Collaborative Virtual Environment

For Knowledge Management

– a new paradigm for distributed communications

Presented By

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Declaration

The experiments in this thesis constitute work carried out by the candidate unless otherwise stated. The thesis is less than 100,000 words in length, exclusive of tables, figures, bibliography and appendices, and complies with the stipulations set out for the degree of Doctor of Philosophy by the University of Melbourne.

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Acronyms and Definitions

3D	Three Dimensional
AIR	American Institutes for Research
AKM	Agricultural Knowledge Management
API	Application Programming Interfaces
APSRU	Agricultural Production Systems Research Unit
CoP	Community of Practice
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVE	Collaborative Virtual Environment
DBMS	Database Management System
DEM	Digital Elevation Model
DKM	Distributed Knowledge Management
DKMS	Distributed Knowledge Management System
DPI	Department of Primary Industry
EM38	Electromagnetic-Induction Measurement to estimate average rootzone salinity
FARMSCAPE	Farmers', Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation
GIS	Geographic Information System
GM	Genetically Modified
GML	Language Encoding Standard
GPS	Global Positioning System
GWS	Geospatial Web Services
HTTP	Hypertext Transfer Protocol
IM	Information Management

IMS	Information Management System
IT	Information Technology
ITIS	Integrated Taxonomic Information System
KM	Knowledge Management
KML	Keyhole Markup Language
KMS	Knowledge Management System
LBS	Location Based Services
MOS	Mobile Operating System
NPS	Non-point Source Pollution
OGC	Open Geospatial Consortium
OS	Operating Systems
SDK	Software Development Kit
SIEVE	Spatial Information Exploration and Visualisation Environment
WGS84	World Geodetic System 1984
WWW (W3C)	World Wide Web

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1. Introduction

1.1 Overview

Knowledge, defined as a personalized entity, can increase the capability of an individual or a group of people to perform effective actions (Alavi & Leidner, 2001; Nonaka, 1994). Knowledge has been widely recognized as the most important source of competitive advantage of an economy (Corno, Reinmoeller, & Nonaka, 1999). Realizing the importance of knowledge, researchers have paid great attention to theories and tools to manage and create it. In this context, the domain of *knowledge management (KM)* was proposed and subsequently has become the focus of organizational and economic research (Alavi & Leidner, 2001; Nonaka, 1994; Nonaka, Takeuchi, & Umemoto, 1996). Knowledge management itself is a complex entity, comprising four distinct but indivisible processes: knowledge creation, knowledge storage/retrieval, knowledge transfer, and knowledge application (Alavi & Leidner, 2001).

As information technology (IT) evolved in the second half of the 20th century, researchers came to believe that IT plays an important role in facilitating knowledge management. Therefore, an IT-based system applied to managing knowledge, which is known as a *knowledge management system* (KMS), was proposed in the 1980s (Akscyn, McCracken, & Yoder, 1988), to support and enhance the four processes of knowledge management. KMS deal with data, information, opinions, experiences, images and other elements of human communication which can collectively be the basis of knowledge generation and communication. Sometimes the term knowledge is loosely applied in this context because of the diversity of forms being managed, e.g., the consulting firm, Ernst and Young, established an online electronic knowledge repository, which was maintained by importing reports, programming documents, technical specifications and training materials of past projects. This provides relevant knowledge for internal staff to search and reuse (Hansen, Nohria, & Tierney, 1999). This thesis follows this precedent.

Knowledge is divided and dispersed among individuals or autonomous groups who are geographically distributed. The processes of creation, transfer and application of knowledge occur in different locations. Management of these processes has been described as distributed knowledge management (DKM) (Bonifacio, Bouquet, & Traverso, 2002). Accordingly, a KMS aiming to facilitate the processes of DKM is called a distributed knowledge management system (DKMS). Empirical studies have shown that DKM is a common knowledge management mode in organizations, especially in the context of globalization. Competitive advantage is obtained through learning and sharing knowledge within or across organizations (Nooteboom, 2000), which may distributed geographically. Orlikowski (1992) provides a detailed investigation of a large consulting firm sharing knowledge within the organization. In this global organization, decentralized information residing in clients, consultant's expertise, markets and industries are shared and updated through distributed work settings. Bresman (2010) studied knowledge transfer in international acquisitions, particularly knowledge transfer between the acquirer and the acquired. In his case study, the knowledge existed as explicit knowledge stored in data bases, or tacit knowledge (mainly experiences) owned by individuals; the purchasing organizations then evaluated the quality and amount of this knowledge, the differences of culture, and the integration difficulties during post-acquisition.

The success of DKM within an organization depends on various factors, such as cooperate culture (Smith & Farquhar, 2000), motivation of knowledge sharing, communications between knowledge sources and recipients, adsorptive capacity of involved members, and any causal ambiguity affecting the knowledge itself (Szulanski, 1996). The former two features suggest an organizational mechanism to motivate members to share knowledge, while the latter three features depend on whether or not members can smoothly communicate and understand each other. This thesis is interested in the latter three features studied by Szulanski (1996). The communication is affected by the geographical distance between involved members, while the other two elements are mainly impacted by the diversity of personal backgrounds which lead to cognitive distance.

- Geographic distance. The main bodies performing knowledge management are physically distributed. As such, knowledge management processes are affected in communication, which not just separates the members in space, but also in time (e.g., information communicated to distant colleague is delayed). People working in distributed units communicate through monthly conference, telephone calls or online forums (Goodman & Darr, 1998).

- Cognitive distance. As illustrated in Figure 1.1, two individuals have different absorptive capacities, which are based on their prior related knowledge and hence ability at interpreting phenomenon and integrating this as new knowledge, in other words, their ability to understand (Cohen & Levinthal, 1990). An individual’s absorptive capacity is determined by the environment including physical and social environment, and past experiences including education (Nooteboom, 2000). In Figure 1.1, while B is lacking prior knowledge related to the phenomenon, the cognitive distance l_b exceeds his absorptive capacity, which may cause errors in interpretation (Nooteboom, 2000). By contrast, A may perceive the phenomenon better than B, as the phenomenon is within his absorptive capacity. In this case, the extent to which these two individuals differently perceive, interpret, and understand the given phenomenon, according to Nooteboom (2000), is called the cognitive distance between them expressed as $|l_b - l_a|$. When interactions occur between these two individuals, their cognitive domain overlap may expand. As a result, the cognitive distance between them has been reduced to some extent, and consequently B becomes more likely to interpret the given phenomenon similarly to A (Cohen & Levinthal, 1990). However, interactions may not necessarily reduce the cognitive distance, unless A can codify his tacit knowledge (experience) to explicit knowledge, which can be understood by B (Alavi & Leidner, 2001). This is another important factor affecting DKM.

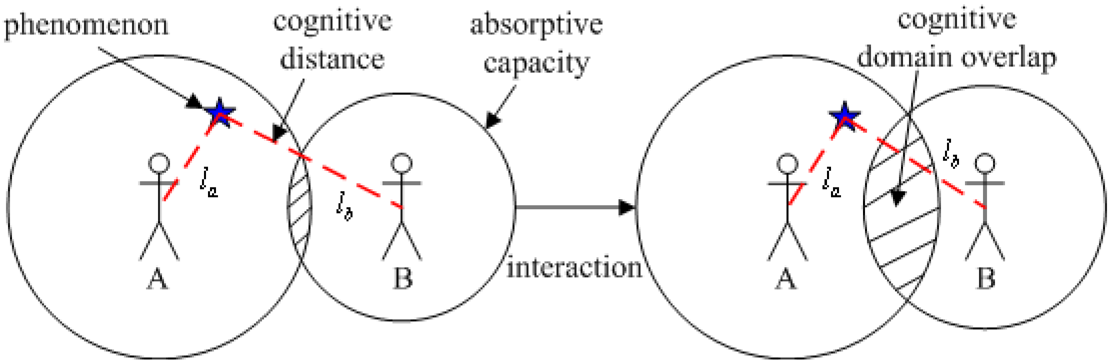


Figure 1.1 Cognitive distance between two individuals

To bridge these two kinds of distance, researchers and scholars have designed specific features into KMS. In the case of Ernst and Young (Hansen, et al., 1999), in the context of a globalized company, staff share knowledge regardless the geographical distance. Moreover, to manage the knowledge repository, the company also assigned specialists who carefully categorize the knowledge and distribute the knowledge to corresponding requesters, which also addresses the cognitive distance to some extent by choosing material appropriate to similar project contexts and staff backgrounds.

The case of Ernst and Young shows a successful example of DKMS. However, the processes of inventing knowledge, consequently transferring to end-users, and implementing into practices, which are components of ‘innovation’, are not a linear progression (Leeuwis & van den Ban, 2004). They involve other elements of human cognition, such as motivations (Goodman & Darr, 1998). Therefore, scientists and scholars have also been studying the learning patterns of these innovation processes and improving the performance of them. Lamb et al (2008) has investigated technology adoption processes by users, and identified a gap between technology developers and users, and this phenomenon is consistent with the *Diffusion of Innovations* theory provided by Rogers (2003). This gap has been recognized as primarily caused by the mistrust or lack of confidence of users towards the new technologies or knowledge (Rogers, 2003). This mistrust or lack of confidence is the result of cognitive distance. In this regard, users of knowledge tend to receive and subsequently adopt knowledge provided by the people who have similar backgrounds and contexts. This increases the likelihood that the knowledge will be beneficial in their cases. Therefore, a DKMS needs to have the capacity to expand the cognitive domain overlap between users (Figure 1.1). In this regard, a DKMS may need to provide a collaborative environment, where users are able to interactively communicate with others to share knowledge and search for knowledge adopters with similar contexts. To facilitate the collaborative environment, a DKMS should have a diversity of supported media, such as text, audio, video, and animation (Goodman & Darr, 1998). Amongst these types of media, three dimensional (3D) representation has been recognized to be useful to aid communication of concepts, learning of tasks and decision making (Hofschreuder, 2004; O'Connor, 2007). In this regard, use of a Collaborative Virtual Environment (CVE) can allow geographically distributed multiple users to interact with the same 3D environment and contents (Benford, Greenhalgh, Rodden, & Pycock, 2001). CVEs have been applied in a wide variety of contexts (Slater et al., 1998), including infrastructure planning (Hui, Jun, Jianhua, Bingli, & Hua, 2010), renewable energy installation (Bishop & Stock, 2010), surgery training (Morris, Sewell, Blevins, Barbagli, & Salisbury, 2004), military training (Mastaglio & Callahan, 1995) and landscape planning (Stock et al., 2008). As CVE has the capability of providing a collaborative 3D working environment for multiple geographical distributed users, it may be also useful as a base for DKMS.

Moreover, there are recently emerging ICT concepts and technologies such as Web 2.0 and Smartphone that have been affecting not only the ways people use the internet, but also the research field of knowledge management (Oreilly, 2007). Web 2.0 enables users of the internet to contribute values to the wider community, successful examples of which include Wikipedia, Facebook, and blogs; meanwhile Smartphone’s popularity facilitates this procedure. As Web 2.0 and Smartphone are widely accepted by the public, this may become another source of inspiration and power for DKMS. Therefore, this research also studies the possibility of employing these technologies into the proposed DKMS to obtain better performance and uptake.

1.2 Problem statement

CVEs have emerged as potential training platforms (Mastaglio & Callahan, 1995; Morris, et al., 2004) but are typically not configured for knowledge management. As knowledge management involves four distinct but indivisible processes, the objective of this research was analyse each of them and design a CVE which could fulfil the requirements.

The CVE-based DKMS should also reduce the two kinds of ‘distance’ discussed above. While geographical distance can be reduced by developing a virtual working environment for users to share resource and communicate, the cognitive distance should be reduced through analysing the absorptive capacities of users and designing relevant functionalities. The emerging popularity of Web 2.0 and Smartphone have the potential to popularise distributed knowledge management; however, integrating these concepts and technologies into a CVE has not yet been attempted. The challenges include not just interoperability between different technologies, but also their functional engagement.

1.3 Objectives

The overall objective is to design a CVE-based DKMS. To achieve this goal, there are four essential steps.

- Formulation of system requirements based on analysis of the processes of DKM.
- According to the system requirements, the issues of geographical distance and cognitive distance must be addressed and solutions proposed.
- Latest ICT concepts and technologies such as Web 2.0 and Smartphone are analysed, and a framework for integrating them into the CVE-based DKMS is discussed and formulated. Consequently a CVE-based DKMS is designed and implemented.
- To evaluate the value of the proposed DKMS, a case study is implemented. Innovation theory is used to evaluate the capacity of this DKMS in decreasing the two kinds of distance.

1.3.1 Delimitations of Scope

This research is carried out in the context of agriculture, which means the proposed DKMS is used for the agricultural knowledge management. This DKMS is named *iFarming* hereafter. iFarming is aiming to present a 3D rural environment, and manage agricultural knowledge for three types of interested parties: scientists, farmers, and agricultural consultants.

The scope of this research was to first define the requirements for iFarming from the perspective of the three farming parties, and then to build a system to fulfil the requirements. A complete controlled experiment to evaluate the value of iFarming was outside the scope of this research. However, a case study was carried out in a real farming environment near Armidale, NSW, Australia.

This research proposes a new paradigm for distributed communications and knowledge management. However, DKM faces different challenges in different contexts, such as human resource management, production management, and financial management. This paradigm is not applicable for all the contexts, but only for land and environment related knowledge management, where involved parties also face the issues caused by geographical and cognitive distances.

1.4 Outline of the Thesis

iFarming was developed to provide a 3D collaborative virtual working environment for agricultural knowledge users and owners to perform a variety of knowledge management processes. Chapter 2 firstly analyses the current situation of Australian agricultural knowledge management, including the contributions of the farmers themselves, their advisors and scientists who study farming systems and related disciplines. I address the issues caused by geographical distance and cognitive distance and the needs of the three parties. Secondly, I introduce the related work of other researchers, and address the strengths and limitations of a CVE in dealing with these issues. Following this, the potential of the latest ICT concept and technologies in assisting CVE to overcome the limitations is discussed. As Information Management Systems (IMS) and KMS share similar objectives and functionalities, but still differ in some features, it is important to analyse the relationship and differences between them, to refine the scope of this research and the objective of iFarming. At the end, I summarise the system requirements of iFarming, and a new pattern of Australian agricultural knowledge management is proposed.

Chapter 3 discusses the design and development of iFarming, with the goal of achieving the new knowledge management pattern proposed in Chapter 2. The design is taking into account the user’s needs and the integration of Web 2.0 and Smartphones and other spatial technologies supporting CVE, such as 3D visualization tools, spatial analysis, and database management system (DBMS). Therefore, this chapter firstly introduces the strengths and limitations of the popular technologies on the market suitable for iFarming, then discusses a mechanism for integrating these technologies, and finally proposes the framework of iFarming.

In Chapter 4, a preliminary case study to evaluate the value of iFarming is introduced. The system was applied in daily farming practices in a trial in the Newholme Area, NSW. A work flow demonstrating the new agricultural knowledge management pattern is addressed and adopted by the local farmers, scientists and agricultural consultants. More specifically, data prepared for this case study and generated by users are introduced, including 3D models, photos, GIS data, and property managing strategies. Moreover, it summarises feedback from the users, and assesses the strengths and limitations of iFarming in farming practices. During the case study, a questionnaire to evaluate the KMS was prepared and completed by users and the workshop audience. Based on the results of the questionnaire, a comprehensive evaluation of the performance and potential of iFarming is presented, in terms of its ability to solve the issues caused by geographical distance and cognitive distance.

Chapter 6 revisits the research objectives, addresses new findings, and presents the future of the research.

1.5 Summary

The evolution of concepts and technologies in the field of ICT has brought great potential of improving and even inventing a range of applications in various disciplines. These developments change the ways people uses IT and make us rethink old research topics. I adopted the latest concepts including CVE, Web 2.0 and Mobile computing, to handle a classis and popular research topic – knowledge management. The DKMS prototyped in this research not just facilitates the knowledge management processes, but also offers a new paradigm for Australian agricultural knowledge management.

My overall objective was a system, which I have called iFarming, which allows multiple geographical distributed users to perform knowledge transfer, storage, retrieval, creation and application.

2. Background

2.1 Overview

Design and implementation of a CVE-based DKMS, iFarming, is the primary objective for this research. This requires a comprehensive investigation of the issues faced by DKM, the formulation of a user requirement based on that, and the employment of relevant technologies to implement iFarming fulfilling such needs.

As this research is focused on the DKM, it is firstly essential to define it and summarize its features. As these features are context dependent, the next section argues the case for development in the context of agricultural knowledge management and identifies the key features of a DKMS in that environment.

Australian agricultural has been suffering exceptional climate events, invasive species and other issues in recent decades (DSEWPC, 2010; Hennessy et al., 2008), and responding to these with appropriate policies and action plans has been demanding on various farming parties. Effective knowledge management including transferring knowledge from scientists to local farmers, collecting onsite data, reporting emerging situations such as locust distribution, and recording farming activities such as fertilizer usage in the history database, may 1) facilitate farming parties to interpret and implement those polices and action plans, 2) enrich farmers’ knowledge of how to handle these issues, 3) help government master the emerging problems, 4) complement scientists’ research, and 5) ultimately contribute to a sustainable agricultural economy and environment. Analysis of the user needs, especially the common issues faced in a distributed environment are necessary to design a flexible, practical, and extendible DKMS.

