile graphics processing units. Figure 2.11 summarizes the above described structure.

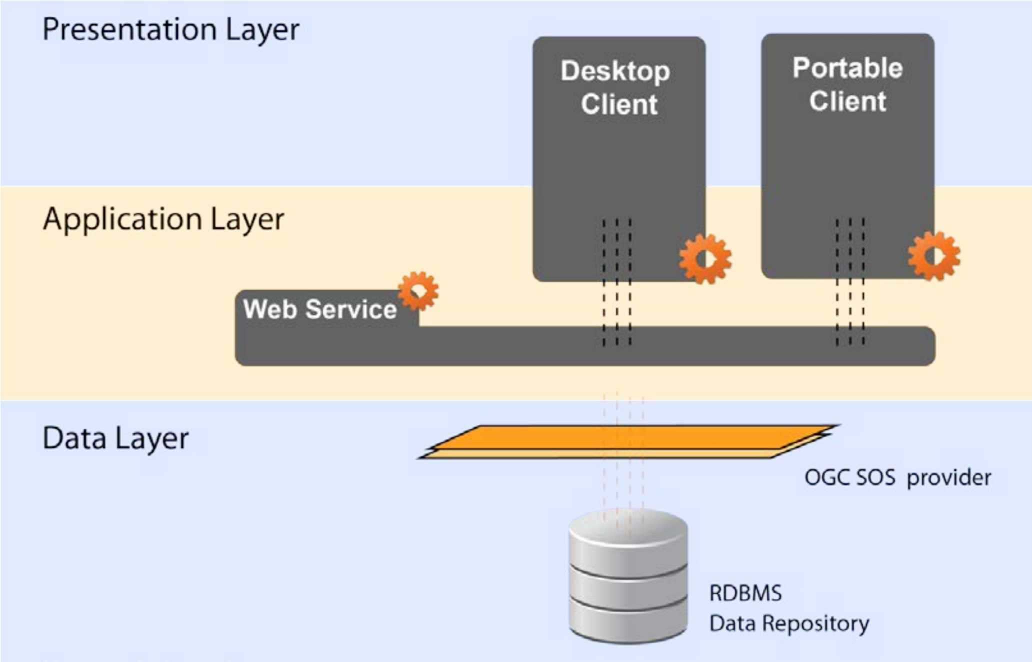


Figure 2.11 Three tier architecture schema.

2.4. Prototype implementation

In order to examine the benfits and difficulties that emerge form the adoption of the proposed system, several case statudies have been discussed. Section 3.1 discusses a large scale mapping project that has taken advantage of the CCLS architecture principles. Section 3.2 presents a more in depth implementation of developed model (OM Standart compliant) and section 3.3 has explored a new educational approach that can provide more in depth understanding of land surveying algorithms and techniques. The above mentioned projects required a prototype implementation of most of the discussed system modules so that not only it would be possible to apply the developed model but also the author could explore the complexity of discussed architecture as it is materialized in application and physical level.

2.4.1. Server side - data - services

During the testing phase of the system implementation, three major versions of data models and RDBM Systems have been used in order to examine the efficiency of diverse approaches that exist as supportive components, part of Data layer. Each one is an upgrade on the previous in order to meet application requirements.

Version 1. MySql RDBMS has been used to apply the first version of the server side concepts in the context of the large scale case study (section 3.1) with emphasis in interaction with the portable android client. It has been created to support the mobile application providing synchronization functions that manage the data flows. The schema is available at *'https://github.com/gssofos/ccls-server/tree/master/data'*.

Version 2. Postgres RDBMS has been used along with PostGis extension in order to implement the developed Data model discussed in section 2.2. The transition to Postgres has been decided so that advanced spatial transformation and queries can be applied to available data but also enable the creation of WMS services through geoserver. All available data were mapped to the new schema, that is available at *'https://github.com/gssofos/ccls-server/tree/master/data'*.

Version 3. Durring the OGC Sensor Observation Service implementation, 52N SOS platform was used. The database that managed the information was auto generated by the platform having predefined structure. In order to feed the service with data, scripts that compile appropriate xml files from existing database have been developed. *'https://github.com/gssofos/ccls-server/tree/master/data/03_sos'* hosts scripts for process object description using SensorML and samples of output files.

This work has gone through varius custom data providing services during the prototyping phase. Additionally, two established frameworks have been used to implement OGC standardized services. The first one is the previously mentioned 52N

SOS software (extensively discussed in section 3.2). The data import functions apply to xml files (see ‘https://github.com/gssofos/ccls-server/tree/master/services/sos’).

The second OGC defined service is a WMS to serve maps of custom visualizations (see section 3.2) implemented by geoserver. The communication with the database is established through sql queries and the styling uses Styled Layer Descriptor (SDL) xml notation. Queries and styling can be accessed in ‘*https://github.com/gssofos/ccls-server/tree/master/services/geoserver*’.

2.4.2. Application layer - Unsupervised Fast Network Computation

Land surveying measurements have a unique attribute that will be discussed in section 3.2.3. They define an “*a priori*” spatial agnostic but at the same time geometric self described network. This means that inspite measurements are collected to define the coordinated of features of interest as a final processing product, themselves are position agnostic. The above statement is compatible with typical land surveying work flow, but it injects a major problem in this work. Every new measurement collected is potentially restructuring the GCP network. One of the major features of CCLS is the “*promise*” of validating measurements in real time and continuously providing updated network space snapshots. This requirement cannot be met by current computational schemas as there is the need for supervised or semi-supervised process execution, that for big measurement datasets are computational intensive (if statistical models and least square algorithms apply).

In the context of the developed prototype, an algorithm has been developed to meet the above requirements. It is designed so that the input is just raw measurements and precision thresholds (angular, linear) and the output is a table of GCPs coordinates with precision metadata. The following list summarizes requirements and specifications of developed algorithm:

☐ Unsupervised. Given the input observation vector (gcp id, target id, angles, distance, heights) the algorithm executes without user interaction.

☐ The output indicates deviation of computed position according to provided threshold.

- ☐ Fast. Real time network recomputation is required upon new measurement acquisition. The network size varies from a few nodes to hundrends. The case studies discussed in section 3.1 and 3.2 managed over 200 nodes that come with several thousands of observations. In order to achieve descent user experience, the algorithm is expected to achieve sub second execution time.
- ☐ Indication of '*orphan*' (not used in network computations) measurements.

Additionally to pre defining the developed algorithm's requirements, it is important to clarify what the described process is not expected to achieve. The output is not to provide the final refined coordinates through high complexity statistical models but rather provide real time (precision predefined) positioning (even triggered) and error candidates. It is processing time intensive and not absolute precision intensive.

Table 2.1 summarizes data input that the algorithm expected as parameters and the data output structure. The algorithm is a procedure that consists of three modules as described below.

Operation	Data table	Attributes	
Input	Observations	oid	observation id
		pid	process_id
		gid	gcp_id
		tid	target_gcp_ig
		ha	horizontal angle (direction)
		va	vertical angle
		sd	slope distance
	Precision	ea	angular
		ed	linear
Output	Observation	oid	observation id
		isf	isUsedFlag
		iec	isErrorCandidate
		eev	estimatedErrorValue
	Node	c[ ]	coordinates
		set	hasBeenSet
		iae	isAngularErrorCandidate
		ile	isLinearErrorCandidateMember
	Edges	dv	distanceValue
		ile	isLinearErrorCandidate

Table 2.1 Data provided as input parameter and returned as output.

2.4.2.1. Measurement preprocessing

This module of the algorithm is executed to compute horizontal distances, rebase direction observations of different processes on same node so that all measurements can correlate, build table for next module.

```
for each node (distinct gid)
        Find one common direction in all Measurement Sets (processes - pid)
        normalize - rebase (direction)

        Compute horizontal distance (distance)

        Build  feature table  {gid, tid, direction[],distance[]}
```

2.4.2.2. Validate network

This module’s aim is to extract edges, ckeck which are well defined and validate networks integrity. As well defined are described the edges A - B where there is the distance AB and additionally the direction observations A>B and B<A.

```
create edge table  {
    distinct(gid-tid), average distance value(dv), ile :bool
        , wellDefined (wd:bool)},
create node table  { distinct(gid), coor[], iae :bool, ile :bool, set :bool}

for each item in Feature Table
        Edge_table.dv = average of gid-tid distances
        if( abs(distance[i] - dv) > ed)
            {       Edge_table.ile = true
                    Observation[oid].iec = true
                    Observation[oid].eev = abs(distance[i] - dv)
                    Node_table[gid || tid].ile = true
            }else{Edge_table.ile = false}
```

for each item in Edge Table

```
if( Edge_table.dv != null && exists_angle_bidirectional)
                                        Edge_table.wd = true
```

for each item in Feature Table

```
average direction(avd) = average of gid-tid directions
if( abs(direction[i] - avd) > ea)
    {       Node_table[gid].iae = true
            Observation[oid].iec = true
            Observation[oid].eev = abs(direction[i] - avd)
}else{Node_table.iae = false}
```

2.4.2.3. Coordinates extraction

The concluding section of the algorithm computes the coordinates of the nodes. A starting node ($node_0$) and an initial back node ($node_{-1}$) is selected for initializing the computation propagation through the network. The starting node has to meet the (!iae && !ile) requirement belong to two well defined edges. After initial coordinates are provided by user, the coordinate propagation follows the rule:

$$x_i = x_{i-1} + dv_{i \to i+1} \times \sin(avd_{i \to i+1})$$

$$y_i = y_{i-1} + dv_{i \to i+1} \times \cos(avd_{i \to i+1})$$

$$node_i.set = true$$

Formula 2.1. Coordinate propagation formulas

Propagate to nodes that belong to all egdes of current node, until the stop condition $node_{i+1}.set = true$ is met.

2.4.3. Portable client application

Measurement collection is the source of information for the proposed architecture. Real time repository observation access and synchronise, but also all the features and services previously described, require tools to handle and process information during collection time. For this purpose and for the demonstration in the context of the case study, a prototype portable client application has been developed to meet the above requirements. The selected hardware platform has been an android based device so that the hardware can be a typical smartphone or tablet. Android OS is an open OS, can be found also in low cost implementations and is the most popular platform of the majority of tablet devices. Research on Android usage on-the-field has been already in progress [62].

In the process of prototype development, many aspects of the system have been exploited and basic functionality for each feature has been built. The application has been developed in Java programming language, initially in Eclipse IDE and later in Android Studio. The prototype source code can bee found online in the github repository platform *('https://github.com/gssofos/ccls-android')*. The following sections discuss some of the core functionality developed.

The first and most fundamental concept to be handled is the way information is received from the surveying equipment. Most typical total station hardware implementations support cable serial communication. On the other hand, android devices are Bluetooth enabled, but not all total stations can use this technology to communicate. The approach selected was to enable Bluetooth by adding an "*Serial to TTL to Bluetooth*" module (Figure 2.12). The bulk module price is in the range 5-10$, so without any cost the existing equipment was modified and communication to the equipment was established.

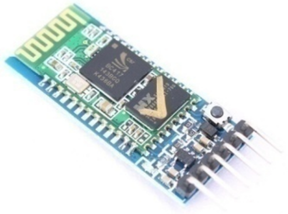


Figure 2.12 Typical TTL to Bluetooth module.

The advantage of using such an approach is not only that existing surveying equipment can be integrated in the described architecture but also that the mobile device can handle total station hardware by sending messages that trigger measurement and other total functions.

The second communication flow to be implemented, was this the android device to the CCLS server and other service providers. For this requirement, use of 3G network (or wifi if available) was built in into every smartphone. The application based on that infrastructure was developed to send and receive calls for data synchronization, but also ask information from other providers (eg WMS orthophoto maps from Greek Cadastre). High bandwith rate communication functions can be disabled so that local resources can be used only.

The application handles two basic data categories, namely vector and raster. In the vector side, data measurements are stored in a local SQLlite data repository while other vector datasets are available locally as kml, shp, and other vector file formats. Raster data (eg eg WMS orthophoto maps from Greek Cadastre) are locally stored in a ZXY folder tree structure so that WMS tiles can be preloaded and available on filed without utilizing 3G network.

The visualization engine used OpenGl ES low-level 3d acceleration API, so that the most responsive user experience cabn be achieved. In every user interaction (new data, parameter modification, option selection), the application recalculates the entire network using the Unsupervised Fast Network Computation algorithm discussed in section 2.4.2. Classes and functions that instatiate the model used can be found in *https://github.com/gssofos/ccls-android/blob/master/app/src/main/java/com/geocloud/topo*. On each recalculation all measurements (coordinates computed, wms raster basemap, vector overlays) are rendered on the application viewport so that the user has access to updated geometries and get informed of possible detected errors.

2.5. Measurement quality

One of the most fundamental concepts to be discussed is the management of measurement quality. Precision estimation and processing is of critical importance to the community of land surveying Engineers, as high accuracy specifications have to be met. High complexity triangulation algorithms and error estimation processes (eg least square method), need measurement precision metrics to be available. This requirement sets quality as a factor to be exploited in order to define the necessary data flows, tools and services to achieve an effective precision and error management. This section discusses three types of measurement evaluation data sources, namely a priory, statistical and user provided.

2.5.1. A priori

Land surveying measurements are acquired using special high precision equipment (lazer distance meters, total stations, GNSS) that provide information regarding the precision of observation procedure. The typical form or the above is expressed by two parts, one static and one variable. Distance precision for example is given in mm ± ppm while for angles it is grad ± ppm. The developed measurement model (Figure 2.4) defines a class for storing this information. Every measurement process refers to an equipment object instatiation that includes the above data. Surveying equipment are registered to the database so that every measurement provided can be retrieved along with the equipment precision specification. This ensures that users that have access to provided datasets can evaluate the compatibility to their project specification, regarding the observation equipment precision.

Additionally to the above, information regarding equipment calibration process is one more property to take into account. Improper use, environment circumstances, production fault or even typical use over periods of time, result into lower equipment precision. This is why this kind of equipment is periodically checked and calibrated so that measurement quality is into normal - required range or otherwise restored. These calibration processes are as critical as the specifications themselves as they verify the paper provided observation quality and are considered into the equipment model so that it can be provided upon request.

2.5.2. Statistical

Every measurement collection is typically used to compute the coordinates of features of interest. This process benefits from advanced computational workflows that make use of statistical models and algorithms that manage error metrics and estimate aposteriori observation errors along with coordinate errors.

The simplest case in the context of the above, refers to observations of the angles of a triangle. The sum should be ideally be 180 degrees so the deviation corresponds to the measurement error. When the total error is distributed to each angle (e.g. 1/3 of total) it is possible to compare with expected error (equipment precision) and attach it to the observation itself. The same principle can be applied to more than one geometries that consist of the same observation (eg neighbour triangles sharing the same vertex) resulting this way to multiple error values for one single observation.

