GAOS: Spatial optimisation of crop and nature within agricultural fields

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Abstract

This paper proposes and demonstrates a spatial optimiser that allocates areas of inefficient machine manoeuvring to field margins thus improving the use of available space and supporting map-based Controlled Traffic Farming. A prototype web service (GAOS) allows farmers to optimise tracks within their fields and explore planning alternatives prior to downloading the plans to their RTK GPS-guided steering system. GAOS retrieves accurate data on field geometry from a geo-database. Via a web interface, the farmer sets options regarding operation properties, potential locations for field margins and headlands, etc. Next, an optimisation script that employs an open source geospatial library (osgeo.ogr) is called. The objective function considers costs involved with un-cropped areas, turning at headlands and subsidies received for field margins. Optimisation results are stored in a database and are available for (1) viewing via the web interface, (2) downloading to the GPS-guided steering system and (3) communication to third parties.

Keywords: Path planning, Web processing service, Controlled traffic farming, Field margins

1. Introduction

Field margins may provide environmental benefits (Borin et al. 2010, Haenke et al. 2009, Holland et al. 2008, Olson and Wäckers 2007, Douglas et al. 2009). Additionally, European landscapes are increasingly being perceived as leisure commodities (Buijs et al. 2006) and flowering field margins have been found to significantly contribute to the appreciation of agricultural landscapes by citizens (Stilma et al. 2009). Tools for planning the spatial configuration of semi natural landscape elements on the basis of spatially aggregated indicators (Groot et al. 2007, 2010) barely address the local spatial preferences of farmers who are to implement the plans at field level. In intensive arable regions such individual preferences are important to consider, though, as was illustrated by Mante and Gerowitt (2009) and de Snoo (1999). De Bruin et al. (2009) showed that there are potential operational benefits to farmers if areas of inefficient machine manoeuvring are allocated to optimally configured field margins, which may vary in width along the edges of the field. Farmers may thus be helped by tools that allow them to optimise local implementation of regional plans for establishing margin strips to their own situation and to judge the results of such optimisation.

Additional opportunities emerge if optimised spatial field plans can be used for Controlled Traffic Farming (CTF) and application control within the cropped area. For example, coverage planning in combination with auto-boom control of a sprayer has been demonstrated to lead to substantial savings in travelling distance and the amounts of inputs used (Batte and Ehsani 2006, Palmer et al. 2003), with benefits to both the farmer and the environment (including reduced soil compaction).

Coverage planning has been a topic of considerable interest over the past few years (Bochtis and Sørensen 2009, Choset 2001, Jin and Tang 2006, Oksanen and Visala 2009, Taïx et al. 2006), but the optimisation of agricultural operations in combination with field boundaries intended here requires a different approach. While coverage planning aims to optimise paths in such a way that the field is entirely covered by the crop, in the latter case non-cropped margins of yet unknown and variable width (within limits) are to be realised along designated edges of the field.

De Bruin et al. (2009) proposed an elementary approach for spatial optimisation of straight cropped swaths and field margins. Since then, the method has been further developed and it was tested in close interaction with a group of 20 farmers in the Hoeksche Waard in the Netherlands, where a network of field margins is being developed on the farmers' land. Furthermore, the implementation of the approach evolved to a prototype geo-web service named GAOS (Geo Arable land Optimisation Service) that can be operated by non-GIS experts from an ordinary web browser.

Hence, the purpose of this paper is twofold: (1) to present the methodology of GAOS and (2) to demonstrate its use by farmers to optimise regional plans for implementing grassed or flowering margins to their local needs, given a set of constraints on the preferred driving direction, width of operation within the cropped area and potential locations of margins and headlands. We conclude by providing suggestions for further development which emerged from the interaction with the farmers in the Hoeksche Waard.