Facing the challenges of climate change and globalization, sustainability in agriculture requires an integrated system based on coordination between various parties including farmers, scientists, agricultural consultants, and policy makers. However, farmers are the ultimate executives of farming. Their decisions or activities may impact others and even the whole region, through, for example, non-point source (NPS) pollution by excessive use of fertilizers (Carpenter et al., 1998). As such, an understanding about the whole region is important for not just the governance, but also the local farmers. Moreover, local knowledge, recognized as an important complementary to scientific research (Carolan, 2006), should be collected and shared with others. To collect data and information of the whole region and share knowledge with others, iFarming should allow users to upload local data and easily retrieve them. Web 2.0, initially developed to be able to provide such functionalities (Oreilly, 2007), has the potential to enrich the capacity of iFarming.

The smartphone, emerging early in the 21st century, with its powerful capability and ‘easy-to-use’ functionalities, has rapidly captured a substantial share of the mobile telephone market with up to 54.3 million users (Gartner, 2010). Smartphones in combination with Web 2.0 have shown strong market penetration. In the case of a popular location-based social networking system--Foursquare™, it provides a mobile interface for users to share their favourite places with others through uploading the information tagged with the smartphone’s location data. However, this research argues that the evolution and wide adoption of smartphones brings opportunities for introducing mobile computing into more innovative professional uses.

CVE has been widely accepted as a useful tool to build the platform for the ‘virtual team’ with a limited number of people involved (Bishop & Stock, 2010; Hui, et al., 2010; Morris, et al., 2004; Normand, 1999; Stock, et al., 2008). However, knowledge management, especially agricultural knowledge management, as discussed above, may involve a wide range of groups, from project teams or functional departments (Hildreth, 2000) to large volume users across the region. Yet, very few studies have investigated the possibility to use CVE as a knowledge management platform applied for large volume users. Moreover, while CVE may be able to solve some issues caused by geographical distance, the issues caused by cognitive distance require further developments of CVE. Through employing the concept of the Web 2.0, and technology of smartphone, CVE may be extended to fulfil those requirements.

2.2 Distributed Knowledge Management

Knowledge management's basic organization unit is the community of practice (CoP) (Brown & Gray, 1995; Smith & Farquhar, 2000), within which the processes of knowledge transfer occur. CoPs, primarily regarded as a feature of co-located environments, have attracted recent interest in their possible use in a distributed international environment under the pressures of globalisation and the trend to a more distributed work force (Kimble & Hildreth, 2005). These emerging CoPs, according to Hildreth (2000), are defined as 'Virtual CoP'. As the objectives of CoP vary, knowledge management does not necessary occur just within organization, but also across organizations (Alavi & Leidner, 2001). Whenever groups of people have a common purpose and an internal motivation, knowledge management can be applied. Therefore, DKM in this research is defined as: groups of people having a common purpose, working in geographically distributed environments and using the processes of knowledge management. Based on virtual CoP, DKM should have similar features, summarized below:

- Users and owners of knowledge are distributed geographically. This is the basic difference to other knowledge management forms. They should work in ‘other locations’ rather than the ‘same location’ (Hildreth, 2000).

- Doing similar jobs or sharing same purpose. This is the reason for their willingness to share knowledge for mutual benefit.

- They have different experiences and backgrounds. This includes the education, training, experiences of the industry practices, and prior living and working environments. These elements impact their knowledge to some extent (Nooteboom, 2000).

- The knowledge is flowing. Collaboration, including solving a problem together and swapping anecdotes/experiences with colleagues, leads to the flow of knowledge from one to others.

Australian agriculture knowledge management was selected as the study case of this research, because it is a widespread DKM environment, having the common features discussed above.

The major practitioners of the Australian agriculture industry include farmers, scientists, agricultural consultants and policy-makers, all of whom are distributed geographically and having the same broad purpose of constructing a sustainable agriculture industry. The educational backgrounds of each of them vary in a wide range, and farming experiences are also different. However, serving the same purpose, most of them already have collaborations of different kinds: 1) farmers share experiences in the local community ‘catch-up’, 2) agricultural consultants teach farmers using latest knowledge, 3) scientists invent technologies to help farmers to have better production, and 4) policy-makers realize the situation of the whole region and formulate appropriate schemes for sustainable agriculture. During all of these collaborations, knowledge is flowing from one to others.

2.3 Agricultural Knowledge Management (AKM)

2.3.1 Overview

Australian farmers have long contended with droughts and floods but have suffered exceptionally high temperatures, low rainfalls, and low soil moisture in recent decades (Hennessy, et al., 2008). These exceptional climate events can have devastating effects on large areas of land, damage agricultural ecosystem, and sometimes cause much loss of livestock and growing crops, which not only affects the farmers, but also the sustainability of the agricultural industry (CSRIO, 2007). Moreover, globalization has also brought challenges for the farming industry. According to Department of Sustainability, Environment, Water, Population and Communities, Australia (DSEWPC) (2010), imported plants, animals and diseases, such as Japanese encephalitis, citrus canker, and sugar smut (ABARE & MAF, 2006), have been threatening Australia's unique biodiversity and reducing overall species abundance and diversity. Globalization also intensifies the competitions with other countries. By 2004, there were around 8 million farmers in 17 countries growing genetically modified (GM) crops, while Australian farmers were still concerned about this new technology (ABARE & MAF, 2006). This late adoption could place Australia at a competitive disadvantage. To overcome the issues above and facilitate the adoption of innovation, the Australia government has released relevant policies and action plans for instructing farming parties, such as National Drought Policy (Hennessy, et al., 2008), National

Livestock Identification System, National Water Initiative, National Action Plan for Salinity and Water Quality, Natural Heritage Trust (ABARE & MAF, 2006) and various kinds of action and recovery plans for protecting native species.

To help farmers deal with the issues above, adapt to new policies and adopt innovations, the ability to access, understand and implement the latest scientific knowledge and solutions is crucial (Ingram, 2008). Although most scientific research outputs can be accessed publicly, the farmers cannot always find or fully understand them, due to the complexity of the knowledge itself. Therefore, most of the farmers in Australia receive the latest knowledge and support from third parties, which are typically extension officers or consultants (hereafter called consultants), provided by government or companies. They travel a long distance to teach the latest farming options and sometimes help in diagnosing on-site farming problems, such as soil erosion and plantation diseases. The consultants are important mediums for transferring scientific knowledge from the scientists to the farmers, and also sometimes collecting first-hand data from local farmers to support the scientists in further research.

Besides transferring knowledge, consultants may also assist farmers to manage the farm by contributing to property planning. This is typically supported by two dimensional mapping which provides for appropriate spatial arrangements of activities but often lacks the context of terrain, landscape and detailed geographic information. During those procedures, consultants can waste time and money in travelling between sites to communicate with the local farmers and, in a different direction, the scientists. Moreover, this traditional knowledge transfer method is inefficient for the propagation of scientific knowledge because of the lack of direct access of farmers to the science, or scientists (whether biophysical or social) to the farmers. Therefore, improving the efficiency of the knowledge transfer is very important for handling a range of issues.

Additionally, a record of response of land managers and of the environment itself to past events, including extreme events which may become more frequent, can provide researchers with a powerful historical database for data mining, analysis and knowledge acquisition.

2.3.2 Existing Diagram of AKM

To precisely indentify the existing conditions of AKM, I made two visits to the pilot site and interviewed the farming parties involved. The existing diagram (Figure 2.1) of communications between the parties was summarized based on those visits. Key elements of AKM were found to include: type, transfer, creation and application. These are similar to knowledge management issues in other domains (Alavi & Leidner, 2001).

- Agricultural Knowledge Types and Storage

Three kinds of knowledge are transferred between the parties involved in agricultural knowledge management (Table 2.1).

Table 2.1 Agricultural knowledge types and storage

Owner	Knowledge description	Type	Storage
Scientist	Expert knowledge: created through experiments	*Explicit*	Database, research papers, newspaper, and information web site
Farmer	Local knowledge: experiences	*Tacit*	Hard to store, mainly on diaries
Consultant	Interactional knowledge: feedbacks from farmers towards expert knowledge and knowledge taught by scientists	*Explicit* & *Tacit*	Database, research papers, interview records

The expert knowledge created or owned by scientists, which is regarded as *explicit knowledge* that has been or can be, according to Nonaka (1994), articulated, codified, and stored in certain media, and readily transmitted to another person. This expert knowledge is written in strict scientific language, which, according to Carolan (2006), is hard to understand for local farmers, not only due to the complexity of the knowledge itself and the education background of the farmers, but also because of the reliance on scientific language and lack of ‘farmer talk’. This knowledge is mainly stored in scientists’ databases, and published to research papers. Sometimes it is partly reported in newspapers and on web-sites intended by research organisation as points of access using simplified language, e.g., Commonwealth Scientific and Industrial Research Organisation(CSIRO)’s on-line sustainable ecosystems (2007) and Department of Primary Industries, Victoria (DPI)’s Victorian Resources Online (2010).

The local knowledge owned by farmers is generally seen as *tacit knowledge* that, according to Nonaka (1994), is difficult to transfer to another person. For example, a farmer may find it difficult to write down or even verbalise their knowledge of grazing arrangements relying on climate conditions and stock habits. As such, the local knowledge is hard to summarize and store. It is regarded as experiences, and sometimes written down in farming diaries, which are the main storage medium.

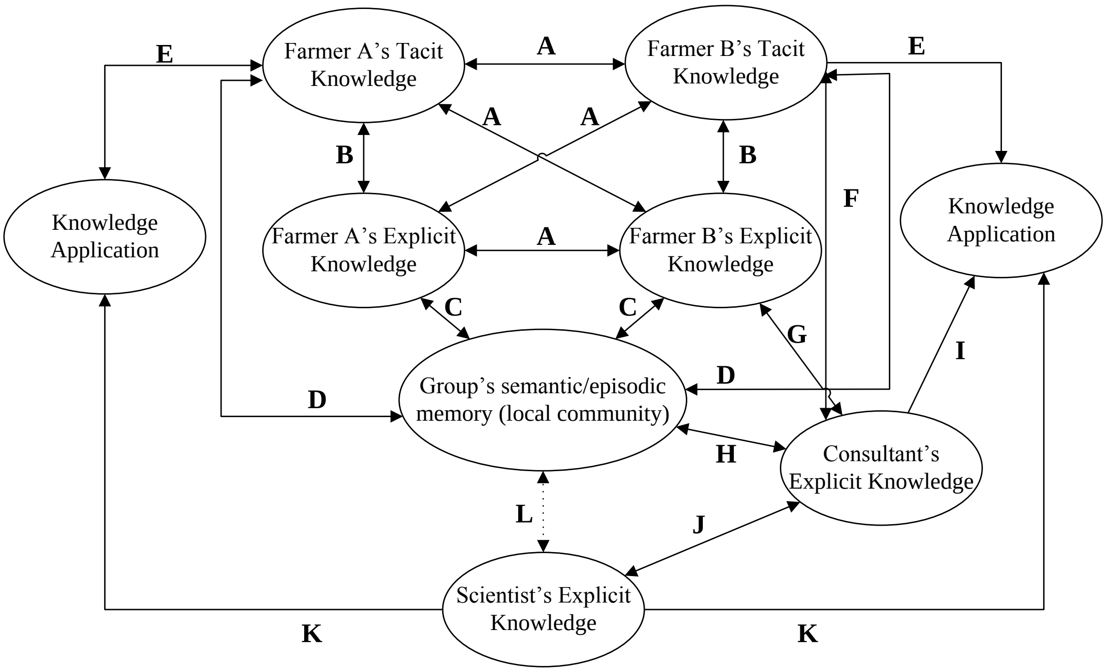
Knowledge is gained by consultants when 1) they are taught by scientists, 2) they visit the farmers and record the opinions of farmers towards the scientists' knowledge, and 3) they provides on-farm assistance based on their scientific knowledge and experiences. As consultants have scientific backgrounds and on-farm experiences, they can transform *tacit knowledge* to *explicit knowledge* (Nonaka, Toyama, & Konno, 2000), which is then stored in a database and even published in research papers. This knowledge, including *explicit* and *tacit*, is important in that it provides farmers with latest knowledge and at the same time first-hand feedback for scientists to complement their research (McCorkle, 1989; Raedeke & Rikoon, 1997).

- Agricultural Knowledge Transfer

Agricultural knowledge transfer is not as simple as handing over the scientific papers or data reports to the local farmers. The goal of knowledge transfer is to 1) not only propagate knowledge from scientist to local farmers, but also from local farmers to scientist, and 2) ensure knowledge receivers fully understand and apply the knowledge to practices.

The current situation of agricultural knowledge transfer is illustrated in Figure 2.1. Farmer's knowledge, especially *tacit knowledge*, according to Carolan (2006), sometimes may conflict with scientific knowledge, and this degrades the trust of farmers towards the scientific knowledge. For example, a grazing method may not work on certain farming areas, even though it worked well in a pilot site managed by scientists. Moreover, local personal networks (e.g., local landcare groups) offer farmers unique learning opportunities, which according to Nonaka (1994) involves “hands-on-experiences”, achieving a faster learning curve (Alavi & Leidner, 2001). As a result, farmers are more willing to learn from the experiences of other farmers who have already adopted the latest knowledge, than from the knowledge published by scientist. Therefore, socialization, the arrows labelled A in Figure 2.1, is easily the most important way of knowledge transfer of farmers. During socialization, farmers share their experiences of farming, including both *tacit knowledge*, such as grazing timing according to climate conditions, and *explicit knowledge*, such as the usage of fertilizers relying on the instructions of the producer. Beside one-to-one socialization, farmers also join the local farming community, labelled C and D in Figure 2.1, where they share knowledge with a wider group, to obtain the latest knowledge from others, and contribute their own knowledge. Moreover, farmers obtain other knowledge by accessing sources, labelled E in Figure 2.1, such as local newspaper, information web sites managed by government, and even sometimes research papers. As shown in Figure 2.1, consultant’s *explicit knowledge* is the major direct source of scientific knowledge for local farmers, because, as explained above, farmers are not able to fully access or understand the scientific knowledge in traditional forms, and consultants play the role of propagating them. The arrows G and F represent the process of in-field consultation with farmers. Meanwhile, as arrow H, a consultant also joins discussion in the local community to explain the latest knowledge and best practices.

Scientists seldom obtain the first-hand in-field data directly from farmers or the farming community (arrow L). Rather, as labelled J, they transfer their knowledge to consultants and obtain the feedback of the farmers through them. The most important contributions of the scientists in these knowledge transfer processes are, arrow K, publishing research papers, setting up on-line knowledge bases and interviews with newspapers.



Legend:
A--Socialization: farmer's tacit knowledge or explicit knowledge will be transferred to others.
B--Internalization and externalization: farmers, through learning or applying knowledge in farming, can transfer their own tacit knowledge to explicit knowledge, vice versa.
C--Explicit knowledge sharing: through joining local community discussion, individual explicit knowledge are shared, and transferred to group's semantic memory.
D--Tacit knowledge sharing: through joining local community discussion, individual tacit knowledge are shared, and transferred to group's semantic memory.
E--The process of learning: farmer accesses the knowledge application, such as scientific papers, knowledge web site, and local news, to learn the latest knowledge.
F--Consulting: consultants teach farmers explicit knowledge and transfer to farmers' tacit knowledge.
G--Consulting: consultants teach farmers explicit knowledge,
H--Consultants' knowledge sharing: consultants join local community discussion, and share the latest knowledge.
I--Consultant's process of learning: consultant accesses the knowledge application, such as scientific papers, knowledge web site, and local news, to learn the latest knowledge.
J--Knowledge sharing: consultant will share the first-hand data and information with scientist.
K--Knowledge propagation: scientist propagates explicit knowledge by publishing journal papers, establishing web site, and advertising in local news.
L--scientist's knowledge sharing: scientists sometimes shares knowledge through joining discussion in local community.

Figure 2.1 Agricultural knowledge transfer process (based on Alavi and Leidner (2001)'s knowledge transfer among individuals in a group)

- Agricultural Knowledge Creation

Agricultural Knowledge Creation, involves 1) a transformation between *tacit* and *explicit knowledge*, and 2) yields knowledge to different levels of users including individuals, groups and organizations (Nonaka, 1994). In Figure 2.1, knowledge creation processes are presented as: 1) Farmer obtains knowledge from other farmers and consultant, through which, as well as a farmer's cognitive processes, farmer's knowledge, including *tacit* and *explicit* is created, amplified, and justified (Nonaka, 1994)., 2) shown as label B in Figure 2.1, farmer's *tacit knowledge* is converted to explicit knowledge (e.g., learning best practices or lessons from others), and *explicit knowledge* is converted to *tacit knowledge* (e.g., understanding of the latest scientific knowledge from discussion), 3) consultant obtains *explicit knowledge* from scientist, and *tacit knowledge* from farmers and community discussions, 4) consultant transform *tacit knowledge* to *explicit knowledge* based on his scientific knowledge and experiences, and 5) scientist's *explicit knowledge* was complemented by collecting feedback from consultants.

- Agricultural Knowledge Application

Knowledge application refers to applying knowledge into practices, which can be performed through three primary mechanisms: *directives*, *routines*, and *self-contained task teams* (Grant, 1996). In the context of AKM, government or research units release *directives* for users to follow, such as the policies and action plans. *Routines* are the result when *explicit knowledge* transforms to *tacit knowledge* and becomes common processes for farmer to carry out, e.g., fertilizers should be applied in area with low nutrition composition. *A self-contained task team*, is the main mechanism for situations where tasks are too complex or context-specific (or "location-specific" (Westney, 2001)) to be performed only relying on *directives* or *routines*. In this regard, farmers and consultants (as well as consultants and scientists) are working together for problem solving. In this paradigm, a consultant is the only bidirectional information sharing medium for exchanging the results of knowledge applications by different farming parties. The existing processes use Information Technologies to facilitate accessibility of *directives* (e.g., CSRIO and DPI's online resource), while the supports for *routines* and *Self-contained task team* are few. As Alavi and Leidner (2001) identified, IT can help capture the context-specific knowledge during problem solving process by *Self-contained task team* and transform this to *explicit knowledge* for providing sources for *directives* and *routines*.