Accordingly, statistical error estimations that refer to distances are produced during the same process but also final position uncertainty (x,y,h error estimators). All the above error values can be attached to the observation, so that multiple quality indicators can be available to any consumer of the data repository.

2.5.3. User feedback

One of the most important factors that will ensure the quality of the available information, is the user himself. The user can provide feedback regarding the observation quality in many aspects .

- ☐ Repository measurements are available on the field, enabling this way the user to verify them in comparison to his own observations. When a measurement is indicated as erroneous as the difference from the repository version is over the accepted threshold, the operator repeats the measurement verifying this way the correct value. This piece information is a continuous observation error watch mechanism that ensures the quality as more measurements are available.

☐ The processing of measurements results through supervised filtering most of the times, where user goes through iterations in order to achieve the best possible result. This workflow requires the user to add or remove measurements accordingly until he reaches the best result. The information of ignored observations can be a valuable indicator that can also be attached to the measurement entity.

☐ Every “operator - equipment” entity that provide a number of observations to the described system, result in multiple error estimators according to the above discussion. The total of these measurements can be used to generate an observation quality index that is attached to every observation. So a combination of all available error metrics that have been produced by the user himself can anonymously define a measurement quality indicator.

2.5.4. Summary

Considering all the above, it is obvious that every observation value can be related to multiple error estimators that can be used to extract the optimum result. If there are:

☐ X users contributing for one observable quantity
☐ N observations of the observable quantity
☐ Q one equipment specified observation quality value for measurement i
☐ Ui internal statistical error estimators for measurement i
☐ Ki solution and field processes that reject or accept measurement i

For each observable quantity there will be (E) estimators (Formula 2.2) available to provide information regarding the quality of each measurement.

$$E = X + N_{of\ Q} + \sum_{1}^{N} U + \sum_{1}^{N} K$$

Formula 2.2. Number of quality estimators for each measurement

2.6. Use cases

The previously described architecture introduces new tools and concepts that can be used in land surveying, allowing specific use cases to take place and meet specific needs. In this section, parameters that define the context of a project’s execution are used in order to categorize its requirements and define the appropriate process, which will help users to achieve the targeted work optimization. Figure 2.11 illustrates a classification diagram by capacity of the measuring crew, used to determine the required methodology adaptation.

The first parameter is the dataset density and reliability that CCLS data repository provides to authorized users. In Figure 2.13, DB content is categorized into three states of dataset availability, pictured as radial zones. The vertical axis is used to define a project’s requirement for productivity - accuracy balance, as these attributes are generally competing to each other. The Horizontal axis denotes the capacity of measuring crews, ranging from "beginner" to "expert".

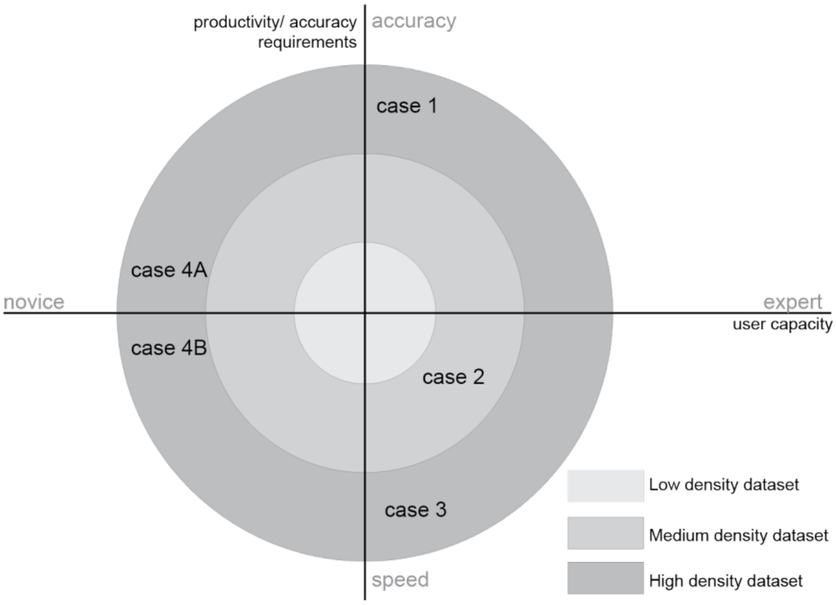


Figure 2.13 CCLS use case classification.

In the indicated segments of this circle, the above factors define a specific requirement combination as the context of a use case. "Case 1" area describes a project that is specified by high accuracy demand, executed by expert users, while the CCLS database provides a high density dataset. These attributes match projects that collect high accuracy data. "Case 2" and "case 3" segments refer to projects where time is critical, executed by experienced users and data availability is of medium and high density respectively. Finally, "case 4A" and "case 4B" require high density, validated datasets available on the cloud in order to grade beginners in situations of high accuracy and limited time availability. These are described in the following.

2.6.1. Case 1: Feature movement monitoring

In projects that require monitoring of features or infrastructure networks, high accuracy measurements are collected and compared to past data in order to detect possible movements. Such tasks are executed by experienced surveying engineers while the availability of temporal spatial data by CCLS is of critical importance. These types of projects combine all of the above specifications while CCLS set the framework that ensures execution optimization. Figure 2.14 shows UML use case diagram.

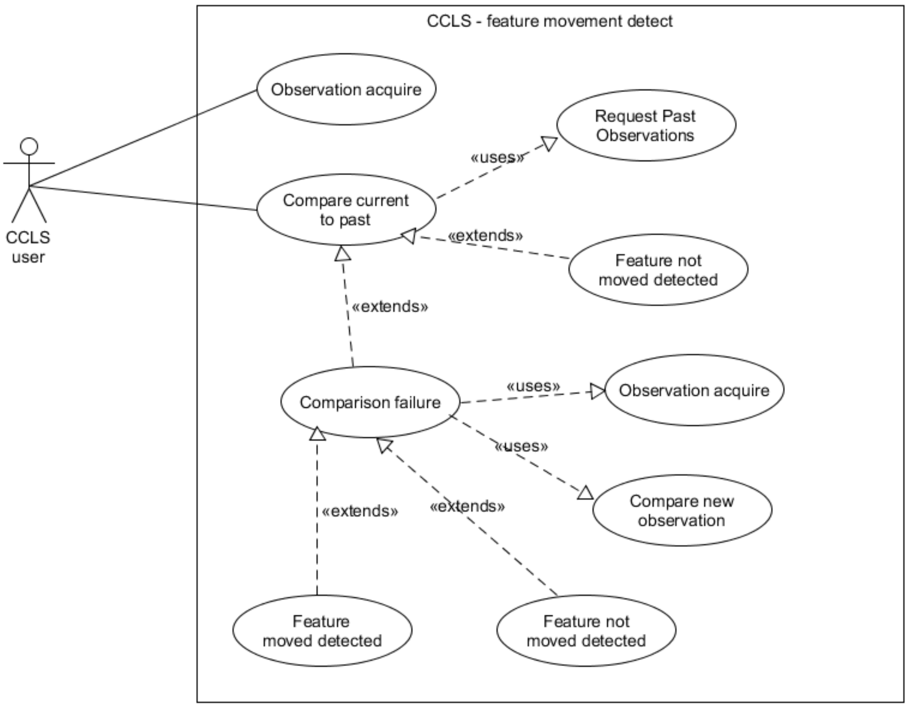


Figure 2.14 CCLS feature movement monitor use case UML diagram.

The proposed methodology provides the data store and access tools that are capable of managing spatio - temporal data. The project manager has access to the full dataset containing both his own team's collected data and other available measurements. On-the-field access to available data ensures that real time observation divergence detection is possible; this is a unique feature of CCLS, which enables a significant measurement accuracy improvement as previously discussed. The above functionality automatically triggers measurement repetition requests; once executed, either an error has been corrected or a feature movements have been detected.

2.6.2. Case 2: Multiple stations

Time can often be a critical factor in land surveying projects, especially in large scale projects where multiple land surveying groups collect data simultaneously. Problems that usually come up in organizing such tasks include group area overlap, CPs naming conventions and complementary observations on area bounds

The CCLS framework uses the concept of a real-time collaborating TSs network (TSs that exchange data over the Internet in real time). Multiple TSs populate the CCLS cloud-hosted database with observations that become immediately available to the rest of the TSs working on the same project and area, allowing each user to overview the progress of the whole project in real time. Users who collect data in adjacent areas have immediate access to all the measurements and features that have been already surveyed by others, which is useful in detecting both errors and missing measurements. Figure 2.15 shows UML use case diagram.

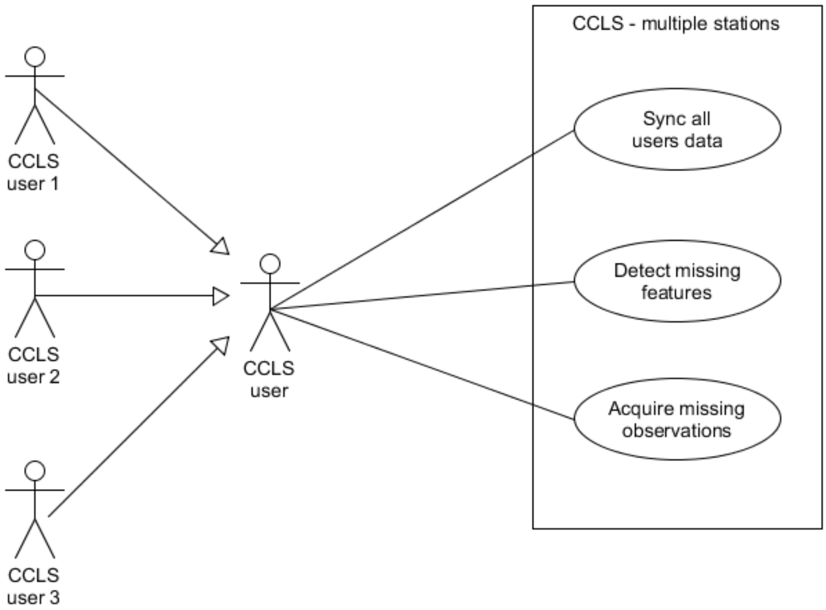


Figure 2.15 CCLS multiple stations use case UML diagram.

2.6.3. Case 3: Fast track

Another type of project where time is of critical importance is defined by areas where data exists in the CCLS data store at a medium-to-high density. In such projects, users of the CCLS approach can maximize the reusability of information. CCLS provides the context of data sharing, access and reuse. Surveyor engineers can evaluate existing information accuracy by re-measuring a sample of the provided dataset, verifying that it can be used as is. Any missing measurements for their specific project can be re-measured which will be also contributed to the cloud-stored database. Figure 2.16 shows a fast track UML use case diagram.

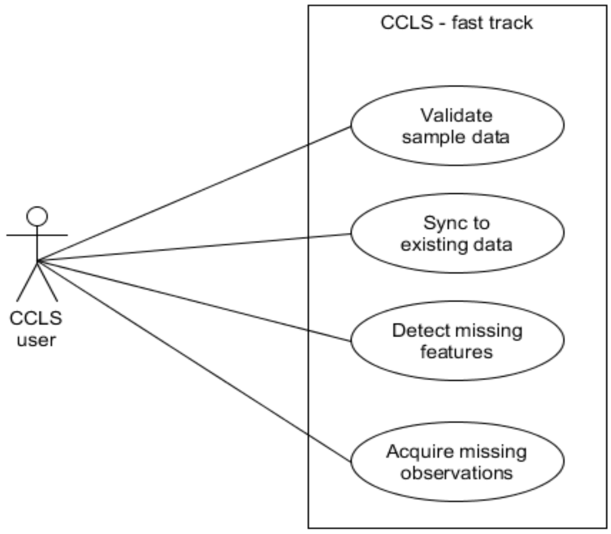


Figure 2.16 CCLS fast track use case UML diagram.

2.6.4. Cases 4A, 4B: User capacity grading

A There are cases where high density verified spatial information are available and there is the need to evaluate how the land surveying process is applied by no-vice users, such as trainees. This case can be part of a teaching process. Cases 4A and 4B (cf. Figure 2.13) consist of high density, validated datasets, which according to CCLS are made available to novice users in conditions of both high accuracy and short execution time limitations, respectively. In university campuses of surveying engineering schools, there are usually areas used by students of land surveying courses in order to exercise their skills. These areas are used every year and observations are repeated by different users. The traditional Surveying Engineering teaching process compares the final product (2D plans) to validated datasets in order to evaluate the skills of novice Surveying Engineers. Errors can be detected, but information of failure source cannot be extracted. Figure 2.17 shows UML use case diagram.

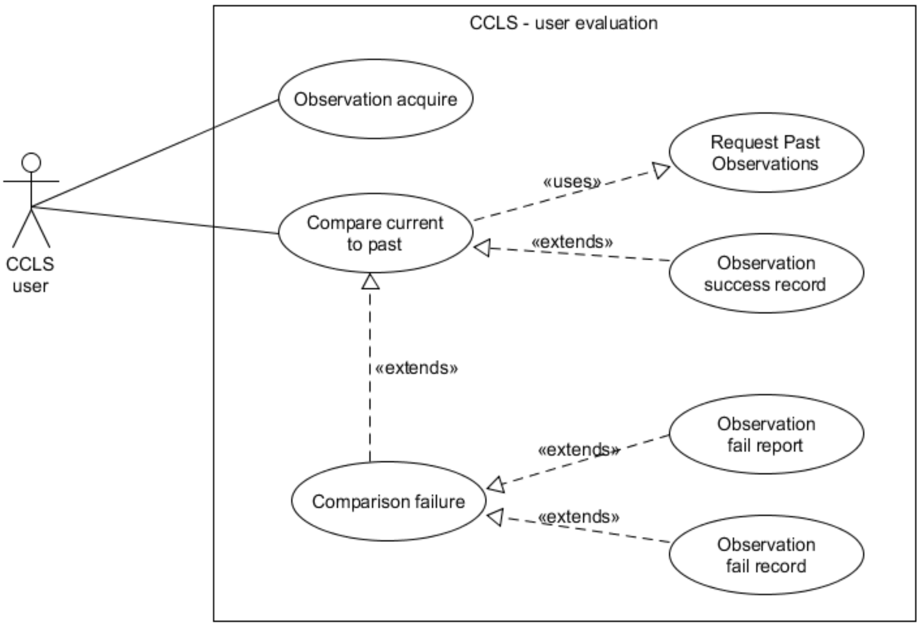


Figure 2.17 CCLS user evaluation use case UML diagram.