2. Materials and methods

2.1 Overall workflow

If a farmer fully relies on measured field geometry for planning and performing field operations, the accuracy of measured field geometry can have considerable impact (de Bruin et al. 2008). Therefore, the first step in planning paths for machine guidance is acquisition of accurate field geometry. In our project this was mostly done by a contractor using a quad equipped with an RTK (Real Time Kinematic) GPS receiver. Next, a shape file of the field geometry in geographic ETRS89 coordinates was transformed to Cartesian coordinates (Dutch grid). Individual edges were automatically extracted by cutting the field boundary at sharp angles detected in triples of vertices, and the field polygon as well as its edges were stored in a geo-database. The farmer was then notified and asked to specify his optimisation wishes and constraints, such as operation properties, any potential preferred working direction, potential locations for field margins and headlands, etc. Via a web interface, these wishes were entered into the database and the GAOS optimisation script was called (see explanation below). The optimisation results were checked and if necessary the previous step was iterated until results were satisfactory. Finally, information for the RTK GPS-guided steering system was downloaded and transferred to the agricultural vehicle. This overall workflow is depicted in figure 1 and it was to a large extent facilitated by a farmer in the Hoeksche Waard who was familiarized with the GAOS web service: the local GI service point.

2.2 Internet GIS client

To manage the data required by the GAOS prototype, a user friendly internet GIS (Geographical Information System) application was developed. This internet GIS client allows farmers to visualise parcel geometries and modify them if necessary. Furthermore, it enables entry of optimisation parameters and provides access to optimisation results.

The internet GIS client relies on several web services; it was developed using the Luigi framework for the Adobe Flex platform which can be used to develop user friendly internet GIS clients (Vanmeulebrouk et al. 2008). In order to prevent a vendor lock in, it was decided to apply open standards. Within the geospatial domain, the standards of the Open Geospatial Consortium (OGC) are widely used. The OGC standards used here are the Web Map Service (WMS) standard and the Web Feature Service (WFS) standard. A WMS produces maps of spatially referenced data dynamically from geographic information. A map is in this case a portrayal of geographic information as a digital image file suitable for display on a computer screen (Open Geospatial Consortium 2004). For this particular application, WMS was used to visualise the fields on a topographic background.

A WFS provides a client with access to the actual features encoded in Geography Markup Language (GML). A transactional WFS or WFS-T allows a client to both retrieve and update geospatial data (Open Geospatial Consortium 2005). WFS-T was used to retrieve and update parcel geometries and optimisation parameters. ESRI ArcGIS® Server software (http://www.esri.com/software/arcgis/arcgisserver/index.html) was used as WMS and WFS-T.

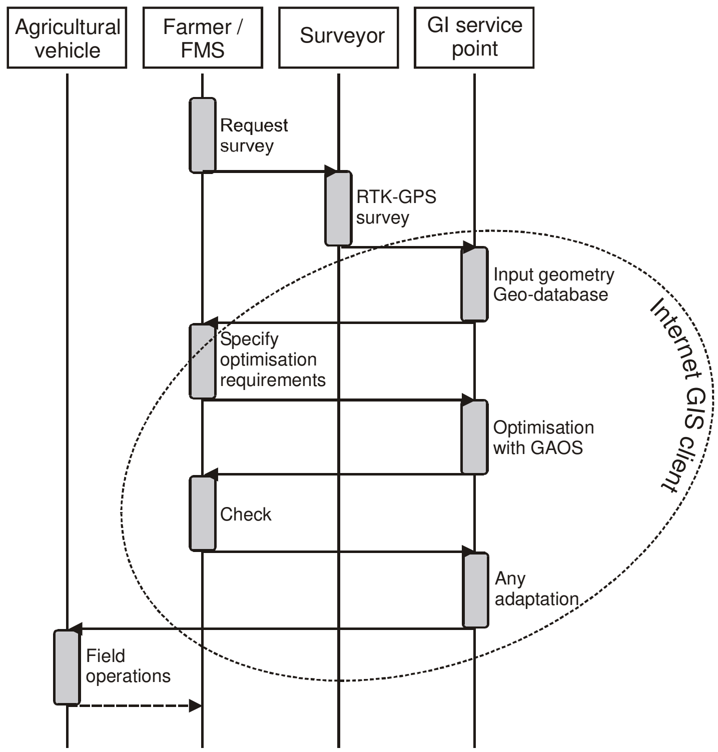


Fig 1: Sequence diagram of workflow including survey of field geometry, spatial optimisation with GAOS and execution of field operations.