In conclusion, even though the existing diagram of AKM has been working well for the past decades, it may not be able to handle the upcoming challenges, especially in the context of globalization and climate change. The next section summarizes the defects of the existing paradigm, in terms of geographical and cognitive distance.

2.3.3 Issues caused by geographical distance and cognitive distance

Geographical distance creates barriers through physical separation. Boh et al (2007) identified the difficulties when projects have members at different sites:

- fostering a collegial social environment (Kraut, Fussell, Brennan, & Siegel, 2002; Nardi & Whittaker, 2002)
- building common ground (Clark & Brennan, 1991)
- maintaining awareness (Weisband, 2002)
- focusing on the project (Kanfer, 1990)

- and making rapid adjustments to surprises (Olson & Olson, 2000)

(Cited papers in this list are identified by Boh et al, 2007)

In the context of AKM, dispersed practitioners such as farmers and scientists are facing the same issues: 1) scientists or consultants working in an urban area may not be able to frequently visit farmers working in rural areas to foster a collegial social environment, 2) they may focus on different projects at the same time (harvest and research conference), and 3) scientists may not be able to respond to emergencies on the sites (locust invasion).

Moreover, geographical distance also increases the likelihood of time separation between practitioners (Espinosa & Carmel, 2004), which may causes delays of knowledge transfer. These delays possibly result in misunderstandings towards others, out of date knowledge being mastered by individuals, and even the failure of emergency response, e.g., the locust control centre may not be able to precisely predict and inform farmers because of delayed locust migration information.

To overcome these issues caused by geographical distance, practitioners may need to spend time and money on 1) setting up information and communication technology systems (ICTs) to facilitate resource sharing and communication across distance (May & Carter, 2001), and 2) coordination of stakeholders to learn these ICTs, matching best expertise to corresponding requirements, e.g., government needs to assign locust experts to provide local farmers with prevention knowledge. All of these costs can be summarized as ‘coordination costs’ for bridging geographical distances. Even though the ICTs may facilitate knowledge sharing and communication and reduce the possibility of delays in knowledge transfer, the opportunities for spontaneous, informal talk, which is the main media for transferring tacit knowledge, are still hindered by the geographical distance.

Cognitive distance, in the context of AKM, represents the differences of physical environment, social environment, education and past experiences between local farmers, consultants and scientists. Farmers in a certain region reside in a similar physical environment, including climate and soil condition, have similar educations by possibly studying in the same school and joining in local community groups such as Landcare, and working within the same government policies, tax conditions or incentives, they may therefore have similar cognition. Meanwhile, scientists and consultants working distantly, whose experiences and knowledge are based on their own surroundings would have different cognition to the farmers. Due to the difference of cognition, the same phenomenon may be interpreted differently by scientists, consultants and local farmers, e.g., soil erosion in certain region may be interpreted as the result of overgrazing by scientists, but flooding by farmers. These different interpretations may lead to misunderstandings towards the in-field situation by scientists, and mistrust in the scientific knowledge by local famers. In the study by Carolan (2006), this point has been established. Lack of confidence towards scientific knowledge, will reduce farmers' motivations for adopting innovation, which, according to Rogers's *Diffusion of Innovations Theory* (2003), slows down the diffusion progress. Meanwhile, as farmers may doubt the scientific knowledge, their motivations for contributing local expertise to scientific research may also be reduced, which influences the potential for in-field data collection by scientists and consultants. Beside this mistrust and low motivation, understanding may also be impacted by individual's education backgrounds, especially when knowledge is written in strict scientific language (Carolan, 2006). Therefore, local personal networks (e.g., the local Landcare group) become the most important sources of knowledge for farmers, as they can obtain "hands-on-experience". However, some authors belief that local networks increase the likelihood of repetition and redundancy in evolving knowledge structures, and reduces the possibilities of novelty (Hansen, Mors, & Lovas, 2005; Teigland & Wasko, 2003).

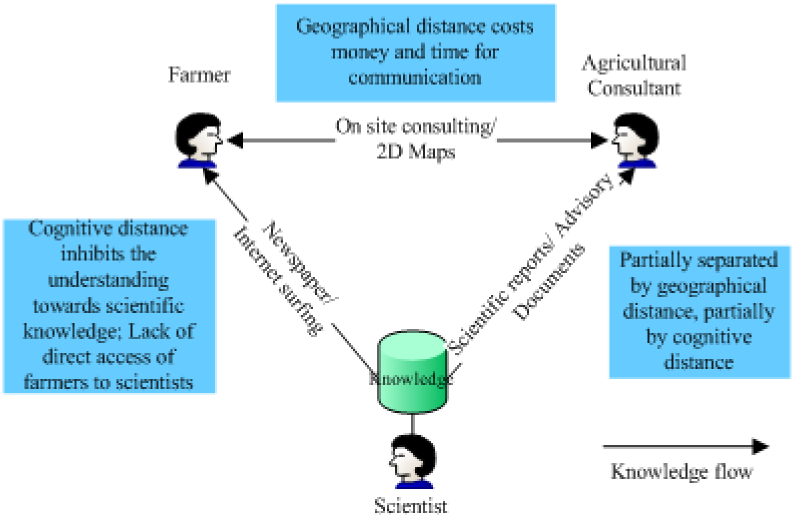


Figure 2.2 Existing AKM diagram

In conclusion, the existing AKM diagram (Figure 2.2) involves a wide range of processes and activities for identifying, locating, sharing, maintaining, storing and application of agricultural knowledge. However, as farming parties are separated by geographical and cognitive distance, the process illustrated in this diagram has three major defects:

- Coordination cost for resource sharing and communication is significant.
- Lack of direct interaction between farmer and scientist causes misunderstanding and confidence issues, which slow down the propagation of innovation and prevent the local knowledge to complement scientific research.

- Knowledge flows within limited boundaries may restrict novelty.

There have been attempts to separately solve both the geographical distance and cognitive distance issues. Wolfert et al (2010) considered primarily geographic distance and provided a method for investigating the problems of information sharing in agri-food supply chain networks (AFSCN). The method involved different concepts and approaches including BPM (business process management), SOA (service-oriented architecture) and Living Labs, providing a complete mechanism (e.g. data exchange standard) and workflow of information sharing between relevant shareholders. Moreover, the study also mentioned that a new cooperation between research and practice should be generated, where information exchange between farmer and researcher is not just one-way: from farm to industry, instead, a farmer can obtain the information in a standardized format, which can be used in their management applications, to ultimately improve their craftsmanship by up-to-date knowledge and farm-specific data. This method can solve the geographical distance issue, however, it didn’t mention any mechanism to assist farmers to understand this knowledge, or any method to help farmers to summarize and contribute their knowledge to the research, nor the issue of heterogeneity of semantics.

CSIRO and APSRU (Agricultural Production Systems Research Unit) are two leading national research institutes in Australia. Their functions include assisting farmers to understand scientific knowledge and also collection of onsite data through participatory and action research (Carberry et al., 2002). These approaches can reduce cognitive distance. However, they may promote only short-term behaviour and be hard to apply to large farming areas. Only farmers who join these researches can contribute their knowledge to the research directly and permanently. As a result, research units gain access to detailed data only on a certain region of interest. This work does not address the issue of geographic distance.

The objective of this research was to devise systems, using emerging technology, which will help users to overcome the cognitive issues and geographical issues together to achieve maximum benefits. Therefore, the solution appears to require a new AKM paradigm, which is addressed at the end of this chapter.

2.4 CVE

2.4.1 Why CVE?

According to May and Carter (2001), ICT can solve resource sharing and communication issues caused by geographical distance. Boh et al (2007), investigated the service company American Institutes for Research (AIR) and found that staff depended on e-mail, facsimiles, long-distance phone calls, and audio-conferencing to collaborate. These are not cutting-edge technologies, but they are common in daily office routine today, still helping staff share resources with each other, and communicating without time delay. However, they do not constitute an integrated system, which considers each facets of knowledge management. This lack of integration can cause other issues: 1) knowledge transferred between different departments can easily be lost due to lack of an organized database system, and 2) team members can lose focus or have divergent objectives on the same project because there is no unified information management mechanism. Therefore, an integrated DKMS, including a well-organized knowledge repository, resource sharing mechanism and retained contextual knowledge is necessary.

Alavi and Tiwana (2002) argued that DKMS can be used to constitute a ‘virtual team’, which has become a common mechanism for harnessing, integrating and applying knowledge for teams across distributed locations. The success of the ‘virtual team’ depends on whether the systems and technologies can provide team members with a collaborative working environment, where communications are performed without geographical restrictions, knowledge is shared using the same language and mental models, purpose is clear and generally translated into certain action steps, and trust is built when collaborations occur (Ebrahim, Ahmed, & Taha, 2009; Lipnack & Stamps, 1999; Powell, Piccoli, & Ives, 2004). Therefore, designing an integrated DKMS which can provide a collaborative working environment is the main purpose of this research.

Empirical studies have shown that DKMS can be effective using text or 2D maps to store and transfer knowledge (Akscyn, et al., 1988; Alavi & Leidner, 2001; Bresman, et al., 2010; Hansen, et al., 1999; Hildreth, 2000). However, DKMS should be able to support knowledge using more diverse representations, because: 1) along with the recent evolution of multimedia, knowledge has been presented in various forms: audio, animation, and 3D data, which can carry more information, 2) onsite data, such as the situation of locust invasion or leakage of the water supply network, are hard to describe in text, and 3) in terms of human cognition, 3D data are often more effective than 2D, as illustrated in Figure 2.3 (Hofschreuder, 2004; Schobesberger & Patterson, 2008).

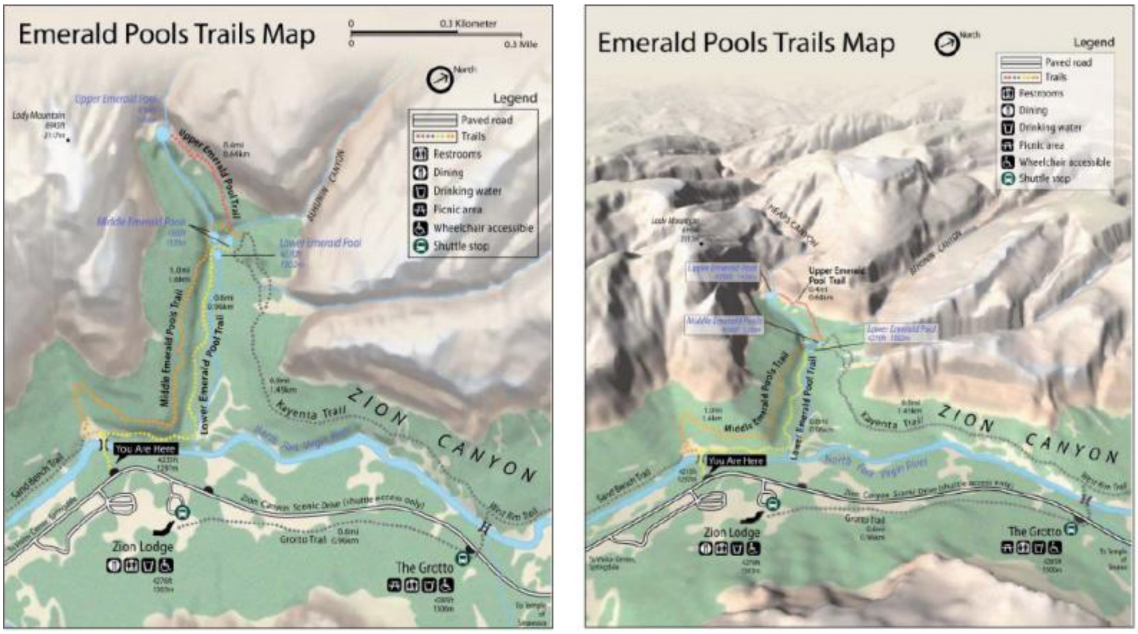


Figure 2.3 Comparison of a 2D map and a 3D-impression map (Schobesberger & Patterson, 2008)

Therefore, a DKMS capable of overcoming issues caused by geographical and cognitive distances should be able to provide a 3D collaborative working environment for the dispersed working team members. In this regard, CVE, which is the ideal technology for providing this capability (Benford, et al., 2001), is employed in the design of iFarming.

2.4.2 CVE in bridging geographical distance

Empirical studies have shown that the coordination cost of a distributed working team can be considerably reduced by employing CVE in the process of knowledge transfer. Hui et al (2010) designed a CVE for the planning of silt dam systems, where planners are able to share data in a 3D environment, through which workload compared with the traditional workflow was reduced by between one third and a half. Bishop and Stock (2010) have designed a CVE – SIEVE (Spatial Information Exploration and Visualisation Environment), and illustrated its utility in the planning of wind energy installations (as shown in Figure 2.4), through which multiple users are able to make changes to the same 3D scenario to achieve a best solution. Compared to classic recursive planning process, such CVE brought planning and gathering feedback together to improve the efficiency.

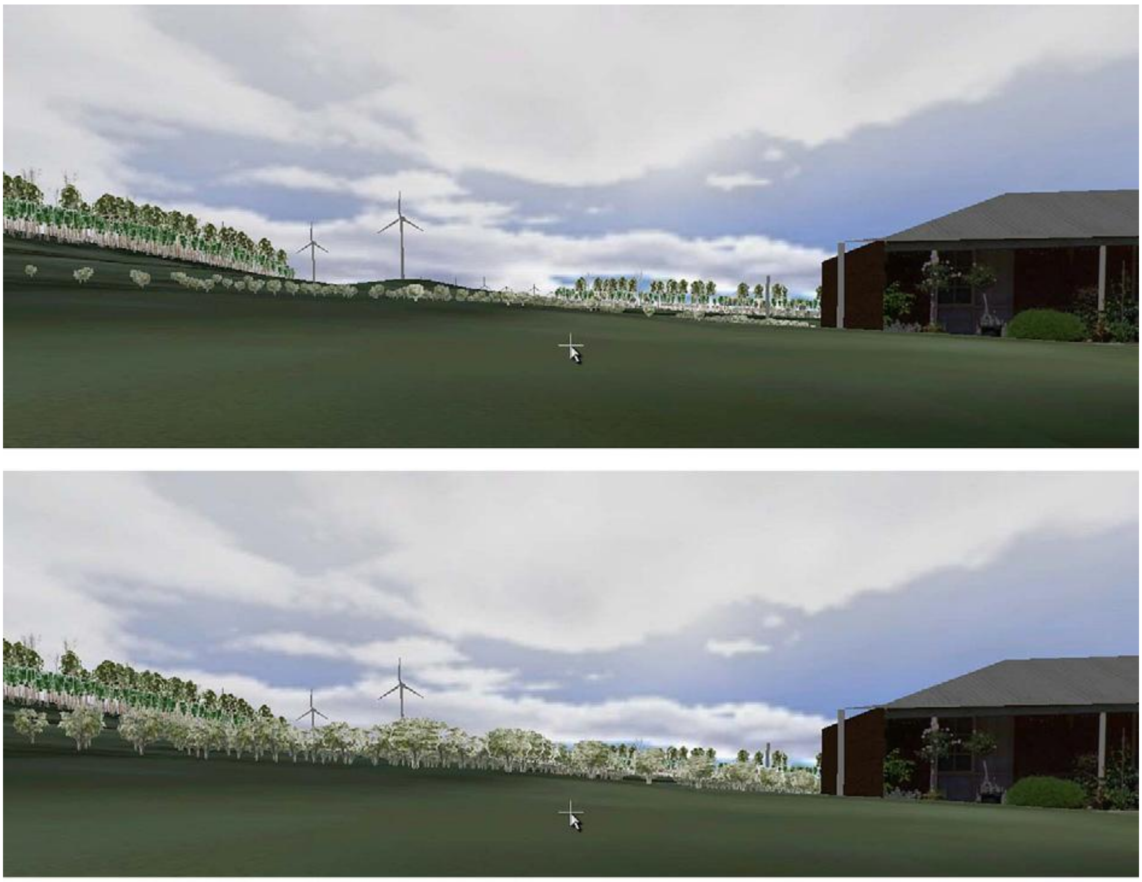


Figure 2.4 CVE for wind energy installations (Bishop & Stock, 2010)

Moreover, CVE also offers opportunities for dispersed team members to perform ‘informal talk’, by providing users with contextual knowledge, communication channels (online message or audio) and the same virtual environment. In SIEVE, online users can chat via online message, and discuss the benefits and defects of each wind turbine installation scenario (Bishop & Stock, 2010). 3D video-conferencing is another successful application of CVE in ‘informal talk’. Kauff and Schreer (2002) designed a 3D video-conferencing system, where users are presented as avatars in a virtual conference space. In these ways, CVE is able to solve the issues caused by geographical distance. The reminder of this section discusses how CVE solve the issues caused by cognitive distance.

2.4.3 CVE in bridging cognitive distance

CVE is capable to provide users with a realistic virtual environment (Benford, et al., 2001; Bishop & Stock, 2010; Hui, et al., 2010; Lim & Honjo, 2003; Stock, et al., 2008; Zhang et al., 2007). The studies by Hofschreuder (2004) and O’Connor (2007) have shown that this virtual environment, presenting scientific knowledge and modelling results, can help users, even those who lack corresponding knowledge backgrounds, better interpret and understand the modelled phenomena.