On the other hand, CCLS can grant novices access to validated data to improve this process. Every collected observation can be evaluated on-the-field in real time so as to trigger repetitions of measurements where needed. If this is part of a learning process, the measurements can simply be stored without notice and be used to create an "observation error" profile that specifies weaknesses in each student's practice. Teachers can use this analysis to improve the teaching process and provide personalized corrections and instructions to each learner. If this process is applied in different conditions (high accuracy, short execution time) then students can develop and evaluate quality skills over multiple land surveying work profiles.

3. Case Study

3.1. Large scale mapping

In order to test and validate the functionality of the proposed approach, it was used in a real project of the Greek Ministry of Culture; this project is about the mapping of the historic centre of Athens including all the archaeological sites, monuments and the private real estate property, as part of the Archaeological Cadastre. As a result, mapping of the area should provide spatial information of places of interest. The study area is about 460 000 m2, 60% of which is urban area of high density.

This project is a great fit for the CCLS because is a large-scale application giving the opportunity to collect and manage large amount of measuring data coming from multiple work groups at the same time. Figure 3.1 visualizes the boundary of work area over OSM and satellite image.

Figure 3.1 Boundary of project area over Open Street Map and Satellite image.

An important aspect within the project's scope is the equipment cost. The case study described, was based on a low priced Kolida KTS-442RC TS (angle accuracy 2'', distance accuracy of ±(5mm+2ppmxD) for non prism and ±(2mm+2ppmxD) with prism). Total stations of medium to low end currently do not support wireless data transfer in their vast majority apart from RS-232 communication. In order to allow TSs for routinely surveying applications to be used, a Bluetooth to serial adaptor can be integrated to enable wireless data transmission and command execution.

During the field work, the android application developed for this project was used as data collector and data manager. Bluetooth adapter were used to establish connections between TSs and tablets. Tablets manage commands to the TSs, as well as data synchronization. Also, all computations were executed and visualized in real-time. Multiple data collectors/ TSs collected the project data that were processed and displayed simultaneously by all clients (Figure 2.6).

During a 4-month data collection period, 8 surveyor engineers and several archaeologists worked together in mixed teams and at least three groups were measuring with TSs on-the-field simultaneously. The participants' working experience during the data collection varied from zero to 20 years. In order to compare the proposed approach, it was requested that some groups used the proposed system during the measurement process, and some others worked on the field using the classical surveying workflow.

At an initial level, the approximate point position for each property and archaeological monument, was located using the existing address along with the Google maps search service, so that the field work would have approximate reference points (Figure 3.2). Furthermore, datasets for some properties were available containing non validated information (such as older topographic maps). Finally web mapping service (WMS) of the Greek National Cadastre& Mapping Agency provided background maps of 20cm accuracy used to overlay both existing and measured data.

Figure 3.2 Position of points of interest over (a) OSM and (b) Satellite image.

Up to writing date, the reference network consisted of 270 CPs covering about 60% of the total project area. After filtering out inaccurate data, 41515 observations that refer to 10379 features of interest, acquired on the field have been used. The CPs and reference network density are shown on figures 4.3 and 4.4, respectively.

Figure 3.3 Control Points over Satellite image.

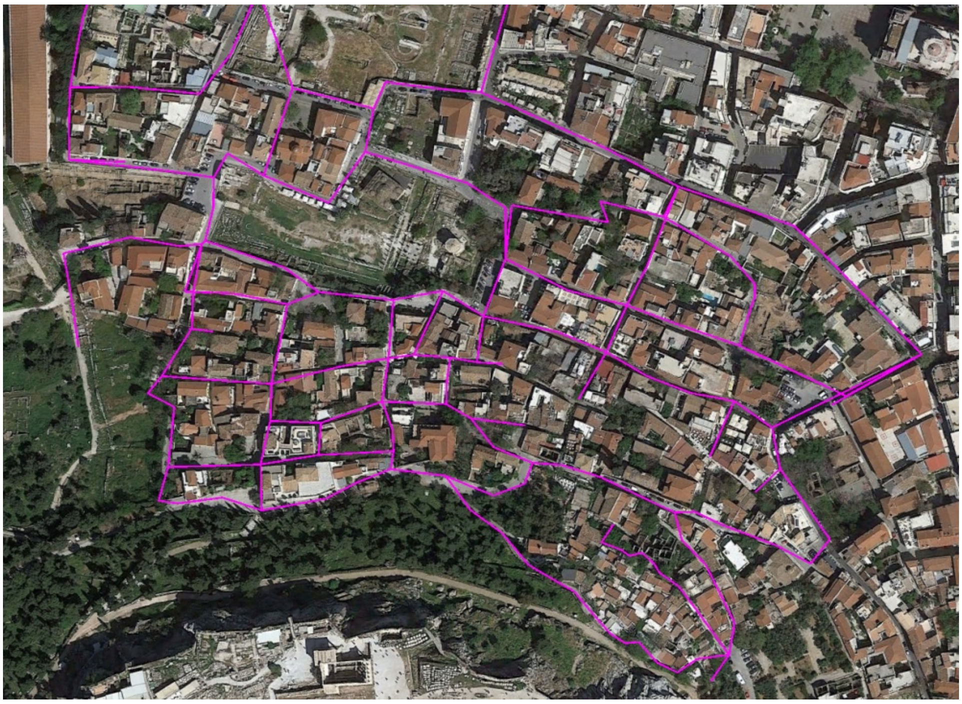
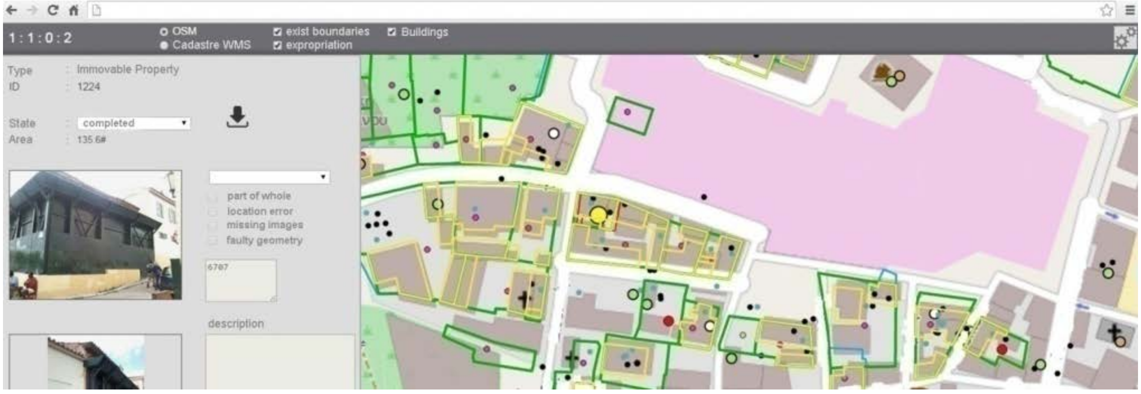


Figure 3.4 Reference Network over Satellite image.

Figure 3.5 depicts part of the created geometries as the Desktop Client overlays on an OSM map. The user interface (UI) allows to select applicable backgrounds (OSM, Cadastre WMS) while thematic layers can be turned on and off by checkboxes on the main bar. There are also multi type CPs that are shown as points with different colours and sizes in order to be able to distinguish property type on site. The sidebar on the left is used to view data of selected properties and set attributes (e.g. state, description, and other info). Finally images taken on-the-field can be uploaded and viewed through the current interface.



Type : Immovable Property
ID : 1224
State : completed
Area : 135.6#

Figure 3.5 Created geometries as Desktop Client overlays on OSM map.

3.1.1. Results

After the processing of the collected measurements from the reference network, a comparison of the results was made between the classical surveying methodology and CCLS. The main comparison refers to traverses (branches of reference network, consisting of several CPs) which were measured using both the typical approach and CCLS.

In the process of traverse solution, the angular and linear errors are estimated by comparing measurements to known geometric information. The angular error is defined as the divergence between measured angles and known geometries and the linear error as the divergence between computed and known point coordinates. The above errors are distributed to each CP. The traverse computations can be found in any standard surveying textbook [63].

	Error			Control Points			Angular error		Linear error	
1 Traverse	2 ang deg $x10^{-3}$	3 Linear (mm)	4 Traverse length (m)	5 Total	6 Surveying	7 **CCLS**	8 surv	**9 CCLS**	**10** surv	**11 CCLS**
S41-S47	7	18	207.47	5	1	**4**	1.4	**5.6**	4	**14**
S44-S46	0.7	9	74.59	2	2	**0**	0.7	**0**	9	**0**
S48-S60	17.8	75	118.97	4	4	**0**	17.8	**0**	75	**0**
S58-116	1.1	99	725.54	15	3	**12**	0.2	**0.9**	20	**79**
S58-116	17.8	102	311.14	10	6	**4**	10.7	**7.1**	61	**41**
S58-116	1.1	85	99.59	16	0	**16**	0	**1.1**	0	**85**
S73-S86	14.3	61	99.59	3	3	**0**	14.3	**0**	61	**0**
S78-S68	19.6	100	170.93	5	5	**0**	19.6	**0**	100	**0**
S80-S93	24.6	9	212.52	7	7	**0**	24.6	**0**	9	**0**
S101-S106	17.9	69	134.51	4	4	**0**	17.9	**0**	69	**0**
S112-ST65	24.9	55	316.03	18	18	**0**	24.9	**0**	55	**0**
SG10-SG67	15.4	79	257.80	4	0	**4**	0	**15.4**	0	**79**
SG11-SG24	16.1	17	308.22	8	0	**8**	0	**16.1**	0	**17**
SG13-SG56	5.8	21	175.72	5	0	**5**	0	**5.8**	0	**21**
ST65-S131	23.3	29	141.13	11	11	**0**	23.3	**0.0**	29	**0**
SG52-S150	0.1	40	1085.5	17	5	**12**	0.0	**0.1**	12	**28**
S31-S245	4.2	58	248.19	7	7	**0**	4.2	**0.0**	58	**0**
S246-S147	3.1	66	460.28	4	4	**0**	3.1	**0.0**	66	**0**
			Total	145	80	**65**	162.7	**52.1**	628	**364**
			Average				2.0	**0.80**	7.9	**5.6**
			Error reduction					**61%**		**29%**

Table 3.1 Error estimation (angular units-degrees x10-3, linear units-mm).

Table 3.1 provides an example regarding a number of baseline traverses and their error information using the CCLS and the classical surveying method. Columns 2 and 3 show the angular and linear solution error respectively of each traverse. Columns 5, 6, and 7 refer to measurement method of CPs, while columns 8 to 11 distribute the total error to the two different methods used. For example, record 5 analyses traverse S58-33-116, consisting of 10 CPs, 6 of which were measured using classical surveying and 4 using the proposed system.

The traverse angular error was computed equal to 0.0178 degrees (0.0107 deg for classical surveying and 0.0071 deg for CCLS) while the linear error was 0.102 m (0.061 m for classical surveying and 0.041m for CCLS). After normalization by dividing the sum of errors by the number of CPs in each case, both the average angular and linear errors per CP for each method are shown. These results indicate that by following the CCLS approach, the angular error has been reduced by 61% while the linear error has been reduced by 29%.

Another interesting result is the productivity boost. For the same work time on the field, there were 80 CPs needed to be set by the teams following the classical surveying approach, while only 65 CPs required by those who followed CCLS. Given the fact that the field groups that followed the classical surveying approach consisted of three members, while on the other hand only two were needed for the proposed method, it can be deduced that there is a cost/productivity benefit of the proposed method.

The distribution of the linear and angular measurement errors is shown in Figure 3.6 and Figure 3.7. It is seen that across the scale of error classifications (X axis), more measurements acquired by the CCLS method have lower error values compared to the number of measurements taken by the traditional surveying methodology. Considering that the participating surveying teams in this project had no previous experience in applying the proposed method, the productivity and accuracy are expected to improve even further. Completion of the project will provide more data to analyse further the results in order to get more feedback.

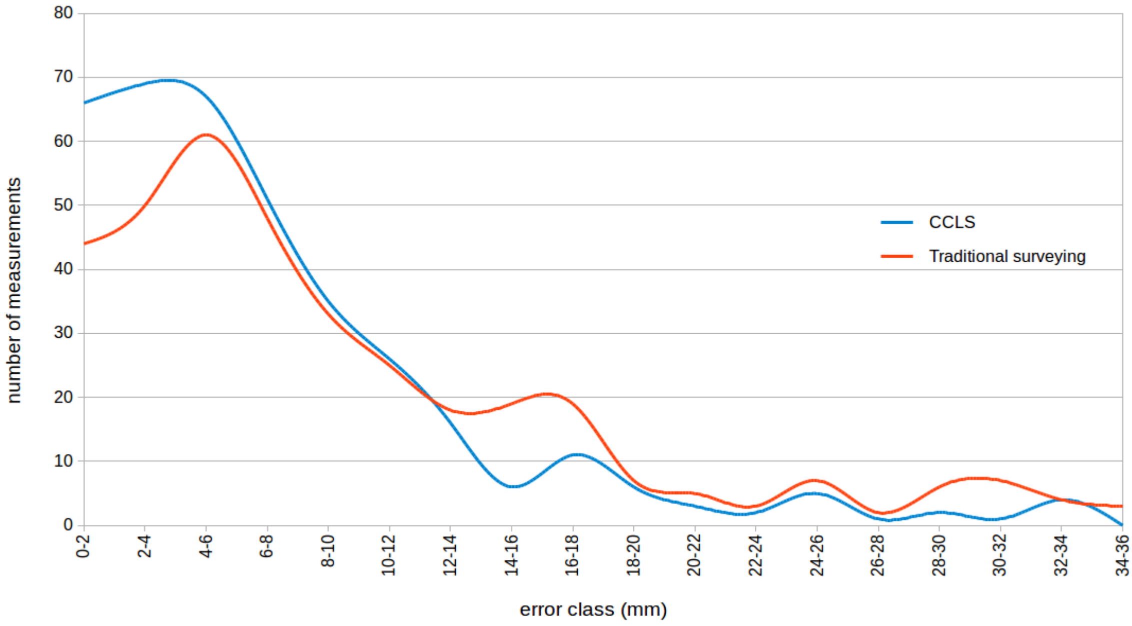


Figure 3.6 Distribution of the distance measurement error.