2.3 Optimisation script

The core of the optimisation procedure is described in de Bruin et al. (2009). Basically, the most efficient orientation and starting point of a pattern of straight parallel swaths on the main body of fields are found by testing several orientations derived from the edges of the field and trying incremental positional shifts after which the swaths are intersected with field geometry. If the farmer has preferences for particular working directions, these overrule automatic retrieval of orientations. The objective function that is minimised considers costs involved with un-cropped areas, turning at headlands and subsidies received for field margins. The algorithm was enhanced by including calculation of swaths in the headlands, which are allowed to be curved. The headland computations involve no optimisation; the swaths in the headlands replace part of the original pattern in the field.

In the current prototype, the optimisation script is programmed in Python (http://www.python.org/), it employs the Geospatial library OGR (http://www.osgeo.org/gdal_ogr) and it runs as a scheduled task checking every 5 minutes whether calculations are being requested.

2.4 Testing data exchange on curves

Prior to application in the field, communication with GPS-guided steering systems was tested using an independent geodetic RTK GNSS (Global Navigation Satellite Systems) receiver (single base Leica GPS 1200 system) with the ATX1230 GG rover antenna mounted on a frame attached to the lift (3-point hitch) of a tractor. Two curves were prepared in Cartesian coordinates and transformed to ETRS89: a sine-shaped wave with a period length of 50m and a peak to peak amplitude of 12m and a portion of a circle with radius 96m. The curves were uploaded to the board computers of the steering systems. The test was performed with support from SBG (http://www2.sbg.nl/) and Geometius-Trimble (http://www.geometius.nl/) using SBGuidance Auto and Trimble RTK-GPS AutoPilot, both with single base RTK correction.

2.5 Field test GAOS

Each of the 20 farmers participating in the trial selected at least one field to be optimised. Optimisation wishes and constraints were collected at the GI service point and entered into GAOS. Any successful output of the optimiser was first checked at the service point and if relevant communicated to the farmer. In case none of the generated GAOS outputs was considered suitable for navigation in the field (e.g. misplaced swaths, omitted headlands or missing connections between swaths) a basis pattern was selected and manually updated using a GIS (ArcGIS®).

Navigation data (reference lines) corresponding to the final pattern were uploaded to SBGuidance Auto and Trimble RTK-GPS AutoPilot systems and used for navigation in the field.

3. Results and discussion

3.1 Geo-database

Thus far, the geometry of 165 fields scattered over the Hoeksche Waard was measured, see figure 2. The average size of the measured fields is 10.9 ha, the total area is 1806 ha and the total boundary length 245.8 km. Measurement from a quad allowed easy entry to the corners of the fields and good sight on the boundaries of the field during measurement.

3.2 Internet GIS client

Figure 3 shows part of the current GAOS interface, which can be assessed from any web browser having an Adobe Flash Player plug-in installed. The client allows farmers to select a field, split and merge its edges via graphical interaction, specify optimisation constraints and preferences and measure distances. When all data have been entered, an optimisation is requested. Since the optimisation requires several minutes to complete, the farmer can continue entering parameters for other optimisations or close the application and return at a later moment. Once the optimisation has finished, the results are made available via the interface and marked by a green check sign (see figure 3, lower left). In contrast, optimisations that fail for some reason are marked by a red cross. Successful optimisations can be viewed using the interface and results can be downloaded for viewing with Google Earth or for navigation in the field (see figure 3).

Fig. 2. Overview of the 165 measured fields (yellow polygons) and the location of the Hoeksche Waard (red polygon, upper left corner) within The Netherlands. Background aerial photograph © DKLN2008 / Eurosense, 2008.