Cognitive distance between team members can also be reduced by training (Tan, Wei, Huang, & Ng, 2000). Tan et al (2000) designed a dialogue technique, including three stages (small talk, sharing mental models and norm building), through which trust and understandings between members were built up. However, this technique may just suit the business context, where team members are easily assembled and have specific duties to perform and team functions. In the context of AKM, the relationships between farmer and farmer, farmer and scientist, and farmer and consultant are looser than in a business organization. Therefore, such dialogue technique could only be implemented when farmers are meeting with neighbours and in the local community. Furthermore, as cognitive distances between farmers and scientists are large, as a result of the differences of education and farming experiences, initiating dialogue between them may also be difficult. Therefore, any mechanism for bridging cognitive distance should focus on extension of dialogue already occurring in the local community and between neighbours.

According to *Diffusion of Innovations Theory* by Rogers (2003), innovators and early adopters, who are often well educated and more socially adept, are the most willing to adopt new technology and knowledge. This group is followed by the early majority, later majority and finally laggards. As trust is more easily built between farmers than between farmer and scientist, and socialization between farmers is the main way of transferring knowledge, this research regards innovators and early adopters amongst farmers, so called *knowledge activists* according to Von Krogh et al (2000), as the target for inception of knowledge transfer within the local community. Enriching them with the latest knowledge from scientists and consultants, they may become the 'preacher' for new approaches in the local community (Figure 2.5). In the context of business organizations, *knowledge activists* may be similarly selected to represent the branches of an organisation to adopt the latest knowledge from headquarters and other sources, through which knowledge may be propagated faster (Hocking, Brown, & Harzing, 2007; Von Krogh, et al., 2000).

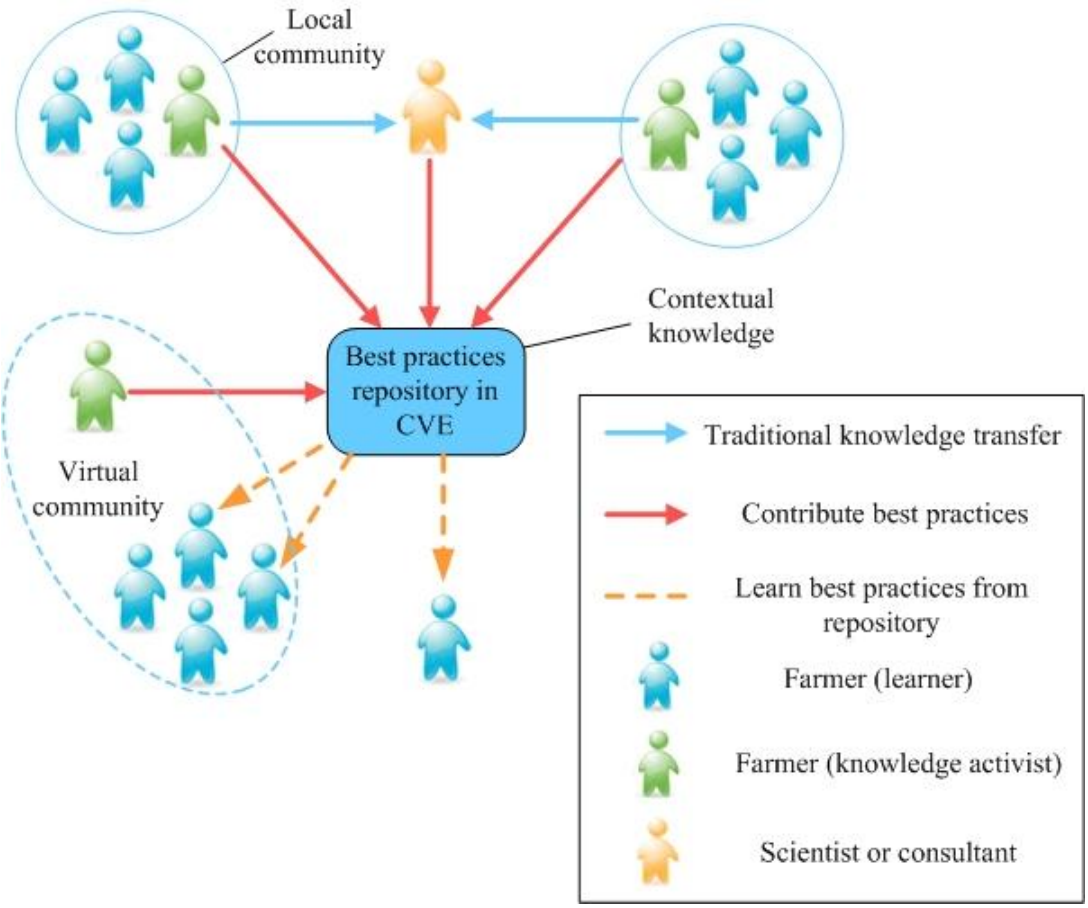


Figure 2.5 Knowledge activists and learner in CVE

In this regard, CVE is the proposed platform for demonstrating the best practices of *knowledge activists*, and allowing others to review and refer, and to ultimately understand and adopt the latest knowledge. CVE’s advantages in such processes include:

- provision of sufficient contextual knowledge, through matching of contexts between farmers, e.g., Farmer A (*knowledge activist*) adopted a new fertilizer in his property with sandy and high pH soil and had good outputs, Farmer B realises his property is similar to Farmer A's, and consequently adopts the new fertilizer.

- Innovators, early adopters, early majority, late majority and laggards are not necessarily geographically close. Based on CVE, they can work as a virtual

> ‘local community’ (Figure 2.5). This feature of CVE allows a bigger ‘local community’ than traditional local communities with their geographical restrictions.

Allowing individual users to upload their best practice information and knowledge in various contexts, and to share this with others, exceeds the traditional CVE’s capability. Existing CVEs either restrict the user groups or the content uploaded. For example, in the CVE designed by Hui et al (2010), users are mainly decision-makers, dam planners, and architects. The content they uploaded and shared is restricted to dam planning related data, which was fixed when the system was designed. In the conceptual CVE by Bishop and Stock (2010), the public are allowed to participate in the discussions. However, they seldom are able to formulate the scenarios due to lack of 3D design skills (Schobesberger & Patterson, 2008). Although 3D data may provide more detail, as discussed above, designing a 3D scenario is hard to achieve by users without related skills. Ideally, a CVE should provide practical interfaces for users to design and upload information and scenarios in 2D or 3D. Therefore, iFarming should be able to allow public users to upload their data with various contexts. To achieve this, the concepts of Web 2.0 are ideal, as discussed in the next section.

In conclusion, CVE may be capable to reduce both geographical distance and cognitive distance. Besides the basic features of traditional CVE, including 3D data support, network communication and contextual knowledge, the design should also provide practical interfaces for public users to upload knowledge within various contexts, including 3D data, and allow a bigger ‘virtual community’ for a more comprehensive contextual knowledge repository.

2.5 Relevant Concepts and Technologies

2.5.1 Web 2.0

Web 2.0, according to Oreilly (2007), is a World Wide Web (WWW) platform, treating content as the core, providing Web services as the portal, evolving itself by allowing users to contribute, and ultimately achieving collective intelligence.

Levy (2009) through reviewing the applications of Web 2.0 and its reflection in organizations, found out that Web 2.0 is very similar in its principles and attributes to knowledge management, and organizations may benefit by adopting its concepts and tools. Successful examples include IBM, Motorola, Procter & Gamble, Ziba, Ford Motors co, Nike, Milestone Group, GM, Pepsi and XM Radio (Audrey, 2006; Levy, 2009). Levy (2009) also suggested WIKI and Blog, which are the most popular Web 2.0 supported applications (Levy, 2009; Oreilly, 2007), can be an easy entry point for organisations. In the context of DKM, Web 2.0 may be able to enrich CVE to better reduce cognitive distance.

Web 2.0 relies on a Client/Server (Oreilly, 2007) structure to allow a user to raise a request and the server to respond with data objects including XML and JSON (JavaScript Object Notation), both of which are widely used formats. In this regard, providing web services to clients is the main task of all Web 2.0 applications. As web services are supported by various types of client, such as web browsers, desktop applications, and even mobile phone, user interfaces to Web 2.0 applications vary. In the context of DKM, this feature of Web 2.0 is important in providing in-field workers with user interfaces (Mobile phones) for access to iFarming. Yet, a CVE relying on desktop applications to share knowledge, seldom considers employing another user interface for among in-field workers' requirements. This may be because web services are not usually employed in the design of traditional CVE.

Similar to CVE, Web 2.0 also allows users to upload content, and both of them support the emergence of collective intelligence (Levy, 2009). However, the amount of users and motivations to contribute are different, which affects the quality of the collective intelligence. Prior studies suggest that the users of CVE are known by each other and have similar levels of advanced education (Bishop & Stock, 2010; Hui, et al., 2010; Morris, et al., 2004; Stock, et al., 2008), which means the number of users in a traditional CVE is limited, and more importantly, the interactions between users has limited novelty due to their similar backgrounds and knowledge structure (Cohen & Levinthal, 1990). The significant advantage of Web 2.0 applications are the large number of potential users (Levy, 2009), because most of the Web 2.0 applications are open to public. Taking Wikipedia as the example, the collective intelligence, wisdom and creativity of the crowd has been shown. In the context of AKM, achieving large numbers of users is necessary, because users' cognitive distances vary, and more users can provide more contextual knowledge, achieve better collective intelligence, and possibly lead to novelty and innovation.

Furthermore, as Web 2.0 applications are open to public, they attract the interest of innovative thinkers. Consistent with *Diffusion of Innovation Theory*, these people who are open to new ideas, work as the early adopters to use, contribute, test, and even promote Web 2.0 applications (Von Krogh, et al., 2000). The incentives which motivate users to contribute may be implicit or explicit. The former are mainly social incentives, users may be pleased to be regarded as important players in their community. The latter includes financial rewards, such as coupons or payments to contributing users (Toluna, 2009). Due to these incentives, Web 2.0 applications can gain large numbers of users and evolve rapidly, e.g., Wikipedia recently reported 14,027,457 registered users, and 3,565,976 content pages (Wikipedia, 2011). As discussed above, a possible method to overcome cognitive distance in DKM is to invest into the innovators and early adopters, and make them *knowledge activists* in the virtual 'local community'. While CVE does normally not have a corresponding mechanism for motivating users to contribute, Web 2.0 shows how this might be achieved. As Web 2.0 applications do, CVE should also make users feel good when they contribute.

Web 2.0 treats content as the core, while CVE focuses on use of the content, which means Web 2.0 applications seem as if there is no specific common objective among the users, while CVE users aim to achieve a specific task. Developers of Web 2.0 applications provide a platform for users to upload data and information in a certain format. The content is changing in two ways: the content itself and the format of the content. As Web 2.0 is based on services, the developers constantly fine-tune old modules and develop new modules allowing users to upload not only new content but also new formats of content. In Wikipedia, for example, the number of templates for users to formulate pages keeps growing. Yet, CVE tends to set up a specific task before it is developed, and as such, format is fixed, e.g., in the study by Hui et al (2010) about silt dam planning, users are only allowed to upload specific content including DEMs and satellite images. Due to the nature of knowledge management, users may have different objectives in using iFarming, e.g., farmers may focus on the best practices of grazing, at the same time, scientists are focusing on fertilizer usage in a certain area, consequently a variety of content format is necessary. This feature of Web 2.0, according to Levy (2009) is called 'perpetual beta'. As the content itself and the format of content vary in time, the services of Web 2.0 applications improve automatically, which may also fulfil the requirement of users in knowledge management, who would be satisfied by the up-to-date services and large volume of knowledge.

Despite the rapid rise in popularity of Web 2.0, there are still issues of concern.

- Content is subjective. As opposed to the norm in knowledge management, content contributed by users is subjective (Levy, 2009). With large numbers of users, Web 2.0 applications are likely to lose control of the quality of the content, even though some applications motivate users to check the content uploaded by others, like Wikipedia. In addition, a user may upload content that offends other users. Developers should be conscious of this in designing the format of the content, and in providing a mechanism to screen and validate the content.

- Adoption of the concept. Assimilation of tools and concepts by organizations takes time (Levy, 2009), which is the reason for some organizations keeping patient in observing Web 2.0 and not adopting it. Even though some organizations have already employed the tools of Web 2.0 (Hoover, 2007), there are still few of them using it in production processes (Hinchcliffe, 2007), which means the concept has not yet been fully accepted. The reason may be that there is as yet little evidence that Web 2.0 will bring big benefits for organizations (Levy, 2009). Therefore, reducing the risk and cost for adoption of Web 2.0 may prompt more organizations to accept the concept. Levy (2009) believes that “the more used, on the level of tools, the easier it is to accept, on the level of concept”, which means user-friendly tools should be designed.

In conclusion, CVE may benefit by adopting the concept of Web 2.0, in reducing geographical and cognitive distance. Table 2.2 summarises the relevant principles and their potential contributions to success in knowledge management.

Table 2.2 Web 2.0 advantages on CVE and DKM

Principles of Web 2.0	Contributions to CVE	Advantages on DKM
As a platform	▪ Broader user interfaces, including mobile applications	Reduce geographical distance
Active user's participation	▪ Allowing a bigger virtual 'local community' ▪ Better collective intelligence and novelty ▪ Mobilizing *knowledge activists*	Reduce cognitive distance
Perpetual beta	▪ Services improve automatically ▪ More knowledge contexts	Reduce cognitive distance

2.5.2 Smartphone

A smartphone has been defined as a mobile telephone that runs on an operating system providing more advanced computing ability and connectivity than a contemporary basic phone (PCMagazine, 2010b). Since the first iPhone™ was released by Apple Inc. in 2007, other manufacturers have released similar products. These smartphones have several common features: 1) running on operating systems (OS) which provide application programming interfaces (APIs) for user development, 2) equipped with other instruments, such as global positioning system (GPS), compass and camera, and 3) using powerful telecommunications networks, such as 3G. These features bring great potential for performing mobile computing, providing geo-referenced services and sharing substantial data volumes. Based on these capabilities, smartphones have rapidly captured a substantial share of the mobile telephone market (Gartner, 2010).

Considering smartphones’ potential, and the wide adoption of them, this research explored the possibility of employing smartphones to enrich the capability of the traditional CVE, and to help overcome the issues caused by geographical distance and cognitive distance.

Along with the wave of Web 2.0 in the IT industry, employing the smartphone as the user interface is a trend of Web 2.0 applications. The case of Foursquare™ has already shown a powerful example of the combination of Web 2.0 and smartphone. Through designing an easy-to-use user interface and using the concept of Web 2.0, it allows a large numbers of users, 10 million according to Foursquare (2009), who are lacking geographic science background and dispersed geographically, to share data obeying a standard coordinate system (World Geodetic System 1984-WGS84). As a mobile application, it only offers a simple wizard for users to upload photo or text, which decreases the uncertainty of the data and ensures the quality. Emerging as a Web 2.0 tool, smartphone is able to solve some issues discussed above including:

- In-field worker’s needs. One of the limitations of traditional CVE is the lack of in-field support. Allowing smartphone to seamless access CVE-like computer systems may fulfil the needs of in-field workers, such as farmers.

- User-friendly interface. The evolution of smartphones, including the advances on hardware and software, have led to better user-interfaces (e.g., touch screen of iPhone™) and allowed mobile developers to design better software (e.g., Facebook™ on iPhone™). With the advances in user-interface, users are more able to take on new products without a steep learning curve, which is important in accepting Web 2.0 tools to achieve adoption of the Web 2.0 concept.

- Content quality control. As smartphone's software is designed carefully according to the user needs, it does not have the flexibility of full computer systems, which means the content uploaded must be more consistent with the rules set by the developer, e.g., the uploaded data must use pre-defined format, such as Extensible Markup Language-XML, instead of various kinds of formats)

The combination of smartphone and Web 2.0 may therefore be able overcome the usage issues in conventional CVE and further reduce the barriers of geographical and cognitive distances. The design of iFarming embracing the concept of Web 2.0 and supported by smartphone is addressed in Section 2.7.

2.6 Knowledge Management and Information Management

Before suggesting a new AKM paradigm, it is necessary to clarify the differences and relationship between IM and KM to confine the scope of the research and the main goals of the system.

To fully understand the relationship between IM and KM, it is important to review the basic definitions of data, information and knowledge. The discussion about the relationship between them in the IT context can be traced back to the 1980s, when data was viewed as raw numbers and facts, information was processed data meaningful to human beings, and knowledge was collections of information authenticated by individuals (Dretske, 1981; Machlup, 1980). Yet, given this hierarchy from data to information to knowledge, there was no effective evaluation method to distinguish them, in terms of content, structure, accuracy or utility of the supposed information or knowledge (Alavi & Leidner, 2001). Researchers realized that those three elements are indivisible: the data are indentified, collected, organized and converted to information when human beings realize this information is meaningful to them; and through processing this information human beings obtain knowledge (Drucker, 2007; Fahey, 1998; Tuomi, 1999). The commonly held view among those discussions is that knowledge does not exit outside of an agent (a knower) (Alavi & Leidner, 2001).

"Information is converted to knowledge once it is processed in the mind of individuals and knowledge becomes information once it is articulated and presented in the form of text, graphics, words, or other symbolic forms" (Alavi & Leidner, 2001).

The statement above implies that 1) for individuals to share knowledge, their conversation must be based on exchanging data or information, and 2) systems designed to support knowledge transfer may not appear radically different from information systems (Alavi & Leidner, 2001), but will provide conditions for individuals to interpret other's information and so capture knowledge. In this regard, this research doesn't sedulously distinguish data, information and knowledge as transferred between farmers, consultants and scientists. Instead, this research believes facilitating users to exchange those data and information can help knowledge dissemination. The proposed system, iFarming, accordingly, should provide users with a collection of contextual information of certain farms to demonstrate best practices or experiences, which becomes knowledge, in the right hands.