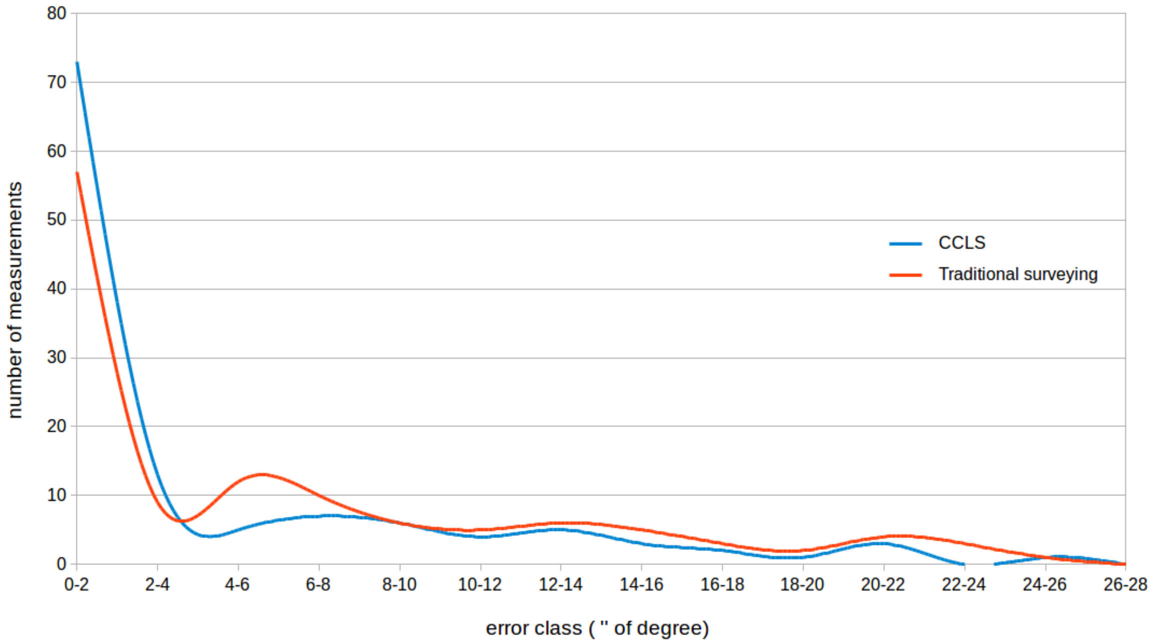


Figure 3.7 Distribution of the angle measurement error.

3.2. OGC O&M Model implementation

Analysis regarding the efficiency and potential benefits emerging from adopting the O&M standard modeling approach requires the implementation of a web interoperable service. Furthermore, a measurement repository along with a web service that will grand access to stored measurements can provide the basis for future research on data driven information analysis concepts, in the domain of land surveying, like unsupervised network analysis or 'equipment - operator - environment' evaluation algorithms. The Sensor Observation Service (SOS) standard that has been defined by OGC, provides the specifications for required operations, and has been implemented by various programming languages and application frameworks.

In the context of this paper, the 52°N SOS software has been adopted as the implementation framework since it is widely used, open source and consistently updated. The server environment is set on Linux Ubuntu 14.04 OS distribution with JRE7 and tomcat installed. The data are stored in a relational database management system (RDBMS) Postgresql 9.1 with PostGis 2.1 extension installed.

The 52°N SOS management module is built as a web application that provides administrative management functions though a simple yet effective to use interface. It supports Core, Enhanced, Transactional, and Result Handling extensions. The described case study has implemented the three operations of the Core profile (GetCapabilities, GetObservation, DescribeSensor) so that users can query the system for available sensors and observations. Additionally, the operations 'InsertSensor' and 'InsertObservation' of the Transactional extension have been used to feed the database with available information.

The test dataset is consisted of 41515 TPS observations which have been collected on field (10379 features of interest) in a high density urban area. The reference network is consisted of 210 Ground Control Points (GCP) over which 228 observation processes have been initialized, as some GCP have been used more than once. Out of the 41515 (10379 features of interest) observations, 3678(1226 features of interest) refer to GCP and define the sub-dataset that is processed to define the geometry of the reference network. Figure 3.8 shows part of the GCP distribution over satellite image and Figure 3.9 depicts the corresponding reference network.

Figure 3.8 Ground Control Point (GCP) distribution.

Figure 3.9 Reference Network for available GCPs.

This case study aims on exploring the use and requirements of Sensor Observation Service implementation. Under this consideration, a direct feed of the Postgresql databases is not the approach to be followed. Instead, appropriate XML and JSON (POST) requests have been developed so that all available data can be entered by utilizing SOS Transactional 'InsertSensor' and 'InserObservation' operations. The above mentioned XML and JSON requests have been developed considering both the requirements of described Land Surveying O&M model (Section 2) and specific characteristics of selected implementation system.

3.2.1. Insert Sensor

The proposed model considers TPS equipment as a sensor device that instantiates a corresponding process every time a measurement procedure is initialized. Insert Sensor operation is the SOS provided web based interface for publishing sensor systems (processes in the context of O&M standard) to the developed repository. 52 North SOS supports SOS2.0 version while the published sensors are described according to SensorML2.0 (sml namespace) specifications. The XML document that structures the corresponding information is consisted, among other data, of three important building blocks that refer to the process – sensor entity. The first encapsulates information that describes and identifies the process itself. Figure 3.10 shows the xml part that provides unique id information, description fields and setup parameters. The second building block (Figure 3.11) is used to define the output of the process (type of measurements, units etc) and the third one (Figure 3.12) provides information about the position of the sensor.

```xml
<sml:identification>
  <sml:IdentifierList>
    <sml:identifier name="uniqueID">
      <sml:Term definition="urn:ogc:def:identifier:OGC:1.0:uniqueID">
        <sml:value> http://www.engicloud.net/sos/ls/procedure/tps0000_3_2_2_S30</sml:value>
      </sml:Term>
    </sml:identifier>
    <sml:identifier name="longName">
       <sml:Term definition="urn:ogc:def:identifier:OGC:1.0:longName">
        <sml:value>Total Station/Positioning System Kolida KTS-442RC</sml:value>
      </sml:Term>
    </sml:identifier>
    <sml:identifier name="shortName">
      <sml:Term definition="urn:ogc:def:identifier:OGC:1.0:shortName">
        <sml:value>TPS Kolida KTS-442RC</sml:value>
      </sml:Term>
    </sml:identifier>
    <sml:identifier>
      <sml:Term
       definition="http://www.engicloud.net/sos/ls/observableProperty/stationHeight">
        <sml:value>1.62</sml:value>
      </sml:Term>
    </sml:identifier>
    <sml:identifier>
      <sml:Term definition="http://www.engicloud.net/sos/ls/observableProperty/stationId">
        <sml:value>S1</sml:value>
      </sml:Term>
    </sml:identifier>
  </sml:IdentifierList>
</sml:identification>
```

Figure 3.10 Insert Sensor XML Request, Identification property (SOS – SML2.0).

```xml
<sml:outputs>
    <sml:OutputList>
      <sml:output name="shv">
        <swe:DataArray>
           <swe:elementCount> <swe:Count/>
            </swe:elementCount>
          <swe:elementType name="Components">
          <swe:DataRecord xmlns:ns="http://www.opengis.net/swe/2.0">
            <ns:field name="targetId">
              <swe:Text definition="http://.../ObjectOfInterestIdentifier"/></ns:field>
              <ns:field name="slopeDistance">
   <swe:Quantity definition="http://sensorml.com/.../CollectorToObjectOfInterestDistance">
                   <ns:uom code="m"/>
                 </swe:Quantity>
               </ns:field>
               <ns:field name="horizontalDirection">
                 <swe:Quantity definition="http://sensorml.com/.../Azimuth">
                  <ns:uom code="degree"/></swe:Quantity></ns:field>
             </swe:DataRecord>
           </swe:elementType>
        </swe:DataArray>
      </sml:output>
    </sml:OutputList>
</sml:outputs>
```

Figure 3.11 Insert Sensor XML Request, Output property (SOS – SML2.0).

```
<sml:position>
   <swe:Vector referenceFrame="urn:ogc:def:crs:EPSG::4326">
     <swe:coordinate name="easting">
        <swe:Quantity axisID="x">
           <swe:uom code="degree"/>
           <swe:value>23.729396455418</swe:value>
        </swe:Quantity>
      </swe:coordinate>
      <swe:coordinate name="northing">
        <swe:Quantity axisID="y">
           <swe:uom code="degree"/>
           <swe:value>37.97121393542</swe:value>
         </swe:Quantity>
        </swe:coordinate>
        <swe:coordinate name="altitude">
          <swe:Quantity axisID="z">
             <swe:uom code="m"/>
             <swe:value>0</swe:value>
           </swe:Quantity>
         </swe:coordinate>
     </swe:Vector>
  </sml:position>
```

Figure 3.12 Insert Sensor XML Request, position property(SOS – SML2.0).

3.2.2. Insert Observation

"Insert Observation" is the required operation, along with 'Insert Sensor' that is used to feed the repository. Just like with 'Insert Sensor', it is part of the transactional SOS operations. The 52 North SOS implementation, supports this operation, provided that the appropriate POST requests are aligned to the previously discussed sensor definition. In order to further explore the supported data formats, this operation has been implemented in the present case study using JSON document structure.

```
{
          "request": "InsertObservation",
        "service": "SOS", "version": "2.0.0",
        "offering": "http:\/\/www.engicloud.net\/sos\/ls\/procedure\/tps0000_2_2_2_S2",
        "observation": {
                  "identifier": { "value": "", "codespace": ""},
                  "type":"http://www.opengis.net/def/.../2.0/OM_Measurement",
                  "procedure": "http://www.engicloud.net/sos/ls/.../tps0000_2_2_2_S2",
                  "observedProperty": "http://sensorml.com/ont/swe/property/Azimuth",
                  "featureOfInterest": {
                      "identifier": {"value": "http://www.engicloud.net/sos/ls/ob/S4/2","codespace": ""},
                      "name": [{"value": "S4","codespace": ""}],
                      "sampledFeature": ["http://www.engicloud.net/.../S4"],
                      "geometry": {
                          "type": "Point","coordinates": [0, 0],
                                      "crs": {"type": "name", "properties": {"name": "EPSG:4326"}}}
                  },
                  "phenomenonTime": "2014-08-19T17:45:15+00:00",
                  "resultTime": "2014-08-19T17:45:15+00:00",
                  "result": {          "uom": "degree", "value": 22.95675}
        }}
```

Figure 3.13 Insert Observation JSON Request data.

3.2.3. Insert Observation

The above discussed repository contains several thousand of observation that should be visualized over other spatial information datasets and base maps. Usually, observations come with known position a priori and provide measurement properties of point of interest. This paper discusses a totally different case that introduces several challenges and problems that should be managed. The two emerging concerns come from the fact that:

- ☐ Collected observations refer to geometry quantities that “will” be used to spatially define the network of sensors and features of interest. It is an a priori spatial agnostic but at the same time geometric self described network.
- ☐ Observable quantities do not describe a property of a known point but rather a set of geometric information referring to spatially undefined features of interest.

The above remarks impose the requirement of an additional a posteriori processing layer definition that should handle positioning ambiguities in both the sensor object and the feature of interest referred by observations. In a so called measurement based gis visualization (MBGIS) [33], coordinates are no longer handled as required input data but rather as output from spatial observation collections. This approach is perfectly aligned with the present work that discusses land surveying observation models and services.

Considering that typical projects could contain several thousands of observations, it is easy to conclude that the fusion of multiple projects over time, space and user dimension create big data repositories [64]. Within the generic work of the Collaborative Cloud Land Survey (CCLC) [6] research, unsupervised observation to coordinates transformation is achieved in real time by developed algorithm (section 2.4.2).

By selecting two nodes of the sensor network (S1, S2) it is possible to fix S1 position and S1-S2 azimuth. The later and the fact that the observation dataset provides sensor to sensor chained measurements over the network node collection, a sequential coordinate computation procedure initiates from S1-S2 (Sc=S1, Sb=S2) and propagates through all available sensor to sensor edges.

By selecting two nodes of the sensor network (S0, S1) it is possible to fix S1 position and S1-S0 azimuth. The later and the fact that the observation dataset provides sensor to sensor chained measurements over the network node collection, a sequential coordinate computation procedure initiates from S1-S2 (Sc=S1, Sb=S2) and propagates through all available sensor to sensor edges. Figure 3.14 shows the main calculation formulas [38] used for each iteration step whe i is the current node, b is the previous (derived from) node and j the nodes to calculate.

$$\underset{j\ in\ target\ nodes}{for}\begin{cases} \bar{a}_{ij} = \bar{a}_{ib} + \dfrac{1}{n_{b,i,j}^{h}} \displaystyle\sum_{k=1}^{n_{b,i,j}^{d}} h_k \\ \bar{d}_{ij} = \dfrac{1}{n_{ij}^{d} + n_{ji}^{d}} \left(\displaystyle\sum_{k=1}^{n_{ij}^{d}} d_{ijk} + \sum_{k=1}^{n_{ji}^{d}} d_{jik} \right) \\ x_j = x_i + \bar{d}_{ij} \times sin\bar{a}_{ij} \\ y_j = y_i + \bar{d}_{ij} \times cos\bar{a}_{ij} \end{cases}$$

i: index of current node

b: index of back node

j: iteration index of observed nodes from i

$\bar{a}_{ij}$: average azimuth angle

$\bar{a}_{ib}$: known azimuth angle

$\bar{d}_{ij}$: average horizontal distance

Figure 3.14 Spatial post processing flow chart.

Figure 3.15 and Figure 3.16 illustrate first and second step of iteration process. Red nodes indicate known coordinates, green indicates nodes to be computed and underline shows current iteration step node. Other concepts like observation declination, error statistics, network loops, etc that are out of the scope of this paper, are also managed.

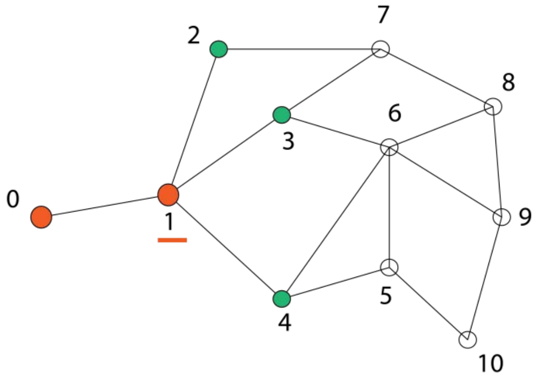


Figure 3.15, First step of iteration.
$i = 1, b = 0, j \in \{2,3,4\}$

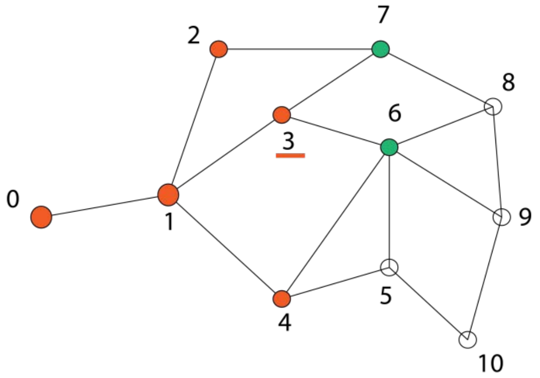


Figure 3.16, Second step of iteration.
$i = 3, b = 1, j \in \{7,6\}$

The above approach handles unsupervised network relative geometry. Given that the user provides approximate coordinates for some nodes or that the repository registry has positioning records of past processing sessions for some nodes, absolute positioning is derived for the entire sensor network. Finally, the same principle applies to the rest of the observed features (those not being part of the sensor network), so that all features of interest are spatially defined.