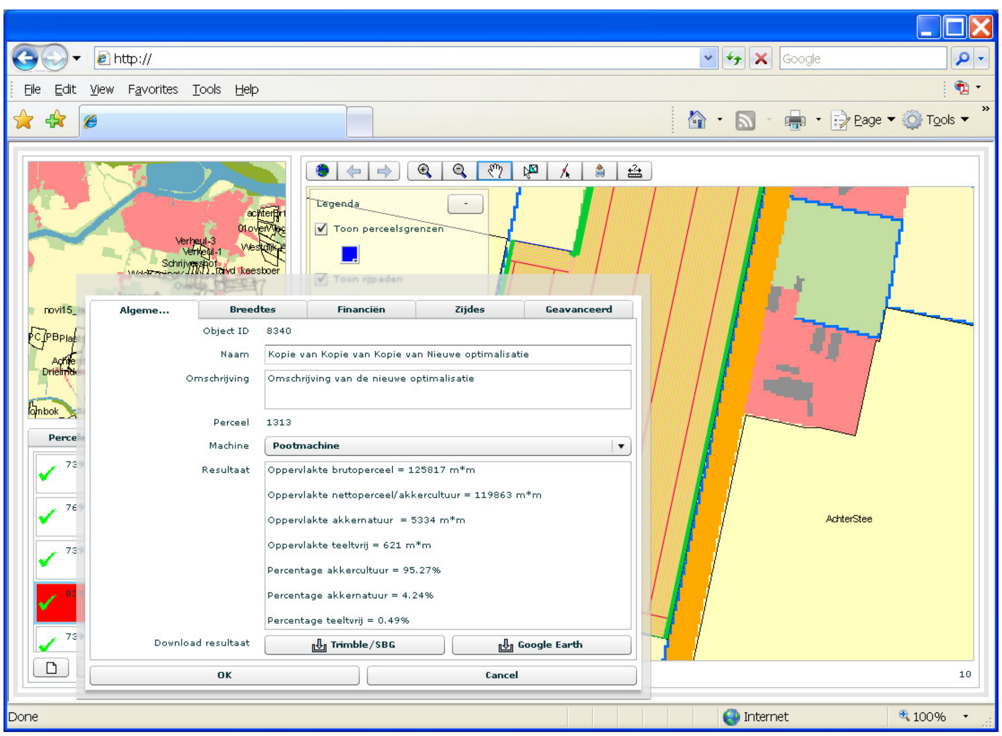


Fig. 3. GAOS interface with in the background in the top left an overview of the area, on the right a zoomed–in view on a field with 3m tracks (yellow), 39m tracks of the sprayer (red) and field margins (green). On the foreground alphanumerical data about the optimisation results and buttons for downloading the plan for viewing with Google Earth and for navigation in the field.

3.3 Test on curves

Figure 4 shows results of the test of data exchange with RTK GPS-guided steering systems. The curves in the sine-shaped wave were too sharp to allow proper navigation, as was anticipated by the suppliers of the equipment. Nevertheless, the data was properly accepted by the navigation systems. Navigation along the smoothly curved line was successful; root mean square errors (RMSE) for the two tests were 0.070m and 0.054m and mean errors 0.048m and -0.019m (in no specific order). Note that our measurement procedure may have introduced some bias which resulted in inflated figures for RMSE and mean error. Despite that, RMSE was well below 10cm and the test confirmed that externally generated paths could be imported for navigation purposes.

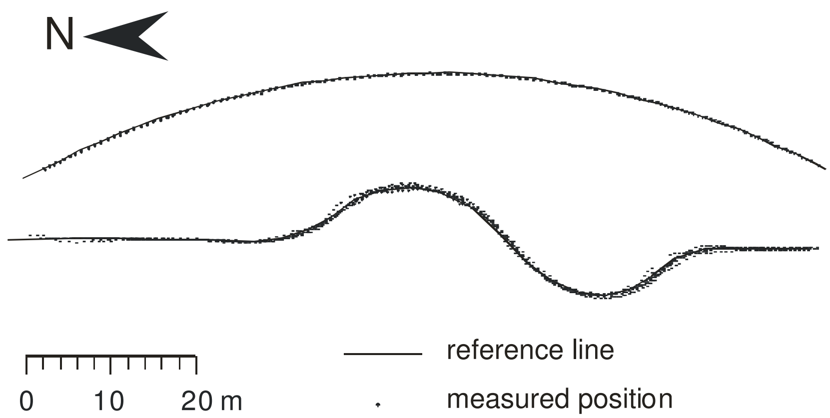


Fig. 4. Test communication with board computer; logged position while navigation system followed externally generated curve.