Moreover, the systems used to support AKM should adopt different implementation strategies from other KMS. FARMSCAPE (Farmers', Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation), provided by APSRU, is a participatory research approach to facilitate knowledge dissemination between farmers, consultants and researchers (Carberry, et al., 2002). This 10 year research program has offered valuable references for the success of AKM. Instead of simply providing software products to farmers for their own use, FARMSCAPE suggests co-learning and communication directly with researchers and consultants to facilitate farmers to understand professional models to improved paddock management, recognising that farming modelling tools have a steep learning curve (Carberry, et al., 2002). In this regard, iFarming only provides a collaborative virtual platform for users, especially farmers, to directly communicate with researchers and consultants, and access the latest experiences from others, to ultimately create conditions for knowledge creation and transfer. Providing farmers with professional modelling tools for further information processing with the intention of advancing knowledge without the interception of consultant or scientist would possibly, according to the lessons of FARMSCAPE, divert the interest and involvement of farmers. While iFarming currently works primarily therefore with measureable data (knowledge of form), as awareness and proficiency grows it may be appropriate to integrate the ability to run models (knowledge of process) drawing on this data. The system framework of iFarming has been designed to be flexible enough to integrate the knowledge of process in the future, which is discussed in Section 5.5.2.

2.7 System requirements and new pattern for AKM

The objective of this research is to build a CVE-based DKMS for bridging geographical and cognitive distances. As traditional CVE is not able to overcome all the issues caused by those two distances, this research employs the concept of Web 2.0 and technology of smartphone to enrich the capability of CVE. Therefore, a new generation of CVE is designed and developed, and a new DKMS based on this development is presented. To achieve these objectives, system requirements are formulated.

2.7.1 System requirements

- User groups. Local farmers, agricultural consultants, and scientists are the main users of iFarming.

- Data. The knowledge transferred and stored includes the knowledge developed by scientists, local knowledge owned by local farmers, and interactional knowledge acquired by consultants. Table 2.3 summarizes this data.

Table 2.3 Data source and original format

Data source	**Data content**	**Original format**
Scientists	Scientific data include: soil condition data, water distribution, digital elevation model (DEM), satellite image, and etc.	Shapefile of Esri; Quickbird image file; These files are of different projection systems (WGS84, GDA94).
Farmers	Land use conditions, onsite problems, fertilizer usage, grazing management.	Map and textbook are the main storage method. Prudent farmers rely on electronic storage.
Consultants	Land use conditions, problem diagnosis report, property planning.	Map, textbook, and electronic storage such as Shapefile for land use data, and 2D maps for property planning.

As shown above, there are three main issues of the data: 1) various formats, 2) various projection systems, and 3) some data are not stored electronically. Therefore, iFarming should be able to convert data with different formats into a unified set of formats, store all the data into one unified data storage – database, and facilitate users, especially farmers, to prepare the data and store it in the database. The third issue should be solved by designing a user-friendly interface, which makes the upload process easy enough for the users. Furthermore, iFarming should also support the upload and visualization of the 3D data, e.g., consultants and farmers are able to upload the property planning and land use data to visualize a 3D farm. Moreover, time is a key element of these data. Therefore, all the data transferred, stored and displayed in the user-interface should be tagged with time information.

- User-interfaces. As computer skills and working environment vary between different users, corresponding user-interfaces are designed to meet their requirements. Table 2.4 compares the differences. As scientists are often working in a laboratory, where internet access is easy to achieve, a computer is the main user-interface for them. While farmers and consultants spend much time in rural area, a computer is not always available. However, due to the rapid development of the mobile broadband network, 99 per cent of Australians, spanning from city to rural area, can access the internet (Telstra, 2011), which allows smartphone to work as the user-interface for rural users. Furthermore, smartphone software should be designed carefully to allow farmers, who seldom master advanced computer knowledge, such as GIS, to upload data to the server.

Table 2.4 Comparison of computer skills and working environment

User groups	**Computer skills**	**Working environments**
Scientists	Moderate. Beside basic computer tools, familiar with advanced tools, such as database and GIS software.	In laboratory, easy to access internet via computer
Farmers	General. Familiar with basic computer tools, such as text editor, excel, and internet explorer.	Rural area, just access internet at home. Seldom be able to access internet on site.

Consultants	Moderate. Computer skills are equal to scientists.	Working environments are switched between rural area and urban area. Can’t access internet when working on site.

- Functionalities. iFarming should provide the basic features of a CVE, which include: 1) users are allowed to upload data, 2) uploaded data can be retrieved by other users, and 3) users can share and manipulate the same 3D scenario and communicate. Besides, iFarming should also offer other features to achieve the concept of Web 2.0, which include: 1) the data is tagged with the name of owners to respect the contributions, 2) users are able to access CVE through their smartphones, and 3) the data content can be modified, e.g., a data table designed for in-field grazing management can be created to allow users to upload the movements of livestock.

2.7.2 A new paradigm for AKM

Like other DKMS, the proposed system is to assist the processes of knowledge management and increase the competency of the organizations or groups of people with common interests. The existing paradigm of AKM (Figure 2.2) is facing issues caused by geographical distance and cognitive distance, including high coordination cost, misunderstanding of the scientific knowledge, and lack of motivation to contribute local expertise. iFarming, considering user’s requirements, offers several customized user-interfaces and provides a series of new functionalities. Most importantly, it may assist scientists, farmers and consultants to achieve a better knowledge management pattern, as shown in Figure 2.6, through which issues of geographical and cognitive distance may be solved.

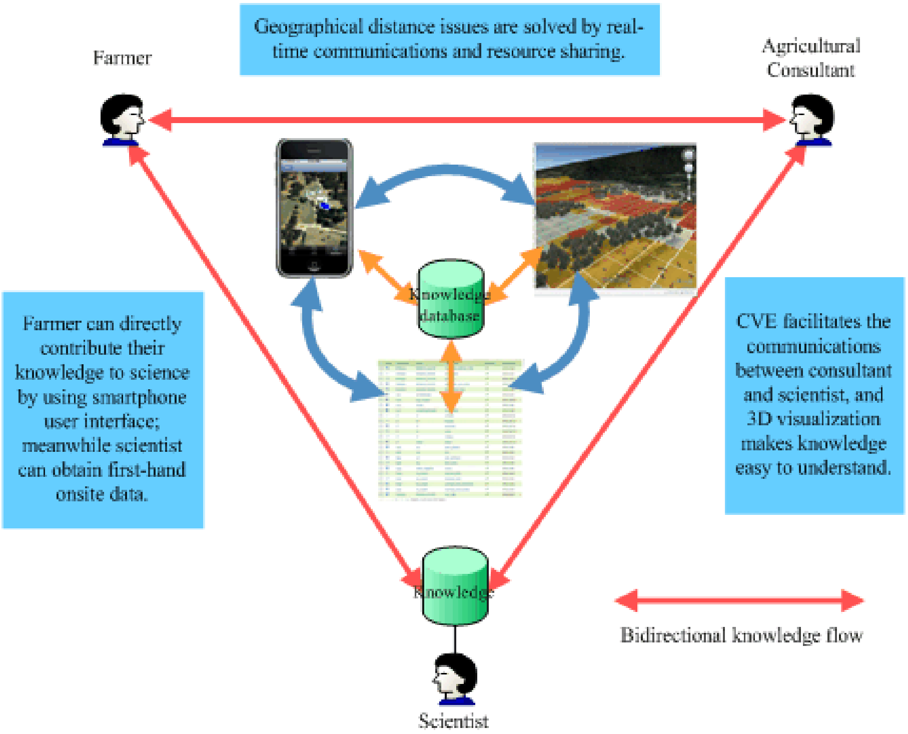


Figure 2.6 New paradigm for AKM

Compared to the existing diagram for AKM (Figure 2.2), the new paradigm has its own characteristics, including:

- Each user groups have their own user-interfaces, which are consistent with the users' computer skills and working environment.

- A centralized spatio-temporal database provides electronic storage for data with various formats, and it enables users to track the history of certain areas.

- The procedure of knowledge transfer is potentially more smooth and efficient, as communications between the three parties becomes bidirectional.

This new paradigm for AKM, as discussed in Chapter 1, is also transferable to other knowledge management contexts, such as land and environment management.

Chapter 3, based on the system requirements, discusses the design and development of iFarming. In Chapter 4, the new paradigm of AKM is implemented in a case study and the performance of iFarming is evaluated.

3. IFarming Design and Development

3.1 Introduction

This chapter describes the design and development of iFarming, to fulfil the system requirements established in Chapter 2. As discussed in Chapter 2, friendly user-interfaces, data conversion and storage, and related functionalities must be achieved. To this end, this chapter firstly reviews the related popular technologies on the market. These can provide users with familiar interfaces and save considerable development time. Secondly, I propose a mechanism for integrating them into the traditional CVE structure. In the last part, the system framework is designed and important functionalities are presented.

3.2 Relevant technologies

Employing popular technologies, with which users are already familiar, as user-interfaces can reduce the learning time and increase the value of look and feel, which is important in facilitating early adopters to accept IFarming. Moreover, some of these technologies provide APIs, which decreases the development time of the whole system. This research used some of the most popular spatial information technologies in the market as shown in Figure 3.1. The components were made interoperable through a three-tiered structure of data layer, service layer, and user portals & and application layer using programming languages as shown. The whole complies with Open Geospatial Consortium (OGC) standards for data communications. The roles of the selected components are reviewed in the following sections.

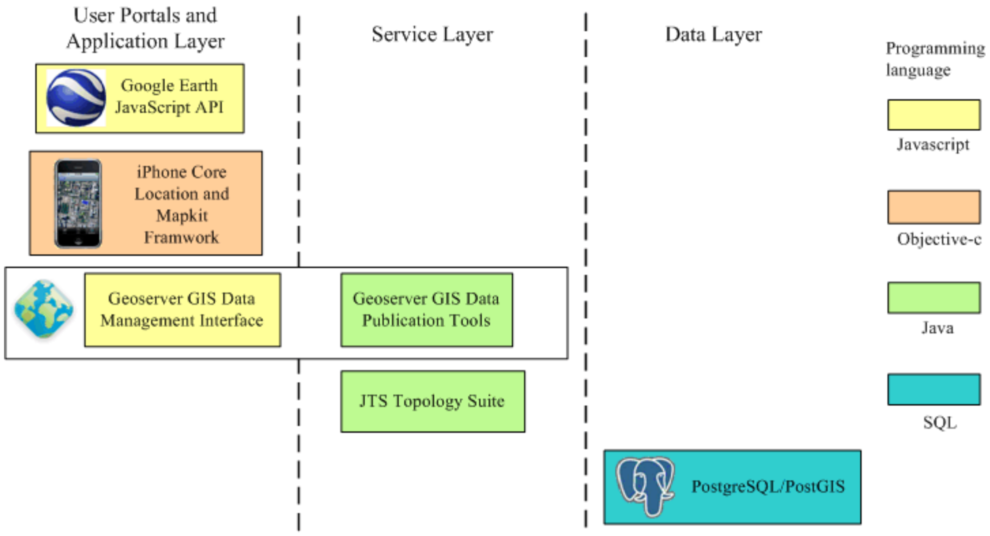


Figure 3.1 Programming language and applicable layer of each technology

3.2.1 Google Earth JavaScript API

Google Earth™ JavaScript API allows developers to integrate the full power of Google Earth™ and its 3D rendering capabilities into web pages (Google, 2008a). Google Earth™ then becomes a powerful and ready-to-use iFarming client providing rich geographic information, including terrain, satellite images as surface textures and supporting 3D model rendering. Additionally, since Google released the GEarthExtensions, which are used to create geometry objects and perform basic spatial analysis, the Google Earth™ JavaScript API has complied with the OGC protocol, KML. However, Google Earth™ JavaScript API does not support complex spatial analysis functions. Therefore, iFarming used Google Earth™ as a rich client in the presentation layer for spatial data visualization, with advanced spatial analysis being undertaken in the service layer.

3.2.2 iPhone Core Location and MapKit Framework

To give users more access to web map services, iPhone™ introduced Core Location and MapKit Frameworks into its software development kit (SDK). Core Location Framework provides real-time user’s location data; while the MapKit provides the

Google Maps service to the users. Communicating through the 3G network and using sophisticated modules in the server for complex spatial analysis, the original iPhone™ was extended, in iFarming, into a powerful and portable device allowing users to collect onsite data and request scientific knowledge. However, sending requests and obtaining responses from the web service server are broadband-consuming procedures. It was therefore necessary to restrict the size of the data sent back and forth through the 3G network. Consequently, iFarming processes the basic computing tasks locally before sending the request. For example, the built-in GPS readings are generated frequently. Instead of sending out all of the points data, the iPhone™ application extracts the valid readings to create polygon data using KML. This requires less bandwidth. The major data transmitted between iFarming and the server is constructed in KML format, which strictly complies with OGC standard.

3.2.3 GeoServer

GeoServer™ is an open source software product written in Java, which allows users to share and display geospatial data (GeoServer, 2010). GeoServer™ provides a friendly interface for users to upload and manage their GIS datasets, including Shapefiles, and databases such as ArcSDE™ and PostgreSQL™. It also supports output to many different spatial data viewers, including Google Earth™. Complying with OGC standards, and written in Java, GeoServer™ could be seamlessly integrated into iFarming as an important spatial data management module in the service layer.

3.2.4 JTS Topology Suite

JTS Topology Suite, written in Java, is an open source API of 2D spatial predicates and functions (Vivid-Solutions, 2010). It complies with OGC standards and provides complete and consistent 2D spatial algorithms for users to perform complex spatial analysis. iFarming uses this Java API as the core module of the service layer to manipulate the data transmitted back and forth between Google Earth™, iPhone™ Application, GeoServer™ and PostgreSQL™ Database.

3.2.5 PostgreSQL/PostGIS

PostgreSQL™ was chosen as the DBMS because it includes a powerful extension, PostGIS, to process some basic spatial analysis functions in the data layer, which considerably improves the efficiency of iFarming in terms of response to data requests from users. It can also work well under OGC standards, and provides a consistent database for the GeoServer™.

3.2.6 Spatial Interoperability Mechanism

Employing various spatial technologies discussed above could result in spatial interoperability issues. Spatial interoperability, according to the OGC Reference Model, refers to sharing spatial data and services among software applications (OGC, 2003), and this sharing process happens at different levels. In this section, the levels of interoperability are briefly introduced, and the necessary levels of interoperability of iFarming are also discussed.

3.2.7 Spatial Interoperability Levels

There exist six aspects of interoperability among the independent system components as illustrated in Figure 3.2. In increasing level of complexity these are*:* *Network Protocols, Hardware and OS, Spatial Data Files, DBMS, Data Model* and *Application Semantics* (Bishr, 1998). Bishr (1998) also proposed that these six levels of interoperability are hierarchical: the lower levels of interoperability must be achieved before reaching a higher level. The levels of *Data model* and *Application semantics* are the hardest to achieve (Bishr, 1998).

DBMS interoperability is already taken care of, as the iPhone™ application and Google Earth™ working as clients are accessing the same spatial-temporal database - PostgreSQL™. As discussed in the last section, heterogeneities of *Network Protocols, Hardware & OS* (iPhone™ vs. computer; iOS vs. Windows or Mac OS), and *Spatial Data Files* among the various spatial technologies restrict the spatial interoperability. Therefore, Geospatial Web Services are employed to resolve these heterogeneities.

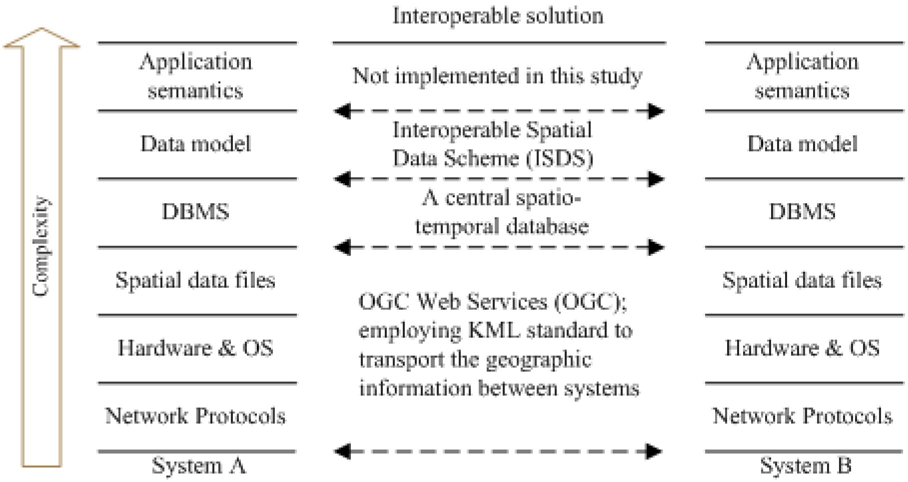


Figure 3.2 Spatial interoperability level and solution (based on Bishr’s (1998) work)

Meanwhile, designing appropriate data models in all these spatial technologies is important to ensure the communications are complete and fluent.

The heterogeneity of *Application Semantics* were not considered when designing iFarming; however, this interoperability issue does exist in a range of farming practices, especially in naming heterogeneity. This is one component of cognitive distance. When iFarming was applied in the case study (Section 4.2), I found that farmers have their own naming habits, which may be different to both widespread common names and to the scientific names, and this heterogeneity causes a lot of issues in communication between local farmers and scientists. A mechanism is proposed (Section 3.3.4) to deal with this naming heterogeneity, but this has not yet been implemented in iFarming.