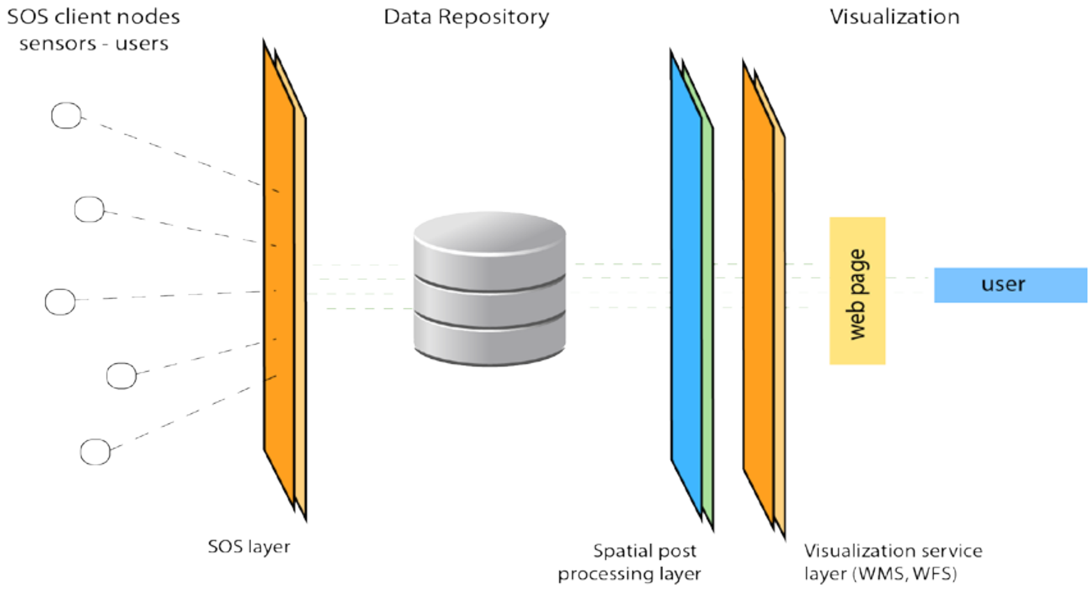


Figure 3.17 System architecture diagram.

The above, observation post processing layer, is injected between the observation repository and the visualization layer (Figure 3.17). The position ambiguity is reduced and selected indexes of available observations are illustrated and overlaid to other datasets on demand. In the context of the current research, various visualization modes have been applied and demonstrated. The following figures are part of dynamic

WMS service implementations that provide rendering of available measurements by applying the appropriate queries, functions and transformations. Figure 3.18 shows a heat map of relative measurement density, based on number of measurements available on each TPS base point. Even though no special data processing is used, it is possible to locate areas that lack of measurements.

Figure 3.18 Heat map of relative measurement density.

Figure 3.19 and Figure 3.20 provide a 2D illustration of the 3 dimensional 'base - target' physical vector, that is the feature of interest as described in model definition. All 41515 TPS observations which have been collected on field form the raw network of 10379 features of interest while coverage by different 'operator - equipment' is depicted with different color. Erroneous observations can be directly spotted as lines that point out if the interest area, whose distance from base is way out of the usual range.

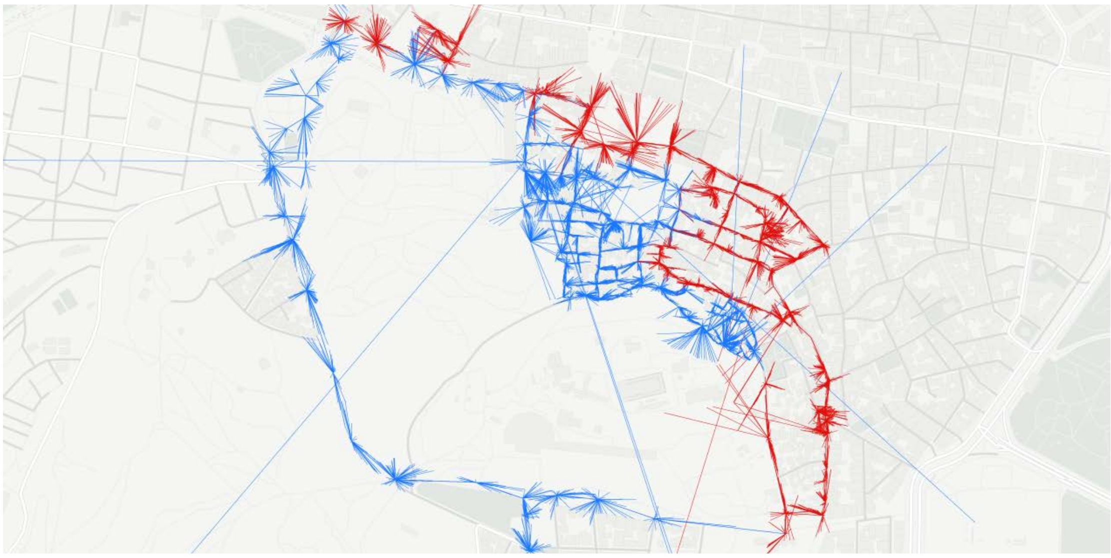


Figure 3.19 Network of observed features.

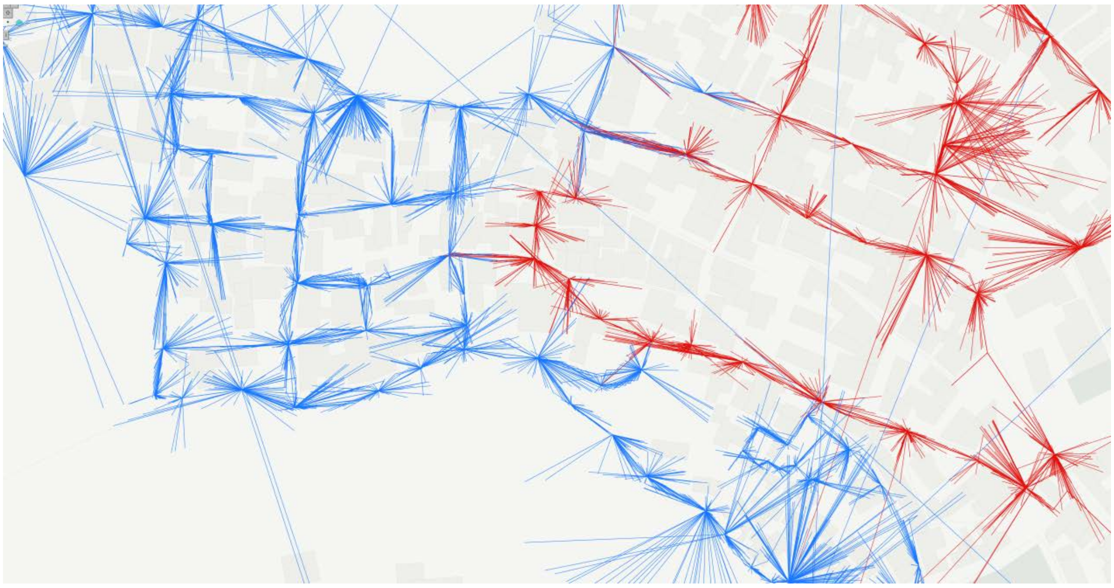


Figure 3.20 Network of observed features scaled.

For each base station, it is possible to create a buffer polygon that contains all points for which observations have been acquired (excluding detected erroneous observations by applying maximum distance threshold, based on equipment specifications). The total of these polygons, once overlaid over each other, provide the coverage of the area that has been the subject of the measurement procedure. Figure 3.21 clearly represents the coverage pattern, and areas that lack of observations (compared to Figure 3.18). Figure 3.22 highlights areas covered by both operators, thus it is expected to achieve higher accuracy level.

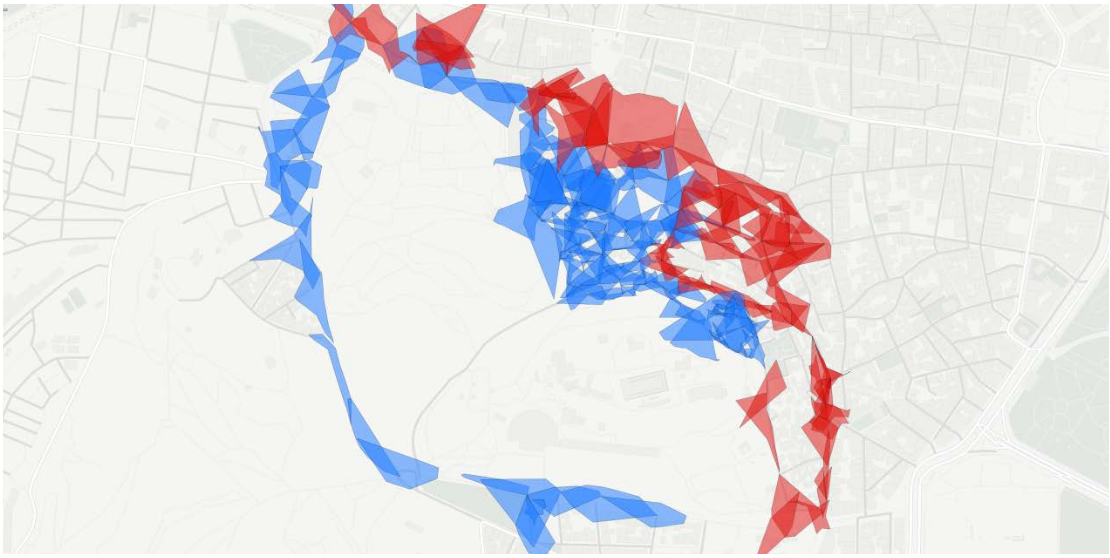


Figure 3.21 Coverage by process polygons visualization. Different color indicates different users.

Figure 3.22 Highlight of overlapping observation areas by different users.

3.2.4. Conclusions

There are a numerous reasons which indicate and set land surveying measurements as information of high value, addressing the scientific community to manage and reuse it on demand. First and foremost, land surveying measurement acquisition requires most of the resources used in projects of mapping objective, considering either working hours or technical equipment. Additionally, spatial information collected on filed, captures a state of space over the dimension of time that cannot be recollected at a later time. Furthermore, it is obvious that raw measurements contain data that can be combined in the future with other datasets to produce new knowledge. The same does not apply to coordinates and maps created as a product dataset at measure time.

All the above reasons have imposed the need for a data model following standards that ensure interoperability. The developed implementation, based on OGC Observation and Measurements standard, meets the modeling requirements of the measured information quantities and sets the framework to create repositories and services providing access to information management (save, query), processing and visualization functions. The developed prototype has followed the Sensor Observation Service (SOS) standard as implemented by 52N platform, and the provided XML and JSON Schemas instantiated the developed model. During this process a number of considerations came up that exposed the special nature of land surveying measurements in the discussed context.

One major difference of land surveying observations to other contexts, is the fact that the spatial representation of the feature of interest is not a point entity but a three dimensional observation vector. Even though measurements are used to a posteriori define the spatial dimension, exact feature position is not available at observation time. That being noted, the data rendering process is not straight forward, but requires an extra processing layer injection between database SOS service and WMS visualization services.

The case study demonstrated how high volume, real world observation data can be managed by implementing the developed model in a SOS platform. The processing layer managed the positioning information and the demonstrated WMS visualization service provided raw observation views highlighting aspects of quality and productivity (e.g. coverage, overlapping) in a novel graphical approach.

4. Educational implementation

4.1. Introduction

An effective knowledge-providing procedure requires more than memorization and recall, which are generally known as lower order cognitive skills (LOCS) [65]. Critical thinking (CT), creative thinking, problem solving (PS) and decision making constitute the family of higher order cognitive skills (HOCS) [66]. Education science is looking towards cultivating skills like wide-thought and creativity in contrast to traditional 'unique correct solution' approach [67]. Researchers have pointed out that assignments requiring CT skills often conclude to failure of students [68]. Teaching procedures that focus in developing critical thinking, through practicing and evaluation helps maximize success [69] [65] [70].

The current model of engineering education is based on lecture delivery, although attempts are made to reform it [71].Though students have certain amount of cognition, the courses are too much content driven with less knowledge of the application of this content in industry practices [72].

In order to cultivate high order cognitive skills, effort is put into inventing novice teaching processes and tools that aim to stimulate students' active participation in real world projects, forging this way their professional identity. In this context, one of the most widely used methods to classify the levels of cognitive domain and thus evaluate both teaching effectiveness and student's problem solving capacity, is Bloom's Taxonomy of Educational Objectives. Bloom's Taxonomy along with their revisions over the years [73] [74], provides a convenient way for instructors to describe the degree of student knowledge, the connection with course content (affect), and skills attained as a result of a course [75].

Currently, international Associations, agencies and scientific communities all over the world, authorize quality assurance of Engineering educational programs and institutes. Based on standards that define desired educational outcomes, the European Network for Accreditation of Engineering Education (ENAEE), the Accreditation Board for Engineering and Technology in US, and other authorized institutes provide accreditation of engineering educational programs. In this context, educational community researches on concepts that apply in structured teaching. Biology [76], Medicine [77], Biomedical Engineering [78], Environmental engineering [79], Music [80], Law science [81], Computer science [82] are a few areas of science where researchers create tools and methods aligned to Bloom's taxonomy and other educational concepts. In the same context, this work describes a structured teaching approach for Land Surveying (which is a major component in the Engineering Surveying Degree), with respect to Bloom's hierarchical levels of cognitive skills that make use of recently introduced Volunteer Geographic Information (VGI) system.

4.2. Bloom's Taxonomy

Bloom's taxonomy was introduced in 1956 by Dr Benjamin Bloom, an educational psychologist, as a tool to classify higher forms of thinking in education opposed to simple remembering. This approach, addresses to analysis and evaluation of primitive concepts, processes, procedures and principles in every educational context. Depending on the learning style that is applied in each learning process, Bloom identifies three domains of educational activities [83]; Cognitive domain refers to thinking or mental skills, that is described as the domain that deals with the recall or recognition of knowledge and the development of understandings and intellectual abilities and skills [84]. Psychomotor domain is about manual and physical skills, and affective domain is about feelings, motion and behavior.