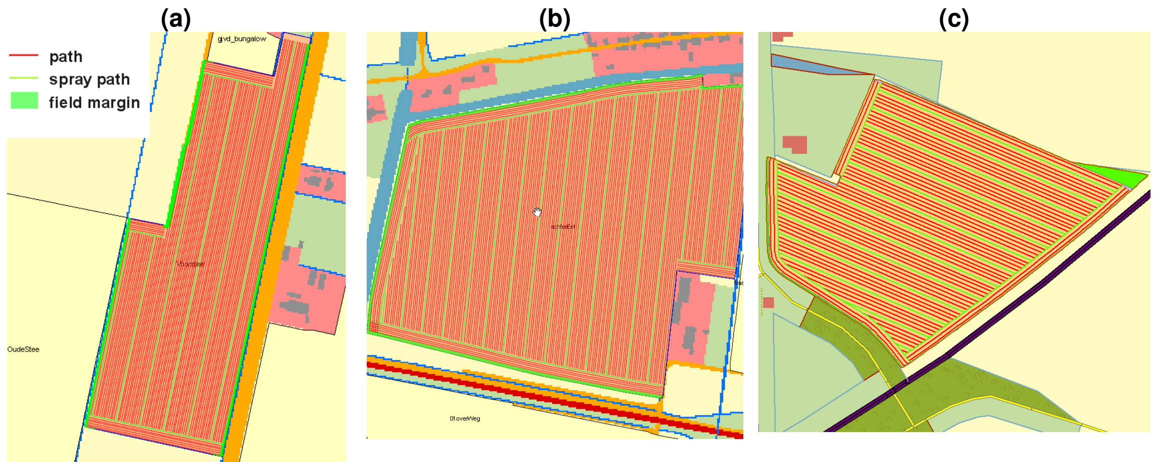
3.4 Field test

Figure 5 shows three examples of optimisation results. Result 5a was solely generated by a GAOS run. On the other hand, result 5b was manually updated using GIS before the data were uploaded to the GPS steering system. In the southwest corner, a short spray path was deleted and the field margin was widened over a length of 60m (not shown here). The current version of GAOS was unable to produce the results shown in figure 5c; these were obtained after manual editing in ArcGIS®.

Complex field shapes with curved edges, closely spaced vertices and especially concave parts caused problems to the optimisation script, which failed to produce output in approximately 30% of the cases. Moreover, corners such as shown at the right of figure 5c were not handled properly. Also, some of the optimization parameters were difficult to explain and caused confusion among farmers and, thus, undesired results. For example, a parameter named “nominal margin width” was used to set a minimal target value for a field margin that is allowed to vary in width, but for which an average width has been agreed by contract. The term “minimal width” might have been more intuitive, but that term was reserved to indicate the minimal width required for mowing the field margin, for example.

Altogether, the tests provided useful suggestions for aspects to be improved in a future version of GAOS. It became particularly apparent that manual updating of automatically generated plans should be supported, since practical constraints and preferences cannot be represented by just a few optimisation parameters.

At the time the full paper had to be submitted (April 30, 2010), the tests in which the generated plans were used for navigation in the field were still taking place and most experiences of farmers obtained during field operations were not yet known to the authors. These experiences will be presented at the conference, however.



	(a)		(b)		(c)	
Gross area	125,817 m^2		228,685 m^2		195,621 m^2	
Cultivated	119,863 m^2	(95.3%)	223,018 m^2	(97.5%)	190,601 m^2	(97.4%)
Field margins	5,334 m^2	(4.2%)	4,853 m^2	(2.1%)	3,829 m^2	(2.0%)
Uncultivated	621 m^2	(0.5%)	814 m^2	(0.36%)	1,191 m^2	(0.6%)

Fig. 5. Example results obtained from GAOS (a,b) and manual editing in a GIS (c).

4. Conclusion

A prototype of a web-based Geo Arable field Optimisation Service (GAOS) was developed and tested on fields of 20 farmers in the Hoeksche Waard, The Netherlands. On the basis of accurate data on field geometry, GAOS allocates areas of inefficient machine manoeuvring to field margins, thus producing optimally configured cultivated area and it can provide a basis for Controlled Traffic Farming (CTF). Access to GAOS is provided via an internet GIS client. The tests involved the full workflow, which included:

- Acquisition of field geometry with cm-level accuracy;
- Specification of optimisation wishes and constraints;
- Running the optimisation;
- Modifying optimisation results, either by adapting optimisation parameters or by editing optimisation results using GIS;
- Data upload to GPS-guided steering systems
- Using the generated plans for navigation in the field

The tests provided useful suggestions for aspects to be improved in a future version of GAOS. An important issue concerns stability of the optimisation script when dealing with fields with complex geometry, such as curves, closely spaced vertices and concave parts. Moreover, support for manual updating of automatically generated plans should be provided, since the variety of existent practical constraints and preferences cannot be represented by a narrow set of optimisation parameters.

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