In conclusion, there are five levels of spatial interoperability iFarming needs to achieve: *Network Protocols, Hardware* & *OS, Spatial data files,* and *Data model*. In the next sections, solutions of these interoperability issues are addressed.

3.2.8 OGC, GML and KML

Geospatial Web Services (GWS) is a services framework allowing various heterogeneous spatial information systems to share spatial data and services over a distributed network environment. Similar to Web Services defined by World Wide Web (W3C), it contains Service Requester and Service Provider, both of which acquire and provide services through sending Hypertext Transfer Protocol (HTTP) requests and returning XML serializations. OGC Web Service (OWS) is one of the most popular GWS in the GIS community. It provides developers the guidance to establish the application interface for spatial data and services sharing, where heterogeneities of *Network Protocols* and *Hardware & OS* are solved by adapting the open non-proprietary Internet standard –HTTP (OGC, 2010).

OGC has also released a specification for modelling, transporting and storing the geographic information, which is known as Geography Markup Language Encoding Standard (GML). GML, according to OGC (2011a), is an XML grammar for expressing spatial and non-spatial properties of geographic feature. As GML is able to transport the geographic information between different spatial systems, researchers adopted it as the XML standard for web services. In the study by Zhang et al (2007), a distributed virtual geographic environment system was designed based on the framework of OWS and GML encoding standard, which allows different platforms and programming languages to communicate and share data and services.

KML (Keyhole Markup Language), adopted by OGC since 2007, is a complement of GML, and its initial purpose was defining geographic objects and their graphical representation (OGC, 2011b). KML has been popular for presenting geographic information since the release of Google Earth™, which has become one of the most common geographic data viewers.

GML and KML serve different goals. The former is focusing on describing the geographic information, while the latter is focusing on how to present the geographic information on an earth viewer. GML needs to contain two parts in its grammar, the *schema* to describe generic geographic data sets, e.g., a road schema indicates the *document* is containing the road data instead of lines, and the *document* to contain the actual data. A GML solution is made more complex and perhaps more error prone by the definition of the *schema* and the need to exchange the *schema* between different systems. For example, when a *schema* is changed by one system (e.g., the units of data), others should be notified and the corresponding native data model should also be updated to correctly interpret the *document*. Moreover, as GML tries to describe all of the geographic information in one standard, GML itself is too big to be integrated into the iFarming programming, e.g., there are few APIs available for Java to wrap and parse GML data. By contrast, KML is a lightweight standard, which is supported by several Java APIs, such as JAK™, Gekmlib™ and Kmlframework™. Adopting these APIs in the programming stage facilitated the development.

Even though KML is a light weight standard, it can still store, transport and describe geographic information. KML provides two ways to add custom data to a geographic feature and display them on Google Earth™ (Google, 2008b): 1) <Data> element for untyped data, and 2) <Schema> and <Schema Data> for typed data. Different to GML, where *schema* and *document* are stored in two files, KML's typed data solution contains *schema* and *schema data* in only one file, which avoids the additional exchange of *schema* during data transfer.The untyped data is relatively easy to implement, but, unlike typed data, does not indicate the type of the data, such as String, Integer, or Boolean. This study employs untyped data rather than typed data for the KML objects, because: 1) objects are mapping in various languages from various components of iFarming and data types are explicit within the languages; 2) the <Schema> of typed data increases the bandwidth required, which is especially important when transferring to or from a mobile device.

This research employs the framework of OWS, and uses KML standard to transport the XML data between systems to solve the heterogeneities of *Network Protocols* and *Hardware & OS*.

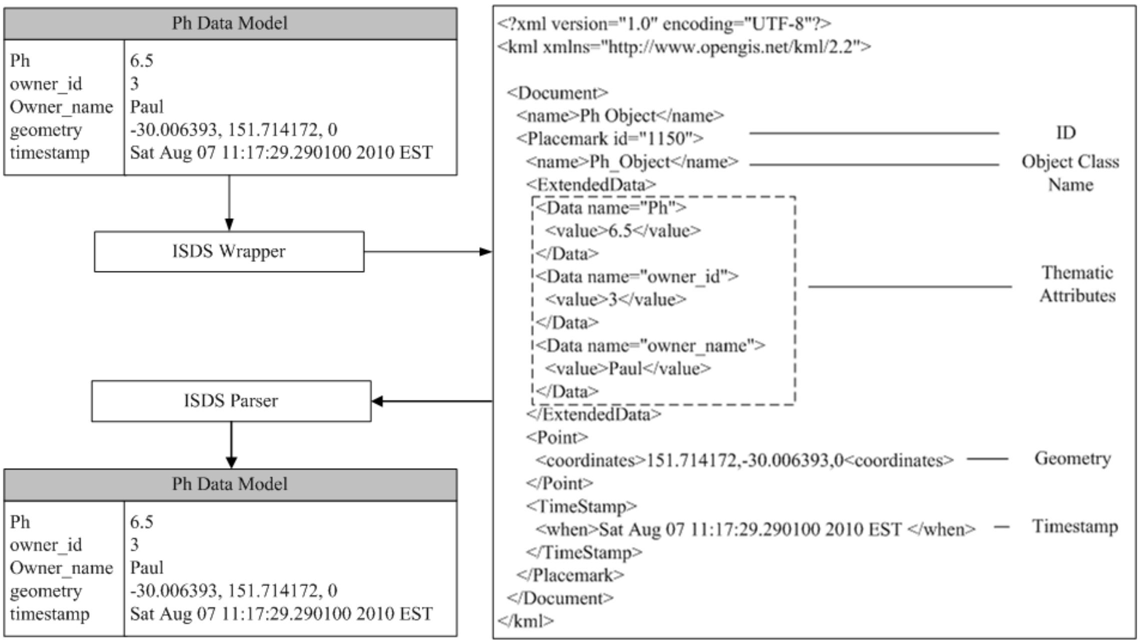
3.2.9 Define Interoperable Spatial Data Scheme (ISDS)

Usually objects in the real world are represented using 3-tuples {thematic attributes, geometrics attribute, ID} or {T, G, ID} (Bishr, 1998). As this research is including time-related events, and recording temporal data, the data model is extended to {T, G, ID, Time}, where Time marks when the object or event is recorded on the server, i.e. its timestamp.

To ensure that the definition of each object is consistent in the various components of iFarming, one-to-one mappings are required, e.g., the data model of object EM38 (Electromagnetic-Induction Measurement to estimate average rootzone salinity (Slavich & Petterson, 1990)) should be synchronously defined as an Object Class in the iPhone™ application, Google Earth™ Javascript, GeoServer™, and PostgreSQL™ database. This ensures that the object information, such as the measurement unit of the data, is consistent between components.

Even though the data models, in the form of object classes, are consistent in various components, there still exists a restriction when exchanging the data due to the internal data formats and external network protocols. Therefore, this research employs the KML standard to model, store and transport these object classes from different spatial systems.

A mapping scheme for assigning these *Data Models* to a standard KML serialization was designed, and is called the Interoperable Spatial Data Scheme (ISDS). The ISDS not only helps the conversion from a Data Model to a KML serialization, but also parses the KML serialization to a corresponding Data Model. Therefore, a set of tools, ISDS Wrapper and ISDS Parser were designed to perform the above procedures. Figure 3.3 demonstrates the work flow of wrapping and parsing of the pH Object with the help of ISDS tools.



Ph Data Model	
Ph	6.5
owner_id	3
Owner_name	Paul
geometry	-30.006393, 151.714172, 0
timestamp	Sat Aug 07 11:17:29.290100 2010 EST