4.2.1. Bloom's Taxonomy levels

Bloom's taxonomy is widely used to classify educational objectives in cognitive domain and has been revised over the years to include affective and psychomotor domains [75]. Educators use it as a way to categorize levels of developed knowledge. Bloom saw the original Taxonomy as more than a measurement tool. It was intended to be a common language about learning goals and provide the means for determining the most effective quantitative relation among educational objectives, activities and assessments in a course [85]. The revised taxonomy consists of the following six levels that differ in their complexity with ‘remember’ being less complex than ‘understand’, which is less complex than ‘apply’, and so on [85]:

1. Remember. This is the lowest level knowledge based skill, that refers to recalling or recognizing previously learned information (terms, procedures, etc).
2. Understand is about the process of determining the meaning of information that comes from either oral or written (including graphics) communication threads. Interpreting, exemplifying, summarizing, inferring, comparing and explaining constitute a set of dimensions that describe this level.
3. Apply is, in most cases, the minimum required skill level in order to characterize a learning process partially successful. The educator should be able to detect the ability to execute or implement the learning objective in appropriate context by students. This area develops a higher level of mentality than understanding, as concepts and theories are used in new situations and problem solving (PS) skill starts to be required.
4. Analyze. This level refers to breaking material into its constituent parts and identifying the relation between them. The understanding of the overall learning material structure is to be achieved through differentiating, organizing and attributing.
5. Evaluate is about making judgments based on criteria and standards. Checking the structure and consistency of learning material by the use of standards and critiquing the approach used or value of work based on clearly defined arguments, establish a higher than analysis intellectual level.

6. Create, initially named as Synthesis, is defined as the ability of putting elements together in order to form a novel, coherent whole or make an original product. Ideas and concepts from multiple domains and concepts are combined to form complex ideas. Key dimensions of this highest level are generating, planning and producing, which aim to cultivate creative behaviors (pattern synthesis, high complexity factor, innovation).

4.3. Current teaching approaches

The typical land surveying workflow (data collection, processing, map creation) is part of a learning process in Surveying Engineering educational communities too, where courses engage both mental and handling skills. Indoor instructions prepare the trainee and cover theoretic knowledge necessary to understand the basics of field training. Students use provided equipment (Total Station) and become familiar with required process in order to collect necessary data. Usually groups of few individuals are formed, which are assigned a specific land area, and have to go through the complete workflow including area exploration, equipment setting and initialization, measurement acquirement, computation execution and final map drawing.

Surveying Engineers initiate the project by exploring the area of interest. After having a good understanding of the environment to be processed, points where the equipment will be set is to be decided. These points usually form closed loops or network of triangles that are to be used as the reference network for all subsequent collected data. The equipment is set on CPs so the user can collect data for the datum definition and also to acquire measurements to features of interest (buildings, roads, property boundaries etc). During this process, a mass amount of horizontal angles, vertical angles and distances are collected in order to feed the processing phase. Indoor lectures provide the theoretical knowledge frame that is necessary to have in order to apply and process fundamental land surveying functions both indoor and on the field. Students are provided with information of generic content regarding their objective, algorithms and statistics that should apply, instructions for field application and deliverable specification rules. Appendix I refers to basic processing algorithms and procedures, which students should be familiar with before any project assignment.

Starting from recalling but also understand how these rules work and finally apply to acquired measurements in the scope of assigned projects, students can only reach level 3 of Blooms taxonomy. Collecting field data and applying define the most basic requirement and procedure. The only evaluation available is the comparison of known points’ coordinates to those computed. This fact does not allow the evaluation of the procedure, as it is not possible to trace how the algorithms propagate and reduce errors through their application.

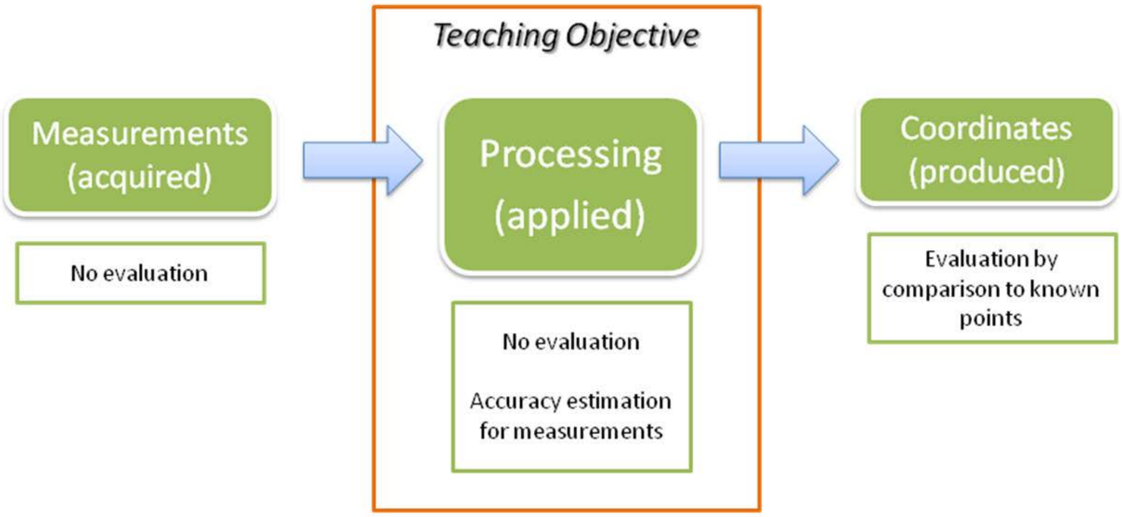


Figure 4.1 Typical land surveying teaching flow.

Figure 4.1 depicts the typical land surveying teaching flow and indicates the fact that there is available external evaluation of the final outcome and an accuracy estimation of the acquired or provided measurements. The above is not optimum or even helpful to HOCS targeted teaching approaches, as the object is the procedure itself and not the specific application. The main objective is applied but there is no form of evaluation regardless the specific datasets. This work ultimately aims to target on evaluating the applied process itself (which is in fact the teaching objective) rather than the result of the assignment.

The field skill development, on the other hand, is delivered through training by a project oriented approach. Small groups of students are formed, and the instructor assigns an area to analyze and map, providing this way the necessary working environment. The area of interest is in the vast majority a part of the university campus, so that there are data in order to evaluate the final deliverables. This approach is easier to handle as instructors are aware of the difficulties, as the same area is used over and over every year, and also have data in order to evaluate the deliverables. On the other hand, working in a specific controlled environment to which students are familiar of, does not provide variety of all the parameters that are met in realistic conditions, thus limiting the possibility to develop creativity by working on real world circumstances.

Table 4.2 summarizes a typical land surveying teaching approach in the context of Bloom's taxonomy. Usually students develop skills that meet the first three levels given available tools and educational means. The three higher order levels that in fact require better understanding and deeper objective knowledge are difficult to achieve due to difficulties and parameters that were previously mentioned.

Bloom level	Project management, Data processing		
	Educational means and tools	Expected behavior	Difficulties
Remember	Lectures, instructions books, slides		
Understand	Description of workflow, assisted field training, algorithm description, example review		
Apply	Project assignment in small groups, data processing assignments, algorithm application		
Analyze		Student is expected to analyze every aspect of the process and its parts. Understand how every sub process is implemented and its impact in the overall working flow.	**Field work** is taking place in known places, usually in university campus thus not providing the element of variation and surprise that will force trainees to develop global thinking and apply different methods. This way, alternative methodologies cannot be used and evaluated nor creativity developed as desired. The recognizable – familiar environment that at the same time is lacking of complexity (topography, constructions, etc) limits in every way the educational process. **Information processing** is applied in collected data. Evaluation is possible through estimations on measurements and output data comparison to other available. The objective itself (methodology - algorithms) cannot be evaluated as there is not information on real impact to data nor error propagation overview.
Evaluate		Student is expected to evaluate each step of the work flow, and be able to decide on the importance, efficiency and applicability in different cases.	
Create		The objective is to be able follow a novel approach, way of thinking, algorithm or methodology. Knowledge and skills from multiple domains are combined in order to form complex ideas.	

Table 4.1 Typical land surveying teaching in the context of Bloom's taxonomy.

4.4. CCLS implementation

Collaborative Cloud Land Surveying (CCLS) enhances the sharing of observation data with the community thus create that infrastructure that will provide the means to reuse acquired measurements and extend their life, use and contribution. In this context, there are available information datasets that have been collected by experienced surveying engineers and can be used to generate a new teaching concept that is based on real world measurements.

The existing process of surveying engineering undergraduate students practicing in known field areas (e.g. in campus) detects failure but does not give the information of the failure source. CCLS on the other hand can manage validated data and grand access to students. By providing access to measurement data in the office or out in the field, there can be multiple benefits regarding the educational process. Starting from data acquisition, the system can perform comparisons to existing measurements and provide information regarding the measurement procedure accuracy (i.e. assistance). In order to engage the students working efficiently in the field, the stage of data collection is where they can start detecting errors. Failure indication provides a huge advantage by enabling the '*trial and error*' learning approach in the field, in real time, in contradiction to the current approach that is defined by '*measure - process - error - revisit field*'. Case UML diagram (Figure 2.17) provides a typical, education oriented workflow.

Each collected observation can be evaluated in the field by any user of the system enabling this way the student to repeat the process or store the collected observations in the dataset. Every student structures an observation failure profile that specifies weak spots, providing the teacher the feedback to both improve teaching process using personalized corrections and instructions to each student. By repeating the same process in different conditions (e.g. higher accuracy, short execution time) the students can develop and evaluate quality skills over multiple land surveying demands.

The above defines a frame for working in the field, accelerate the learning procedure and elevate cognitive domain objectives understanding regarding the measurement procedure. The other fundamental objective is the entire data processing flow which can be improved by implementing the CCLS concept. The data processing algorithms use measurements as input and export point coordinates. The current evaluation procedure is often limited to comparing these coordinates to known values and having statistical accuracy estimators for data input and output. The CCLS approach, though, can be useful to detect the overall success of a student's work and provide information about the procedure itself (e.g. transformation of data or in what way errors propagate through algorithm execution). This is achieved through distinct process execution steps and transparent processing pipeline.

Figure 4.2 Typical data processing flow diagrams.

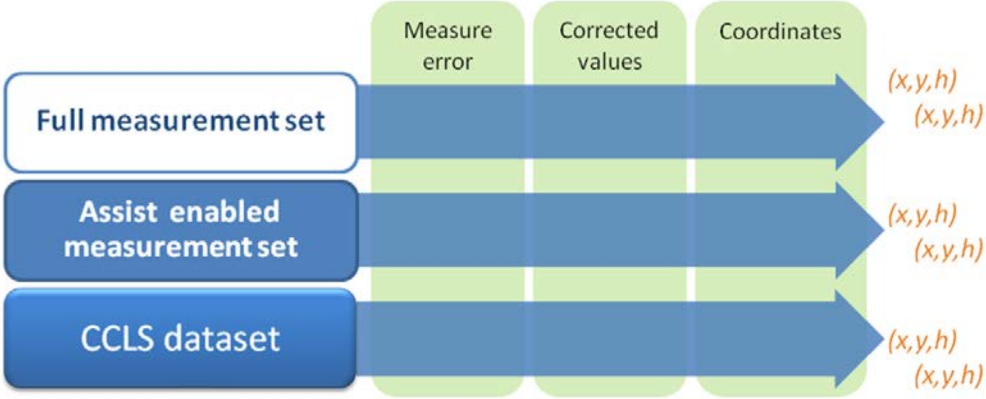


Figure 4.3 Proposed data processing flow diagrams.

The typical approach (Figure 4.2) applies a set of transformations giving information about the input and output. Statistical estimators of measurement accuracy are used to correct the observation set, although this approach is not always optimum. The proposed approach (Figure 4.3) on the other hand, has the advantage of multiple datasets, i.e.

- ☐ The full raw measurement dataset (of the student)
- ☐ The measurement dataset that results from filtering out the gross errors detected in the field by the CCLS indicators (assisted)

☐ CCLS valid observations available in a database, provided by professional land surveyors.

These three datasets provide the necessary means not only to apply algorithms but also track produced data in every stage and have deep understanding of the process. As the processing takes place, it is possible to trace the measurement error propagation and how the corrections transform the erroneous data to accurate data.

Table 4.2 summarizes the key implementation information and benefits that emerge by following the proposed approach, in the context of Bloom's taxonomy levels. Starting from "*Apply*" and going up to "*Create*", a set of CCLS functions and tools provide the means that will help the student build high order cognitive skills.

Bloom level	**CCLS impact**	**Project management, Data processing** Implementation - benefits	
Remember			
Understand			
Apply	**X**	System platform provides on field data access thus provides additional information (orthophoto, past measurements, etc) and functionality.	
Analyze	**X**	Provided validated information, allows tracing transformation and error propagation through applied algorithms. Student can develop the necessary conceptual connections between process and impact.	
Evaluate	**X**	**On field**, the possibility to have instant knowledge of measurement failure with the use of provided data can be used to inform the student and repeat. This fact brings evaluation of measurement procedure on field and maximizes the assignment efficiency through trial and error approach.	**Information processing** is transparent in every step. Having information about real measurement values, every applied transformations output of students' dataset is comparable and values or errors emerging or reducing are available. The algorithms themselves can be evaluated this way.
Create	**X**	Study area restriction removal, makes possible the use of real world cases. The full spectrum of methodologies can be used and combination of skills and knowledge is necessary in order to successfully complete project objectives	After safely understanding and evaluating every aspect of processing procedure, the student can apply different processing approaches by modifying algorithms. The output can also be reviewed and compared to CCLS DB information, thus examine the efficiency of new approach.

Table 4.2 CCLS implementation information – benefits by Bloom taxonomy level.

4.5. Discussion

The proposed approach is studied by using CCLS to measure and evaluate the method's results. A prototype case study has taken place in a non familiar study area of approximately 4000 sqm, where a 3 control point loop is set. During the measurement procedure, typical Total Station equipment was used that was CCLS enabled (Kolida KTS-442RC TS, angle accuracy 2'', distance accuracy ±(5mm+2ppm•D) non prism, ±(2mm+2ppm•D)with prism, where D is measured distance). In order to apply the proposed approach, the CCLS database provides data of the study area. The data in the CCLS database have been collected by professional surveyor engineers. The above dataset provided a precise model of the study area (ground truth).