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2">

  <Document>
    <name>Ph Object</name>
    <Placemark id="1150">
      <name>Ph_Object</name>
      <ExtendedData>
        <Data name="Ph">
          <value>6.5</value>
        </Data>
        <Data name="owner_id">
          <value>3</value>
        </Data>
        <Data name="owner_name">
          <value>Paul</value>
        </Data>
      </ExtendedData>
      <Point>
        <coordinates>151.714172,-30.006393,0<coordinates>
      </Point>
      <TimeStamp>
        <when>Sat Aug 07 11:17:29.290100 2010 EST </when>
      </TimeStamp>
    </Placemark>
  </Document>
</kml>
```

Ph Data Model	
Ph	6.5
owner_id	3
Owner_name	Paul
geometry	-30.006393, 151.714172, 0
timestamp	Sat Aug 07 11:17:29.290100 2010 EST

Figure 3.3 ISDS Work Flow of pH Object

This Interoperable Spatial Data Scheme (ISDS), instead of employing a typed data format, which includes various data types recognized by GIS programs (Google, 2008b), uses an untyped data format to carry the thematic attributes. Even though the

ISDS doesn’t indicate the data types of the thematic attributes, the data receivers, various spatial technologies in this context, still can identify the data type based on the object class defined within them.

Through unambiguously defining the ISDS of each object, the spatial interoperability level of *Data Model* was achieved. Moreover, as ISDS was working as data translator among the spatial technologies, the heterogeneity of *Spatial Data Files* was also solved through converting various data files to a standard format, e.g., the spatial data file Shapefile was converted to ‘Geometry’ data type in PostgreSQL™, and afterwards translated into standard KML format according to ISDS.

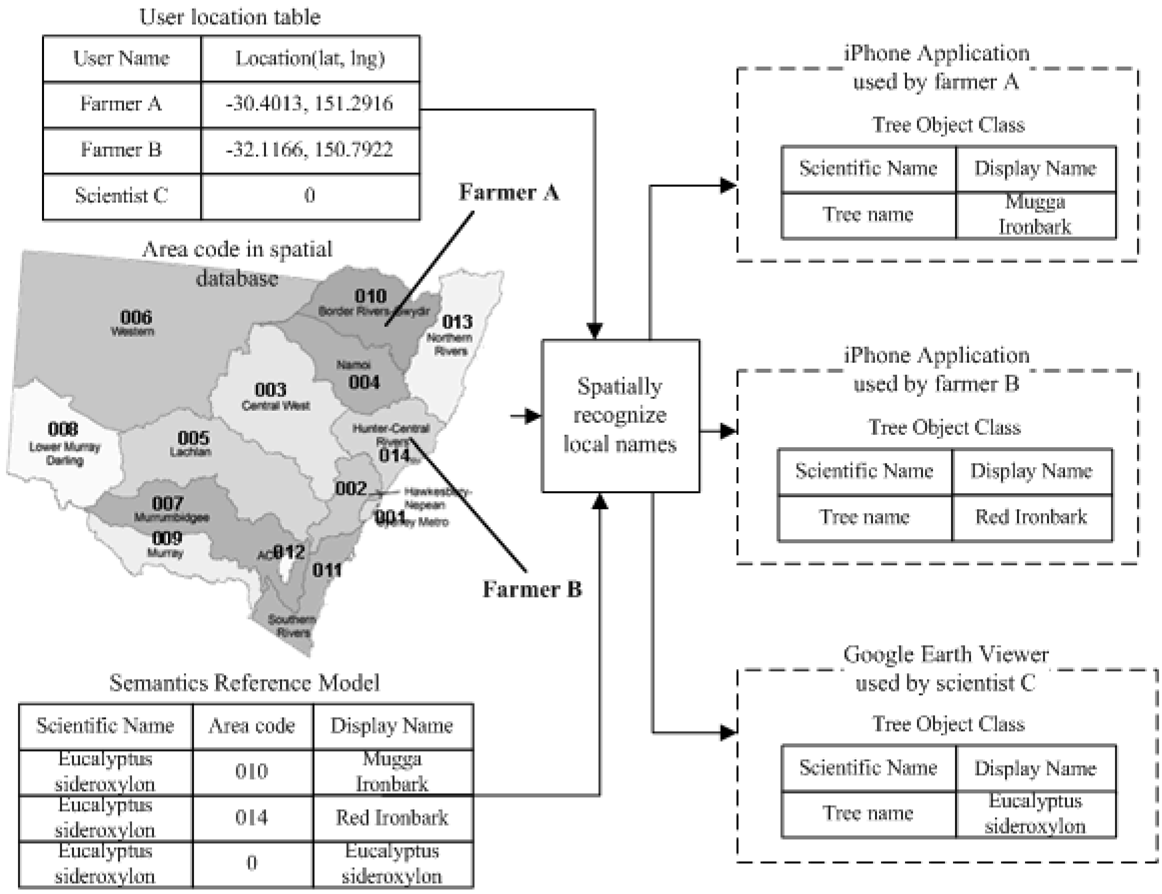
3.2.10 Spatially Intelligent Naming Mechanism (SINM)

The semantic issue does not become significant until other aspects of interoperability have been solved. A possible solution was provided for the semantics issue but this has not been implemented because of its complexity and the shortage of necessary information, e.g., lack of a complete spatial database for taxonomic synonyms.

As the iPhone™ application is designed to be used by farmers who are distributed geographically and seldom have the specialized knowledge of the scientists, the heterogeneity of *Application Semantics* is mainly in the area of Naming Heterogeneity (Bishr, 1998), in which a particular real world concept or entity might be named differently, e.g., soil moisture (understood by farmers) and EM38 (scientific shorthand for moisture interpreted from electro-magnetic data) are two names describing the same thing.

To solve this semantics issue, a Spatially Intelligent Naming Mechanism (SINM) was designed to map the two names with the same Object Class, and ensure the appropriate name is displayed to the corresponding user interfaces. Figure 3.4 demonstrates how the SINM would deal with the Naming Heterogeneity of three different user interfaces.

The user location table records the user's location when they log into the system. Through spatially searching these locations in the area code data table, the corresponding area code of each user can be retrieved. After looking for the corresponding local names (e.g. common name for tree species) in the semantics reference model in the database according to the scientific name and area code, each user could receive the corresponding local names and scientific names. The SINM ensures the scientist and farmers are discussing the same object even though it has different names for different users in different parts of the distributed area. Farmers normally participate in local communities to transfer local experiences, and these communities are organized by local authorities (such as catchment management authorities or local government areas). The area code proposed in this research is therefore relying on the formation of corresponding communities. Moreover, through offering object's scientific name when providing corresponding local name, iFarming would enable individual users to move towards semantic homogeneity in the long term.



User location table

User Name	Location(lat, lng)
Farmer A	-30.4013, 151.2916
Farmer B	-32.1166, 150.7922
Scientist C	0

Semantics Reference Model

Scientific Name	Area code	Display Name
Eucalyptus sideroxylon	010	Mugga Ironbark
Eucalyptus sideroxylon	014	Red Ironbark
Eucalyptus sideroxylon	0	Eucalyptus sideroxylon

iPhone Application used by farmer A — Tree Object Class

Scientific Name	Display Name
Tree name	Mugga Ironbark

iPhone Application used by farmer B — Tree Object Class

Scientific Name	Display Name
Tree name	Red Ironbark

Google Earth Viewer used by scientist C — Tree Object Class

Scientific Name	Display Name
Tree name	Eucalyptus sideroxylon

Figure 3.4 Spatially Intelligent Naming Mechanism assigning names into three user interfaces

There is a precedent for this approach. CBIF (Canadian Biodiversity Information Facility) (2011) has an Integrated Taxonomic Information System (ITIS) for maintaining taxonomic synonyms of species. This system also indicates the distribution of taxonomic species. While this is not sufficiently detailed for our application, setting up a spatially intelligent naming database, where synonyms are marked with geographic locations and corresponding area codes, is central to implementing a practical SINM.

However, the farmers naming habits may also still vary for reasons of history or geography, so the spatially intelligent naming mechanism needs further research.

In the next section, I describe how these various interoperability mechanisms were integrated into the framework of iFarming, to allow various spatial technologies to work harmoniously together.

3.3 Implementation of the system

One of the objectives of iFarming is to assist farmers, consultants and scientists to transfer knowledge. This includes two facets: real-time knowledge transfer and non-real-time knowledge transfer. The former is used in the context of farmers reporting on-site issues, with distant consultants or scientist providing immediate solutions; while the latter is used in the context of scientists analysing and publishing knowledge, and farmers and consultants accessing the published data. As iFarming is a multi-client system and it provides real-time data transfer support, the framework is based on a three-tier structure as detailed in Figure 3.5.

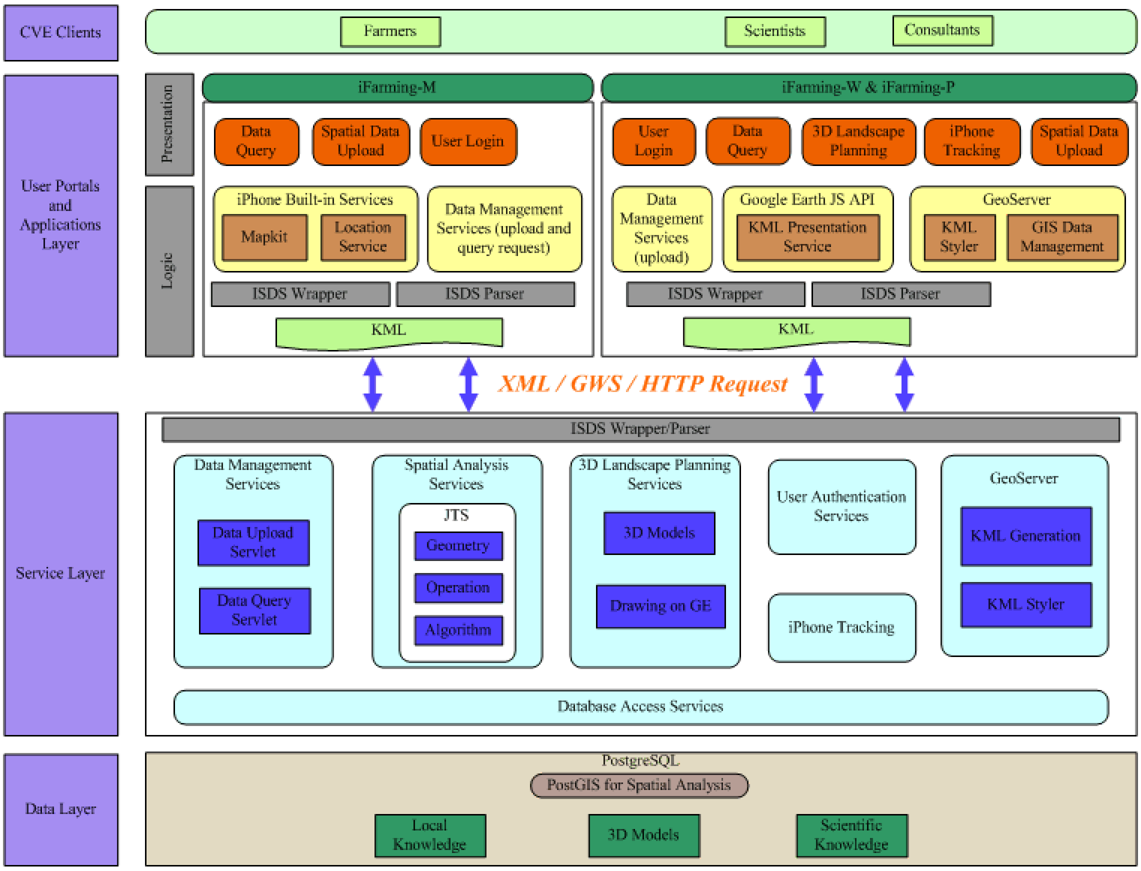


Figure 3.5 System Framework of iFarming

3.3.1 Data Layer

The data layer is the foundation of the KMS, containing a spatio-temporal database, which is built on PostgreSQL™. A PostGIS extension was installed to enrich the spatial capability of PostgreSQL™, to support basic topology, data validation and coordinate transformation (PostGIS, 2010).

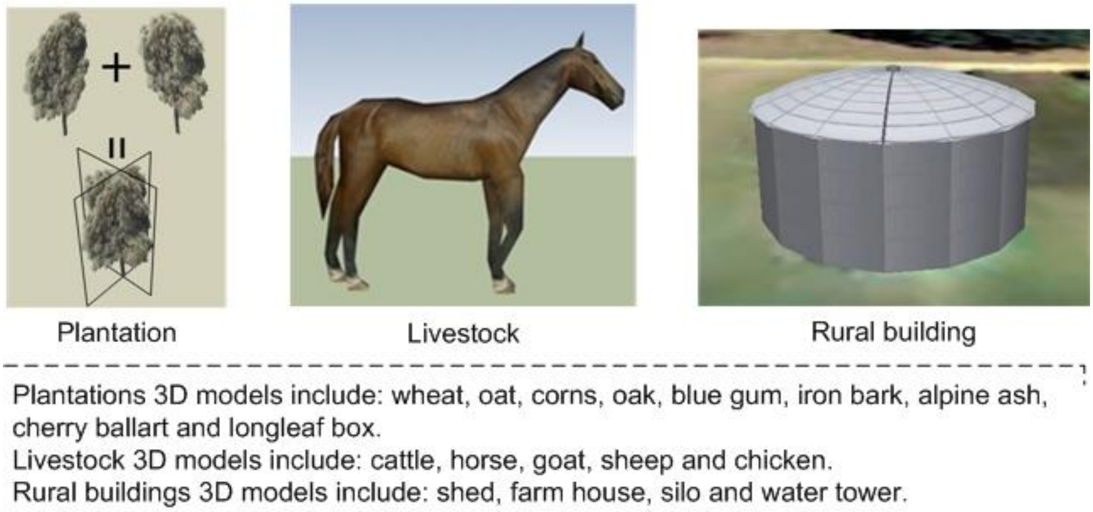
According to the data requirements of iFarming, there are three kinds of data tables: 3D models, scientific knowledge, and local knowledge. The 3D models table stores the 3D models of the plantations, livestock and rural buildings. These models can be added into KML files for visualization. Scientific knowledge stores the data uploaded by scientists or consultants, while local knowledge stores the data uploaded by farmers, who use iPhone™ application to upload images, point data, and polygon data. Both scientific knowledge and local knowledge contain time dimensions, as timestamps stored in each record.

3.3.1.1 3D models

The main advantage of iFarming is to provide users with a shared 3D virtual world. For rural area visualization, iFarming adopts three kinds of 3D models, plantations, animals, and rural buildings.

Along with the development of the 3D visualization technologies, design tools, such as Google SketchUp™ have become available and easy to use. As such, large numbers of 3D models have been produced and shared online. Among these, Google 3D Warehouse™ is one of the most active service providers. The 3D models are available in several different formats, including SketchUp, Collada, and KMZ file. SketchUp file is used for storing the raw data of the 3D model, but is not able to be directly visualized in Google Earth or integrated into the KML file. KMZ file, which is a compressed archive of a KML file, can be visualized directly on Google Earth (Google, 2008a). Collada is a XML schema that contains a 3D model file .dae, and associated texture images (COLLADA, 2011). KML supports the integration of Collada. As iFarming uses

KML as the data standard to visualize 3D models, integrating additional KMZ models into the KML file would possibly increase the size of the transferred data. Therefore, Collada was chosen as the 3D model format stored in the database and ready to be carried by KML to present a 3D scene. Figure 3.6 shows three kinds of 3D models used in iFarming. The external 3D model repositories, e.g., Google 3D Warehouse™ allow extending iFarming's 3D model database.



Plantations 3D models include: wheat, oat, corns, oak, blue gum, iron bark, alpine ash, cherry ballart and longleaf box.
Livestock 3D models include: cattle, horse, goat, sheep and chicken.
Rural buildings 3D models include: shed, farm house, silo and water tower.

Figure 3.6 3D models for visualization

3.3.1.2 Scientific knowledge

Scientific knowledge is built on information which may be available in various data formats and projection systems as illustrated in Table 2.3. Currently iFarming only accepts .shp (vector data), .asc and .tif (raster data) as the data formats for uploading to the database (Figure 3.7). It uses WGS84 as the unified projection system for data conversion. A process was designed for performing uploading (Figure 3.7). The main steps include: 1) converting the vector data to unified data formats, 2) uploading these data to the data server through FTP, 3) using PostGIS™ data processing plug-in, converting .shp files to 'Geometry' data type of PostgreSQL™ and storing into the database, 4) publishing vector and raster data through GeoServer™ publisher which can automatically recognize the projection system of the data, and 5) generating KML with the projection system of WGS84 when clients request this data. This information, which then forms part of the body of scientific knowledge, not only includes the knowledge from scientists, but also consultants.

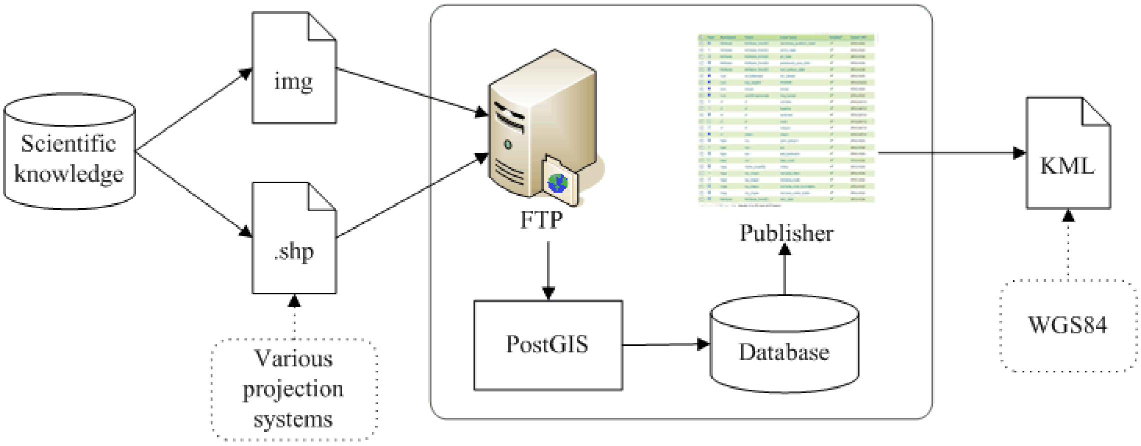


Figure 3.7 Scientific knowledge storage and retrieval

3.3.1.3 Local knowledge

Local knowledge includes knowledge from both farmers and consultants. As addressed in Table 2.3, most farmers use maps, diaries and ordinary computer softwares such as Excel™ to manage their farming records, while consultants use more advanced software, such as MapInfo™. iFarming provides an additional iPhone™ application to assist recording and retrieving the in-field data as illustrated in Figure 3.8. The main steps in collection and storage are: 1) collecting point or polygon data, 2) generating KML with projection system of WGS84, 3) sending the KML file to data server for converting to geometry data type of PostgreSQL™ and store into the database. The processes of data publishing and KML generating are the same for the scientific knowledge.

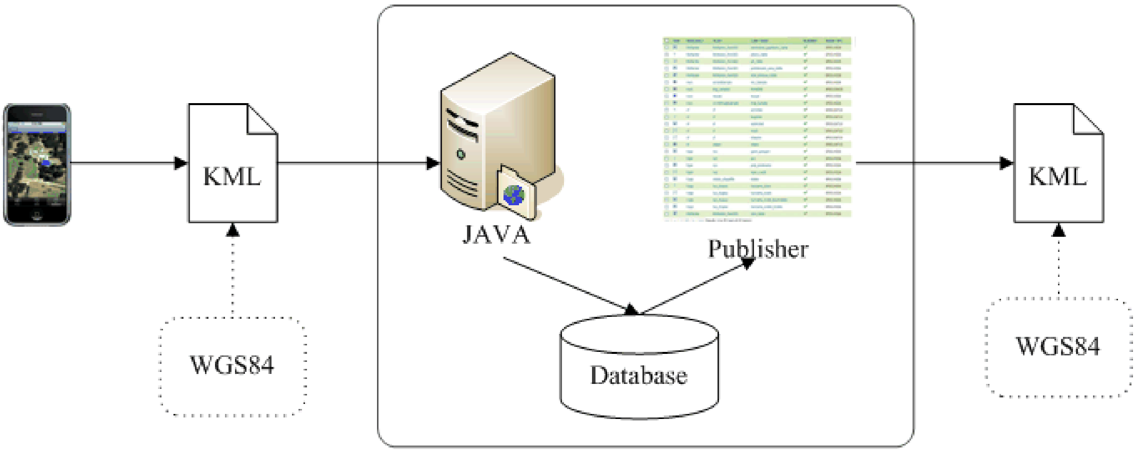


Figure 3.8 Local knowledge storage and retrieval

3.3.2 Service Layer

The Service Layer is the core of iFarming. This layer includes the services described below:

- Two basic servlets based on SOAP (Simple Object Access Protocol) to process the XML data transferred between different components, return KML serializations to the service requester and save corresponding spatial data into the database. The service requester encapsulates the KML serialization in the <soap:Body> tag. Then the service responder parses the information through JAK™'s Java API for KML.

- Spatial analysis modules of JTS enable various spatial analyses including Contains and Buffer Analysis, to assist user in-field authorization and geospatial data query. For example, in addition to the password protection, a farmer is not allowed to login through the iPhone™ application if he is outside his own property, so that the data of each farm are secured and privacy is protected. However, this in-field authorization mechanism turned out to be inappropriate in the case study presented in Chapter 4, given that farmers are still able to access data from other properties through iFarming-W. The privacy issue is reviewed further in Section 5.4.2. Geospatial data query service allows users to query the spatial data according to area, and cluster the data in an organized KML structure. The detailed procedure is described in the next section.

- 3D landscape planning service enables generation of KML to represent a farm management scenario in 3D. This service calculates the planning area, retrieves corresponding 3D models and builds up a KML for representation. The 3D landscape planning function is presented in next section.

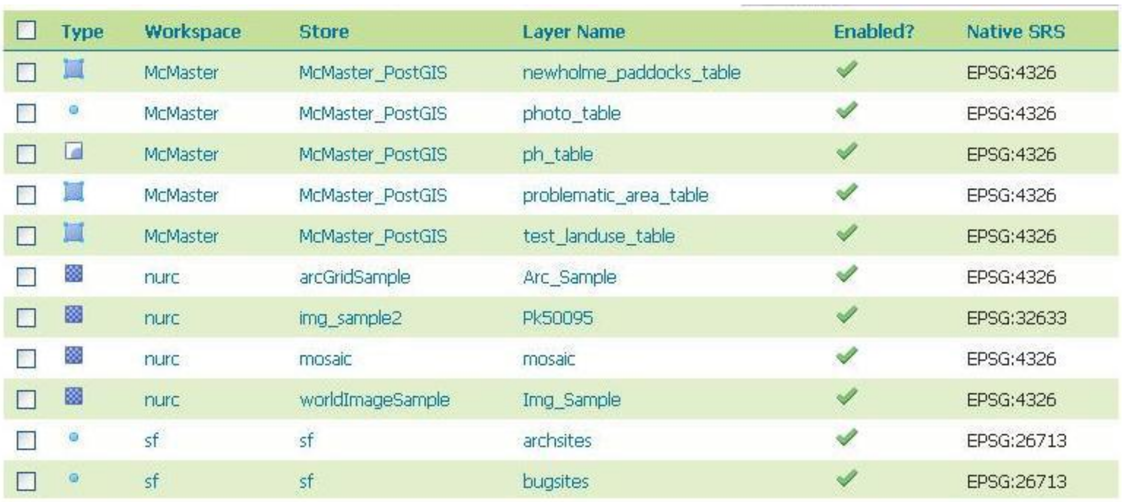
- GeoServer™ service enables users to upload, publish and symbolize the spatial data. This service also builds up a KML based on the users query criteria, which defines the area of interest and the style of the representation.

3.3.3 User Portals and Application Layer

As addressed in Table 3, users of iFarming have different working environments and computer skills, so iFarming provides three user-interfaces, an online data publisher (iFarming-P), a web portal (iFarming-W) and an iPhone™ application (iFarming-M).