The case study was conducted on two application scenarios. The first case was that of typical surveying engineer trainees, who acquired the necessary field measurements so that the study area would be processed as a project in a non familiar workspace. Both angles and distances of the defined triangle reference network were measured so that their exact geometry could be defined. The second scenario was developed so that errors would deliberately enter in the observation phase, in order to trace their propagation through algorithm application. The level of the prism was deliberately decalibrated, ensuring this way that both angles and distances would include gross error. After measurement acquisition for all cases, the data were processed and final GCP reference network coordinates were estimated. The three available datasets that this study processed are:

- ☐ Measurements by experienced professionals (Case A)
- ☐ Measurements of student's activity (Case B)
- ☐ Measurements that introduce equipment error by decalibrating the prism level (Case C)

Table 4.3 summarizes the information available in a typical training approach as implemented in surveying engineering degrees. Each scenario (Case B, Case C) has a set of measurements (angles and distances). The angles are given in row 1 for every GCP. As the geometry primitive is a triangle, the sum of these should be equal to 180 degrees or 200 gradients (or grads). Due to the measurement procedure, there is a closure error that is used to adjust the angular data. Rows 2, 3 and 4, list this information. The same basic principle has been followed for distance measurements. Starting from P1 and sequentially computing the coordinates of every point, a three dimensional set of coordinates (x, y, z) is calculated. For simplicity, the network is a closed loop, thus the estimated coordinates of P1should coincide with their starting values. Row 9 provides the linear closure errors required to estimate the final coordinates. In completion of the above procedure, a comparison of the computed coordinates to precise pre-known values defines the evaluation criterion of the project success.

Qualitatively speaking, the highlighted fields of rows 3, 9 and 11 indicate information available for evaluation. Row 3 provides angular closure error (which is used as estimator for the error of the angle measurements) and row 6 provides linear closure error (which is an estimator for the error of the distance measurements). Row 8 provides the resulting error by comparing final coordinates of Case B and Case C to ground truth (Case A) and measurement error estimation. All of the above refer to geometry accuracy but they do not provide information that would allow students to evaluate the process itself.

#	Description	Item	CASE A	CASE B	CASE C	Units
1	measured angles	P1		41.0864	41.1152	grads
		P2		115.2728	115.3428	
		P3		43.6579	43.6018	
2	sum			200.0171	200.0598	
3	closure error			-0.0171	-0.0598	
4	adjusted angles	P1		41.0807	41.0953	
		P2		115.2671	115.3229	
		P3		43.6522	43.58187	
5	measurement error					
6	adjusted angle error					
7	measured distances			37.604	37.617	meters
				35.714	35.708	
				57.674	57.697	
8	measurement error					
9	linear close error			-0.002	-0.051	
				-0.011	-0.013	
10	final coordinates	x1	1000.000	1000.000	1000.000	
		y1	1000.000	1000.000	1000.000	
		x2	1022.614	1022.615	1022.605	
		y2	1030.038	1030.037	1030.041	
		x3	1000.000	1000.000	1000.000	
		y3	1057.674	1057.67	1057.697	
11	coordinates error			-0.001	0.009	
				0.000	-0.003	
				0.001	0.009	
12	mapped points' error estimation by GCP					mm
13	mapped points' total error estimation					

Table 4.3 Typical processing procedure (grey rows indicate evaluation information).

Table 4.4 provides the processing procedure using the CCLS approach. Although the same processing flow has been applied, through the CCLS platform, raw measurements are always available to enrich the typical procedure for each trainee. The real error values are available and error propagation can be traced through model application. The highlighted cells indicate additional information made available for evaluating the process in different phases, when using the proposed methodology.

#	Description	Item	CASE A	CASE B	CASE C	Units
1	measured angles	P1	41.0798	41.0864	41.1152	grads
		P2	115.2661	115.2728	115.3428	
		P3	43.652	43.6579	43.6018	
2	sum		199.9979	200.0171	200.0598	
3	closure error		0.0021	-0.0171	-0.0598	
4	adjusted angles	P1	41.0805	41.0807	41.0953	
		P2	115.2668	115.2671	115.3229	
		P3	43.6527	43.6522	43.58187	
5	measurement error	P1		-0.0059	-0.0347	
		P2		-0.0060	-0.0760	
		P3		-0.0052	0.0509	
6	adjusted angle error	P1		-0.0002	-0.01477	
		P2		-0.0003	-0.0561	
		P3		0.0005	0.0708	
7	measured distances		37.603	37.604	37.617	meters
			35.712	35.714	35.708	
			57.674	57.674	57.697	
8	measurement error			-0.002	-0.014	
				-0.002	0.004	
				0.000	-0.023	
9	linear close error		-0.002	-0.002	-0.051	
			-0.008	-0.011	-0.013	
10	final coordinates	x1	1000.000	1000.000	1000.000	
		y1	1000.000	1000.000	1000.000	
		x2	1022.614	1022.615	1022.605	
		y2	1030.038	1030.037	1030.041	
		x3	1000.000	1000.000	1000.000	
		y3	1057.674	1057.67	1057.697	
11	coordinates error			-0.001	0.009	
				0.000	-0.003	
				0.001	0.009	
12	mapped points’ error estimation by GCP	P1	sx	± 0.8	± 3.0	mm
			sy	± 1.3	± 4.1	
		P2	sx	± 2.5	± 14.3	
			sy	± 3.8	± 19.1	
		P3	sx	± 4.1	± 14.0	
			sy	± 4.0	± 31.3	
13	mapped points’ total error estimation		sx	± 2.9	± 12.1	
			sy	± 3.4	± 22.1	

Table 4.4 Proposed approach procedure summary (grey rows indicate additional to the latter table information available for evaluation).

The above table sums additional information for every distinct processing thread, and can be used as a tool for the understanding of used concepts, algorithms and procedures. In the following, the processing of the individual data of angles, distances and position coordinates are discussed in the context of Bloom's taxonomy for achieving higher level of cognitive skills.

4.5.1. Angle data

Row 1 lists the values of measured angles. As a first indication of the achieved accuracy, the comparison of real values (Case A) to Case B (Typical student) and Case C (instrument problem) is used.

Case B user has a uniform systematic angular error of ~0.0060 grads, that is nine times the instrument maximum accuracy, so there is an indicator of an 'error generating habit', or a 'miss calibration' (instrument leveling, etc). Adding three angles gives a closure error of 0.0171 grads. After distributing the error to the three measurements, the final corrected angles deviate by a maximum of 0.0005 grads from the 'ground truth'. This fact indicates that the uniform systematic angular error is corrected by internal angle error distribution (Figure 4.4**)**

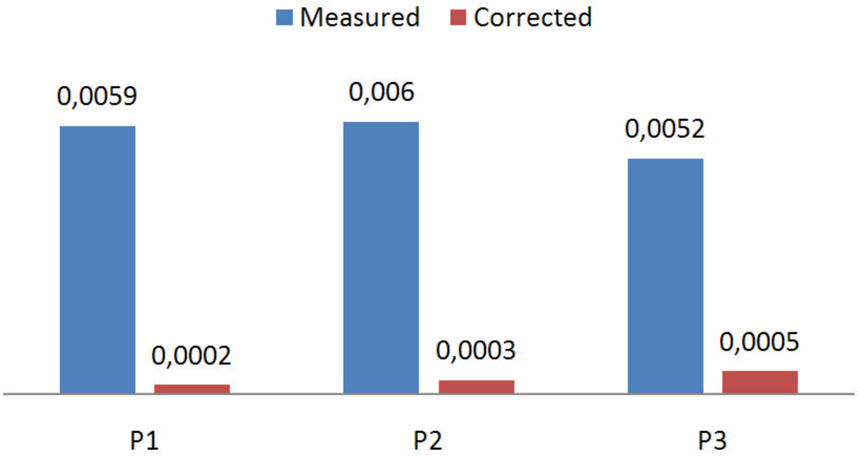


Figure 4.4 Case B angle error, before and after processing.

Case C user includes non uniform large angular errors (0.035, 0.077, and 0.050). Applying the same procedure, the corrected values still include errors (0.016, 0.056, and 0.070). In such a case (i.e. inclusion of gross error) the final angles fail to adjust to true values. In fact two angles have values to the 'truth' but the third angle has increased errors (Figure 4.5).

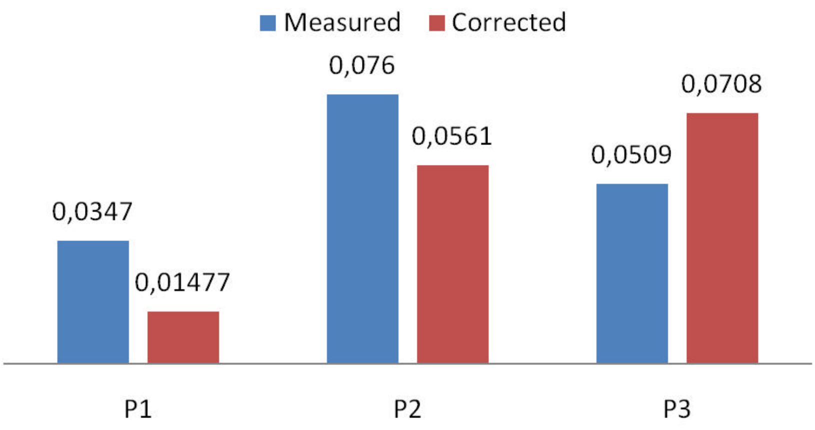


Figure 4.5 Case C angle error, before and after processing.

4.5.2. Distance data

The distance errors of Case B are about 0.002 m (which are within the instrument accuracy specifications as defined by the manufacturer) indicating that either the user has a better understanding of the distance measurement procedure, or any possible miss calibration does not affect the distance measurements as much as the angles. The latter can be justified if the total station leveling procedure fails. After linear corrections, the final distance is computed from the CP coordinates. The a posteriori error is 1 mm, as the algorithm has absorbed the remaining errors (Figure 4.6).

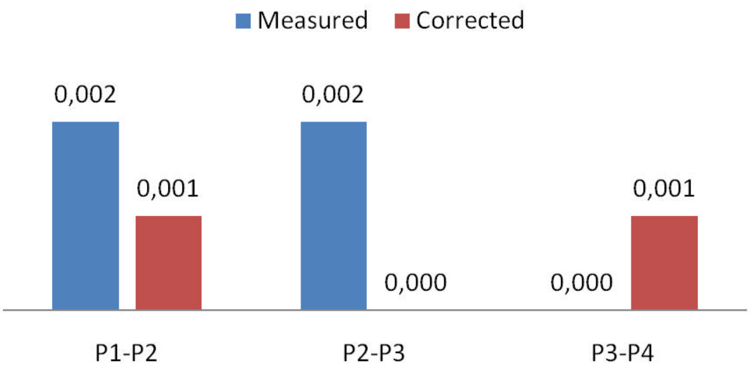


Figure 4.6 Case B distance error (mm), before and after processing.

In Case C, the errors are not uniform and reach 12 times the manufacturer’s specifications. After a linear correction is performed, the final error is limited below 5 times (9mm) the manufacturer’s specification value (~2mm). This informs the student that the distance error is handled more efficiently than the angle error (Figure 4.7).

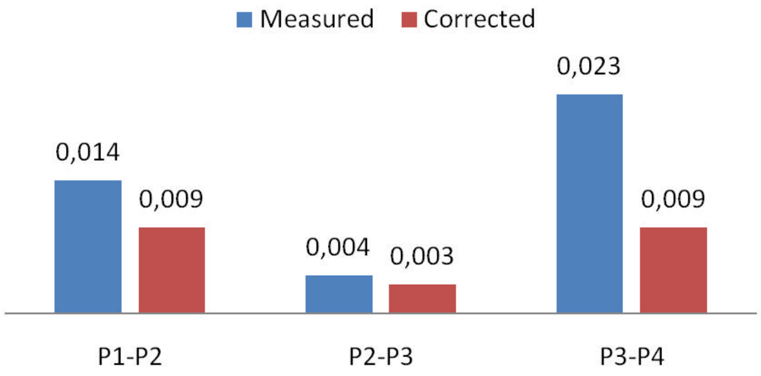


Figure 4.7 Case C distance error (m), before and after processing.

4.5.3. Position coordinates

Based on the reference network coordinates, the student will be asked to map, by acquiring measurements of angles and distances, the study area (buildings, infrastructure, etc). Having now corrected the angle and distance measurements as discussed previously, the calculations for position coordinates of the points of interest can be performed. Applying coordinate computation on an imaginary measurement set that has values ranging to the full spectrum (angles: 0 – 400 grad, distances: cm – several meters) or by using the existing CCLS dataset measurements, it is possible to estimate the final error propagation on mapped features. The latter is possible due to the existence of real error knowledge both on coordinates and measured values. With this information, a number of statistical measures such as the standard deviation of the estimated coordinates (sx, sy) can be computed. Figure 4.8 depicts that for Case B, the ground CP coordinates differ by 1 mm but the measured points may deviate by about 3 mm. For Case C (Figure 4.9), it is seen that the error of GCP coordinates propagates to 31 mm.

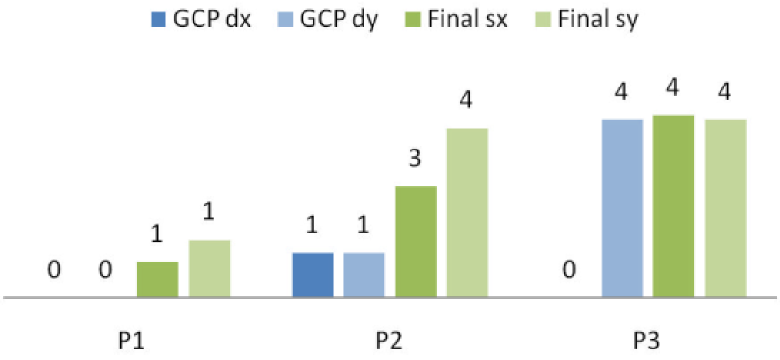


Figure 4.8 Case B coordinates error (mm - GCP and mapped features).

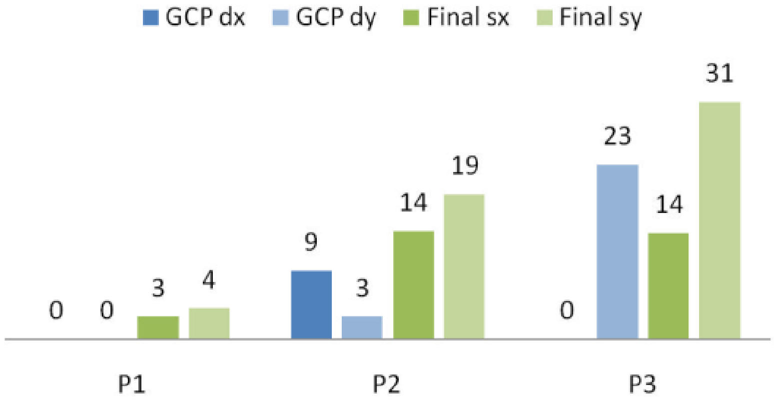


Figure 4.9 Case C coordinates error (mm - GCP and mapped features).

All the above workflow adds value to the educational procedure as the students are provided with tools enabling them to recognize the effect of each process from data collection to the creation of the final product. Personalized error source and correction information allows maximizing the student's fault detection skill (and minimize error propagation effect). Students can compare the results of various algorithms to real error detected, engaging this way their high level of understanding and connecting algorithm trace philosophy to real world measurement behavior.

5. Conclusions

This work has introduced CCLS, a methodology that challenges the classical topographic surveying process by using VGI along with modern collaborative network-based concepts. CCLS initiates novelties in the way data are collected and processed, unifying both these processes. It introduces field networking for TSs while a central data store is used to synchronize all the connected devices that now have access to the full dataset that is available while on the field. The concepts of CCLS can be implemented also in the collection and processing of other types of geospatial data. In the above context, this section summarizes the outcomes of the present work, discusses some benefits that came up through the process and important problems that were faced during the development phase and application of the proposed methodology. Each case study’s feedback provides the necessary information to evaluate the result compared to typical land surveying processes and trace basic problems that emerge.

5.1. Data model

The developed OM_model suggests an evolving path for land surveying information management, indicate a novel data access – usage scheme and set the framework to further develop new methodologies to apply on temporal, multi-user collected datasets. Information science evolves and every bit of collected land surveying data acquired but not saved in a consisted structural way, proves to be the loss of a potential benefit in aspects of precision, cost of recollection and new data usage methods.

As the 3.2 Section (OM model implementation) indicated, one major difference of land surveying observations to other contexts, is the fact that the spatial representation of the feature of interest is not a point entity but a three dimensional observation vector. Even though measurements are used to a posteriori define the spatial dimension, exact feature position is not available at observation time. That being noted, the data rendering process is not straight forward, but requires an extra processing layer injection between database SOS service and WMS visualization services. High volume, real world observation data can be managed by implementing the developed model in a SOS platform. The processing layer managed the positioning information and the demonstrated WMS visualization service provided raw observation views highlighting aspects of quality and productivity (e.g. coverage, overlapping) in a novel graphical approach.

5.2. Production - efficiency.

Considering that all the measured and computed information will be stored in an online repository, allowing reusability by authorized users, the dataset is expected to grow rapidly as CCLS will be adopted in the surveying engineering practice. This kind of data feed creates self-expanding and continuously self-improving networks, like reference networks, power stations, hydrographic networks etc.. Common VGI data coming from citizens without appropriate knowledge have not yet proven to meet the standards of topographic base projects [23]. By using the proposed approach, the area of “*Social Surveying Engineering”* (a term defining scientific behaviour of sharing raw surveying measurement data by specialized users) can be expanded thus enabling the development of VGI projects of special interest and high accuracy demands, allowing for the first time the re-use of large-scale spatial information of Engineering-level accuracy.

property	benefit	Description
Data-recycle	cost reduction	use existing data, speed completion time
Field process	-accuracy improvement - detect erroneous observations - spatio-tempo feature tracking - large scale multiple station approach - interactive network ontology data approach -direct availability	continuous comparison to existing data, real time model solution

Table 5.1 Potential benefits.

point	Surveying	CCLS
Work flow	2 step flow, data collect (field) data process (office)	data collect - process unification
Total Station topology	isolated working node	part of an interactive network
Data form	distance-angle station depended, data files	structured database modeling spatial information along with metadata
Time frame	static, time fixed object description	multi epoch data collection, temporal measurement repository
Project overview review	time dependent incoherent project overview after every data collect - data process cycle	real time project progress – overview, continuous remote review
Data flow	field data collection saved to local media	real time data route from and to CCLS database
Data access - reusability	limited access - availability, hard to integrate due to lack of modeling	real time open access through web service, easy to integrate - structured information

Table 5.2 Key differences.

Production cost should decrease by both productivity raise and equipment upgrade. The application developed for this project, has been set on android OS and requires only a TS with basic serial interface that accepts terminal commands. This transforms a low budget, high accuracy equipment, to a networked device accessing multisource - multi type data instrument with up-to-date processing power and abilities which can improve the surveying methodology. Table 5.1 provides the main advantages of the proposed approach and Table 5.2 summarizes the differences between classical surveying and the proposed method CCLS.

5.3. Case study (1)

Section 3.1, describes a large scale application of the proposed methodology compared to typical surveying process. The case study presented has applied the proposed method and the results indicated a substantial error reduction by 61% on angular measurements and a linear error reduction of 29%. Ensuring however, the data quality and credibility is of critical importance in such an approach, as VGI related research has pointed [86]. Additionally, a productivity raise of 22% during the corresponding measuring period has been achieved, regarding both the quality and quantity of collected data.

During the production of the final topographic plans, there were several cases where need to revisit the field was essential in order to confirm the dimensions or other missing information. None of these cases had used CCLS, which further indicates the effectiveness of the approach. Moreover, during the field data collection, there were cases where more than 2 CPs had been set within few cm spacing by different users over time, making difficult to determine the correct one. These cases are considered as error sources, so users had to measure all CPs, in order to be sure not to miss the correct one. Afterwards, during the post-processing procedure, each of those CPs had to be used separately in the solution in order to detect which one is the correct. Alternatively, groups which followed the proposed approach were automatically notified of the measurement and the respective solution error.

After the completion of the field work, users were asked to give feedback on user experience provided by the new data collection procedure. The total response set included many interesting remarks from the user’s point of view that can be classified into three generic benefit categories, namely:

- ☐ Rapid area awareness. The combination of selective dataset overlay (WMS, vector files, etc) along with real time feature drawing provides immediate space orientation and identification.
- ☐ Observation certainty. The fact that errors were indicated on site for existing features, along with the real time drawing, made the users feel more confident on observation execution. For example, the use of non prism distance observation method was used more than normally would, because reflections on environment obstacles (tree leafs, wire fence, etc) could be immediately detected. Also, real time network computations and drawing provides awareness on missing observations that ensures a complete collection session.

☐ Overall working time reduction. The users responded that the preparation time before field work was minored, as most of the information were available on the CCLS portable unit UI (CPs, other measurements, raster maps) and most of the preparation work was overridden (existing CP identification, project progress review, map printing, etc). This fact along with the previous two reported benefits, led to overall working time reduction for the same amount of observation acquisition, as users indicated.

5.4. Educational application

Section 4, introduced the implementation of CCLS into Land Surveying educational process. A discussion was made to link Bloom's taxonomy levels to current teaching approach, the difficulties that arise and how the CCLS content and tools can be used to advance into higher levels and thus develop desired cognitive skills. Finally, a multiple scenario case study was analyzed with the provided results (quantitive and qualitative) indicating the improved understanding of a land surveying concept using the proposed methodology.

The typical teaching methodology has been found that is difficult to achieve more than the three bottom levels (Remember, Understand, Apply). The main objective of Land Surveying education can be considered that is dealing with measurement error management through special procedures and algorithms. Due to restrictions such as:

☐ Predefined site study area
☐ Lack of error detection directly in the measurement procedure
☐ Lack of 'true' values of measured quantities

it is not possible to detect the error sources and trace the error propagation through data processing. As a result, the 'Analyze' level is difficult to achieve as the process itself is in fact a 'black box' with input and output (regarding the true impact of algorithms on error propagation). The 'Evaluate' level is by definition not possible to achieve as previously discussed. The only evaluation is that of the overall success after project completion (educator task), which is not to be confused with the desired skill to evaluate the teaching objective (student side). Finally, the 'Create' level skills fail to be developed, as these would require the last two ('Analyze', 'Evaluate') and real world study cases that provide non familiar conditions thus force students towards knowledge synthesis procedures.

Implementing CCLS in Land Surveying teaching, as discussed in this work, has been found to provide major benefits that support HOCS development and achieve to access the three top levels of Bloom's taxonomy (Analyze, Evaluate and Create).

☐ Tools that grant access to available measurements, provide real time error feedback on each observation made by students. Measurement procedure is evaluated on field and students can apply 'trial and error' to develop required skills. This fact implies direct benefits regarding 'Apply', 'Analyze' and 'Evaluate' taxonomy levels.

☐ The proposed data processing flow, as described and applied in the case study, provides tracking of data transformation and error propagation though every processing step. This way the impact of the applied algorithms on measurements and errors allow the evaluation of the process itself (in favor of 'Analyze' and 'Evaluate' taxonomy levels).

☐ Real world project areas are available to study, providing high complexity conditions and non familiar working environment. The full spectrum of methodologies can be used and combination of skills and knowledge is necessary in order to successfully complete project objectives. This way creativity is forced to be developed as students face the complexity of real world project requirements.

5.5. Future considerations

This work sets a new framework for land surveying, integrating volunteer geographic information that users provide through appropriate services. Current technological achievements allow the creation of a system that would provide such functionalities, while at the same time data networks allow information sharing in real time. Benefits of this new concept have been analysed and results show that accuracy and productivity increase significantly.

There are many open questions regarding issues such as dataset development - sharing - usage evolution in this specific scientific area. Such architectures that would enable geographic information integration are currently under research [87]. Globally, interest is focused on community-created, yet quality-evaluated content that offers multiple benefits. Surveying engineering evolves this way, as recent trends have proven to be enabling new approaches.

Adoption of CCLS will depend on several factors including the mentality of the Surveying Engineering community, dealing with which is out of the scope of this work. The results obtained so far are more than promising, which is a clear indication of the value of this approach that exploits and specializes the VGI concept into a discrete engineering domain. Future work will integrate the full dataset of this project as soon as measurements are available for the whole area of interest. Updated results shall complete this stage of evaluation and provide further comparisons regarding accuracy and productivity. Future projects that integrate currently collected information will allow over time reusability and enable spatiotemporal data processing, revealing the potential of geographic information sharing among surveying engineering community members.

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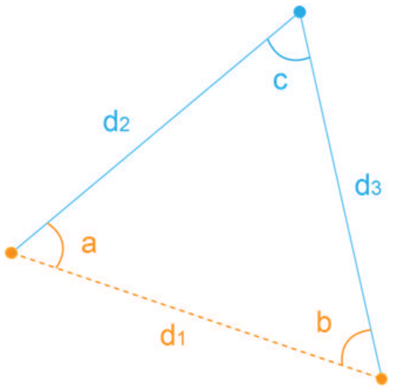
Appendix

The basic GCP network primitive, is a triangle that is established on field. In order to define its geometry, angles and distances are acquired. The basic concept is that more than necessary observations are collected so that the level of accuracy is as high as possible and erroneous measurements can be detected and rejected. For example, the minimum measurements that are required in order to determine the distance between 2 points is one. In data collection phase, the distance between 2 GCPs is measured more than 2 times, so that a better estimation is possible and an error would be detected when two measurements differ more than expected (few mms depending on equipment specifications). In that context, the more the measurements collected for the same feature, the better the accuracy level provided. The same principle is applied to angle measurement.

Considered the least complex GCP reference network (triangle), the minimum required (error free) measurements that can define its plane geometry are three, two angles and one distance. In fact Figure 0.1 illustrates the above principle and formulas applied. Angles a,b and distance d1 are measured, while angle c and distances d2, d3 are computed.



- $c = 180 - a - b$
- $d_2 = \frac{d_1}{cosc} \cdot cosb$
- $d_3 = \frac{d_1}{cosc} \cdot cosa$

Figure 0.1 Basic triangulation formulas.

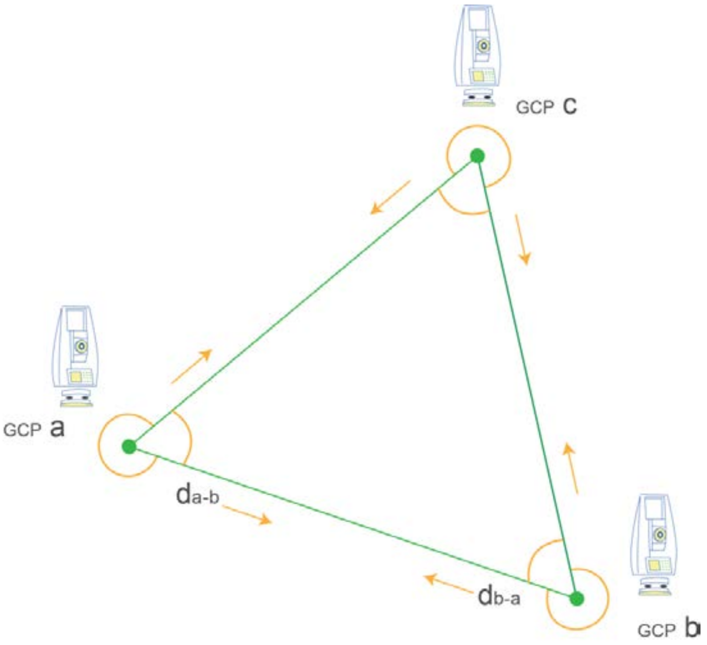


Figure 0.2 Possible measurements to be acquired in a triagle.

Due to the fact that no measurement can be error free, observations go far beyond three and computation is more complex. So for the same case, the minimum measurements are 6 angles and 6 distances (Figure 0.2). So angles are corrected by closure error and distances come as the mean value of multiple 'aller - retour' measurements.

☐ $\bar{a} = \frac{a_1+(180-a_2)}{2}, \ \bar{b} = \frac{b_1+(180-b_2)}{2}, \ \ \bar{c} = \frac{c_1+(180-c_2)}{2}$

☐ $e = 180 - (\bar{a} + \bar{b} + \bar{c})$

☐ $a = \bar{a} + \frac{e}{3}, \ b = \bar{b} + \frac{b}{3}, \ \ c = \bar{c} + \frac{c}{3}$

☐ $d_{AB} = \frac{d_{a\to b}+d_{b\to a}}{2}, d_{AC} = \frac{d_{a\to c}+d_{c\to a}}{2}, d_{BC} = \frac{d_{c\to b}+d_{b\to c}}{2}$

This is the first phase of corrections. The next step is to adjust Cartesian coordinates to the reference network. Given the coordinates of one GCP and a known direction, coordinates of the rest GCPs are computed. So given [(x,y)|A], [(x,y)|B] is computed. Then given [(x,y)|B] it is possible to compute [(x,y)|C], and finally [(x,y)|A'] (setting $A^{'}$ as GCP A computed by the procedure. Given that $A \equiv A^{'}$, any difference should be used to further correct the coordinates of the reference network. So in case of

$dx = x_A - x_{A'}, dy = y_A - y_{A'}$, coordinates [(x,y)|A,B] are adjusted by $\frac{dx}{2}, \frac{dy}{2}$. Finally, given the processed GCP coordinates, surveyor Engineer applies direct computation of Cartesian coordinates for the whole set of measured points.

The above procedure is the least complex that could be applied in a typical project and aims to minimize error propagation while at the same time achieve maximum possible accuracy.