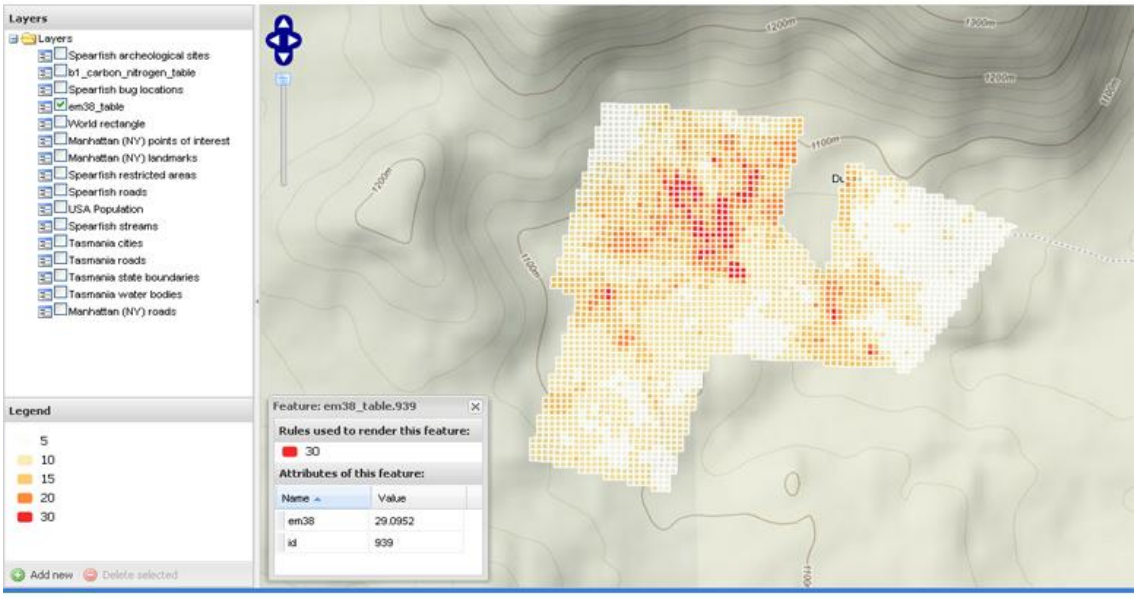
3.3.3.1 iFarming-P

As described above, iFarming provides a user-interface for data conversion and storage, which is called iFarming-P. It comprises a FTP server for uploading data, a Java server for receiving data from iFarming-M, and a data publisher for selecting uploaded data to display on iFarming-W. In Figure 3.9, uploaded data is displayed under the data store (in this case, McMaster_ PostGIS), which was defined previously in iFarming-P to link the database for displaying all the local geographic data. The layer name indicates their data table names and the tag of Native SRS (Spatial Referencing Systems) indicates the projection system the data is using. The styler is used to customize the presentation style of each data layer. User can change the colour of the points, lines, and polygons. Moreover, rendering rules can be set to features, e.g., features above certain value should be rendered in red. Accordingly, these changes can impact the data appearance in the data viewer, iFarming-W.



☐	Type	Workspace	Store	Layer Name	Enabled?	Native SRS
☐	▦	McMaster	McMaster_PostGIS	newholme_paddocks_table	✓	EPSG:4326
☐	●	McMaster	McMaster_PostGIS	photo_table	✓	EPSG:4326
☐	◪	McMaster	McMaster_PostGIS	ph_table	✓	EPSG:4326
☐	▦	McMaster	McMaster_PostGIS	problematic_area_table	✓	EPSG:4326
☐	▦	McMaster	McMaster_PostGIS	test_landuse_table	✓	EPSG:4326
☐	▩	nurc	arcGridSample	Arc_Sample	✓	EPSG:4326
☐	▩	nurc	img_sample2	Pk50095	✓	EPSG:32633
☐	▩	nurc	mosaic	mosaic	✓	EPSG:4326
☐	▩	nurc	worldImageSample	Img_Sample	✓	EPSG:4326
☐	●	sf	sf	archsites	✓	EPSG:26713
☐	●	sf	sf	bugsites	✓	EPSG:26713

Data category in data publisher



Layers

Layers
- ☐ Spearfish archeological sites
- ☐ b1_carbon_nitrogen_table
- ☐ Spearfish bug locations
- ☑ em38_table
- ☐ World rectangle
- ☐ Manhattan (NY) points of interest
- ☐ Manhattan (NY) landmarks
- ☐ Spearfish restricted areas
- ☐ Spearfish roads
- ☐ USA Population
- ☐ Spearfish streams
- ☐ Tasmania cities
- ☐ Tasmania roads
- ☐ Tasmania state boundaries
- ☐ Tasmania water bodies
- ☐ Manhattan (NY) roads

Legend

⬜	5
🟨	10
🟧	15
🟧	20
🟥	30

Feature: em38_table.939

Rules used to render this feature:

🟥 30

Attributes of this feature:

Name ▲	Value
em38	29.0952
id	939

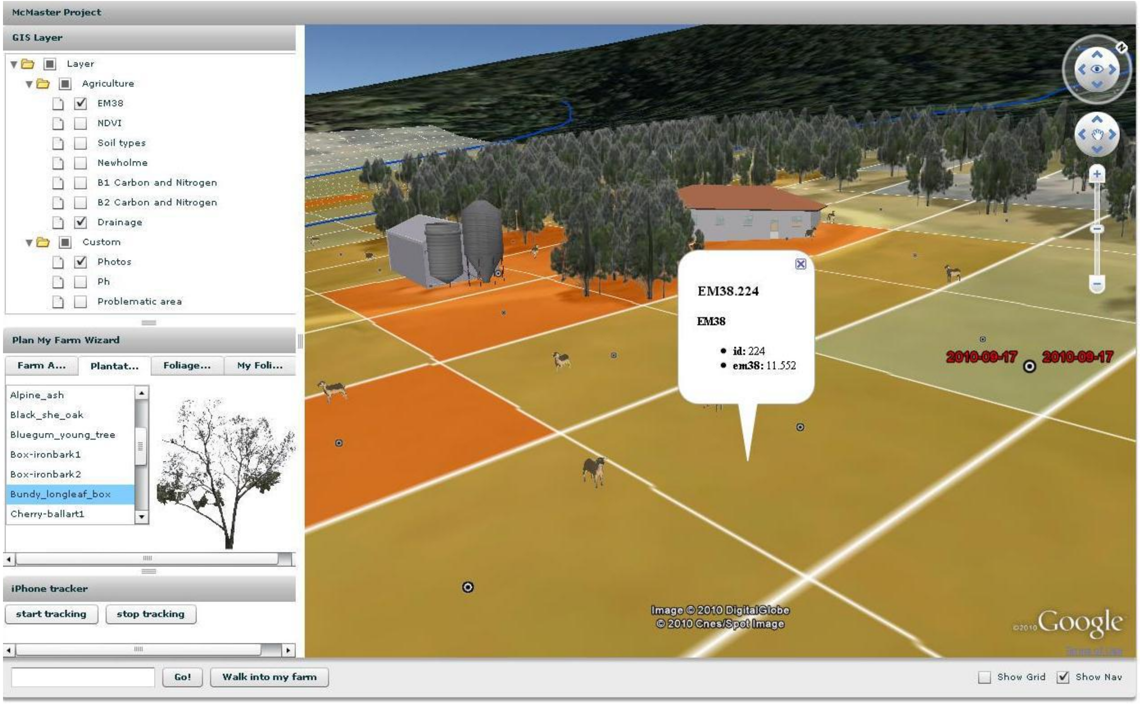
Styler in data publisher

Figure 3.9 Data category and styler in iFarming-P

3.3.3.2 iFarming-W

iFarming-W employs Google Earth™ JavaScript API as the core. The major functions include: (1) visualization of spatial data, (2) a module called ‘Plan my farm wizard' to select 3D models to distribute on Google Earth™, and (3) a module to track the iFarming-M user's location.

As illustrated in Figure 3.10, 'GIS Layer' lists the data category published by iFarming-P. By selecting these layers, data can be visualized on Google Earth™ with customized presentation style. By clicking on the points, polylines or polygons on the virtual world, corresponding content of the data layer is displayed.



Layer
- Agriculture
  - ☑ EM38
  - ☐ NDVI
  - ☐ Soil types
  - ☐ Newholme
  - ☐ B1 Carbon and Nitrogen
  - ☐ B2 Carbon and Nitrogen
  - ☑ Drainage
- Custom
  - ☑ Photos
  - ☐ Ph
  - ☐ Problematic area

EM38.224

EM38

- **id:** 224
- **em38:** 11.552

☐ Show Grid ☑ Show Nav

Figure 3.10 iFarming-W interface

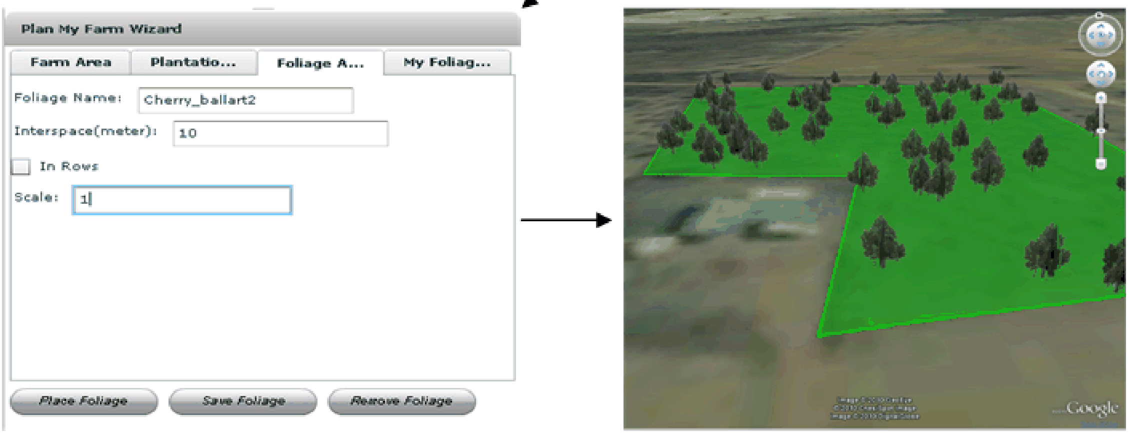
Using the network link technology, once iFarming-M uploads in-field data to the data server; the updated data is immediately displayed on iFarming-W For example, when a farmer using iFarming-M takes a photograph of a diseased plantation and uploads to the server, the photo would be automatically displayed in iFarming-W for consideration by a consultant. Through this seamless data transfer procedure, the in-field user can transfer data, as an image in this case, to the distant user to diagnose and provide instant feedback. This process will be further illustrated through the case study in the next chapter.

The "Plan my farm wizard" module allows users to simulate their farm on Google Earth™ using four simple steps, which are shown in Figure 3.11. The virtual farm assists users to have a clearer idea of the properties. It reflects the numbers of livestock, the variety and density of the plantations, and even the facilities on the farm. The usage of the virtual farm is addressed in the next chapter.

Alpine_ash
Black_she_oak
Bluegum_young_tree
Box-ironbark1
Box-ironbark2
Bundy_longleaf_box
Cherry-ballart1

1) Draw planting area

2) Choose tree model



Foliage Name: Cherry_ballart2
Interspace(meter): 10
☐ In Rows
Scale: 1

3) Fill attributes (interspace and scale)

4) Plant the trees

Figure 3.11 Four steps to distribute 3D models on Google Earth™

The iFarming tracking module enables iFarming-W to display the location of the iFarming-M user in real time. It is useful for a virtual farm management meeting, allowing office-based users to know where the in-field user is and guide him to the spots of interest.

3.3.3.3 iFarming-M

The design of a user-friendly mobile application for less science-trained users, such as farmers, is one of the challenges of this research. Through two visits to the pilot site and interviews with the farmers who run the properties, we summarized the requirements as:

- An extra handheld device would be a burden in the daily farming practice; a mobile phone with sufficient functionality is preferred.

- Data query and data upload are necessary to support daily farming practices. Complex data query and upload procedures are not preferred, e.g., drawing on a map to query data, and uploading data to the drawn area.

- The uploaded data can be later viewed at home to allow tracking the events.

Based on these requirements, I compared various popular smartphone platforms (PCMagazine, 2010a) in the market (Table 3.1) to select the proper mobile platform for development. As Smartphone’s functionalities mainly rely on its mobile operating system (MOS), this comparison focused on the differences of each MOS. It only compared features related to the requirements.

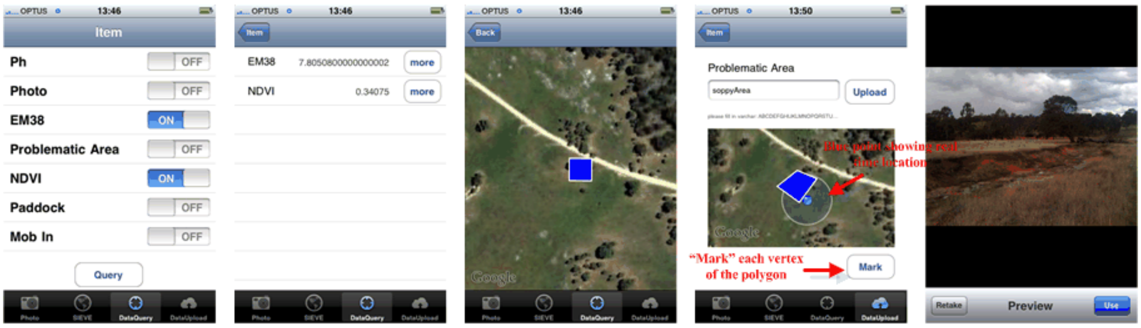
Table 3.1 Comparison between different smartphone platforms

MOS	GPS	Display Size	Camera	Other
Apple’s iPhone OS	Y	3.5" 640 ×960	Y	digital compass
Google’s Android	Y	variable	Y	digital compass
Nokia’s Symbian	Y	variable	Y	variable

BlackBerry's RIM	Y	variable	Y	variable

As Android, Symbian and RIM have different hardware configurations, some mobiles may lack digital compass, which is important in indicating the in-field photos' directions. Moreover, the variations of display size require a developer to adjust the mobile application according to hardware condition, which can possibly cause the failure of display and increase development time. Therefore, this research selected iPhone as the mobile platform.

Four main functions were developed: (1) query spatial data, such as point or polygon data, according to the user's location, (2) take photographs with location information and upload these to the server, (3) collect onsite data, including point data and polygon data, and (4) send GPS data to the server to allow iFarming-W to display the location of an iFarming-M user in real time. Figure 3.12 illustrates the functionalities of the iPhone™ application.



Ph OFF
Photo OFF
EM38 ON
Problematic Area OFF
NDVI ON
Paddock OFF
Mob In OFF

EM38 7.8050800000000002 more
NDVI 0.34075 more

Problematic Area
soppyArea

Data list

Data query result showing attribute

Data query result showing area

Polygon data upload

On site photo upload

Figure 3.12 iFarming-M functionalities

Data category:

As in iFarming-W, iFarming-M lists the layers published by iFarming-P. It should be noticed that some data layers are readable only, such as EM38 and NDVI. These data layers are scientific knowledge, which would be uploaded only by a scientist or consultant.

Data query:

Switching on the data layers, user can query the content of each of them. As illustrated in Figure 3.12, when EM38 and NDVI are selected their values at the current location are displayed. Even though these data layers, such as pH, photo, EM38 and problematic area, are not physically linked together in the database, they are linked together implicitly by location. When users query multiple layers on the same location (Figure 3.12), the data will be reported together.

Besides displaying the value of each layer, through pressing the 'more' button following the value, the corresponding geographic feature can be displayed on Google Maps™. This spatial analysis function is supported by the service layer (Figure 3.13). The server 1) obtains the request from iFarming-M, 2) analyses the user location and layer of interest to generate a query in SQL, 3) uses spatial analysis module to calculate the results, and 4) ultimately constructs a KML to send back to iFarming-M for display.

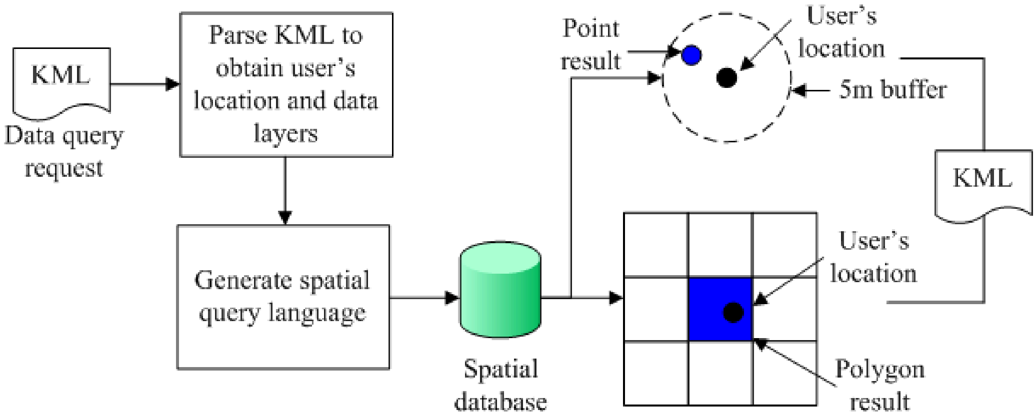


Figure 3.13 Spatial analysis for data query

Data upload:

Data upload is the core function of iFarming-M. It enables users who lack advanced computer skills to contribute their local knowledge to the server, or to share issues of immediate concern. It contains two main divisions, photograph upload and spatial data upload.

As illustrated in Figure 3.12, when the user takes a photograph, iFarming-M extracts the real-time user's location, orientation and timestamp, and sends the KML file, together with the image, to the server for data conversion and storage. Once database is populated with a new photograph record, an icon indicating the location of the photograph is automatically displayed in iFarming-W for a distant user to review.

Spatial data upload supports two types of geographical data, point and polygon. The first step is to select a data layer in the data category. When the data layer is writable, iFarming-M analyses its geographic type and provides either a point data upload interface or a polygon data upload interface. For example, if user selects pH data layer, which is a point feature, iFarming-M would allow user to enter the pH value of the specific location where they are situated and have taken the pH measurement. When the 'upload' button (Figure 3.12) is pressed, the pH value tagged with location information is sent to the server for processing and storage. If user selects Problematic Area data layer, iFarming-M will provide the interface shown as the fourth image in Figure 3.12. The user firstly marks the initial point on the boundary of the area, secondly walks or drives around the exterior of the area and marks the vertices, and finally finishes the polygon and enters text to indicate the problem. After pressing the 'upload' button, iFarming-M constructs a KML enclosing the polygon information and value, and sends this to the server for processing and storage.

iFarming-M tracking:

iFarming-M tracking allows a distant iFarming-W user to track the real-time location of the iFarming-M user. iFarming-M sends the location information every 2 seconds, the database stores the latest location of the iFarming-M user and presents a dynamic icon on the Google Earth™ view in iFarming-W.

3.4 Conclusion

Based on the system requirements discussed in Chapter 2, this chapter designed and implemented a prototype system, iFarming. The main achievements include 1) a spatial interoperability mechanism which allows multiple spatial technologies to work together, to save considerable development time, and 2) three user-interfaces meeting needs from three different user groups, to achieve the new paradigm for distributed communications. Even though the spatial interoperability mechanism has solved the heterogeneity issues of *Network Protocols, Hardware* & *OS*, *Spatial data files*, and *Data model*, the *application semantics*, which was regarded as the hardest heteogeneity to achieve, remain unsolved.

4. Testing the New Paradigm

This research argued DKM could be more effective through implementing a new communication paradigm (Figure 2.6), where users' geographical and cognitive distances were both reduced. The prototype system, iFarming was designed to achieve such requirement. To test the functionality and as a field assessment of the strengths and deficiencies of iFarming, a case study was carried out in Armidale, NSW in August 2010. A farmer, an agricultural consultant and a scientist were invited to participate in this application, and to complete a survey about their experiences. This group of users has provided testing and feedback related to four specific functions:

1. publishing scientific knowledge using iFarming-P,
2. creating a 3D landscape based on reality or future options,
3. uploading and querying local knowledge using iFarming-M,
4. interacting with the 3D scenario using iFarming-W, to review the uploaded knowledge and communicate with distant users to solve specific problems.

Afterwards a group of people, 4 farm managers, 2 academic staff, 1 consultant, and 2 students studying agronomics were invited to a workshop for demonstrating this case study to gain feedback on whether or not the new communication paradigm of agricultural knowledge management can be achieved with the support of iFarming. Both academic staff were regarded as scientists, as they were dedicated to developing new methods or devices for precision agriculture.

The feedback from both of these groups is summarized and analysed in this Chapter.

4.1 Introduction of case study area

The pilot area was a farm, Newholme, located near Armidale, NSW. Newholme has an area of 1200 hectares: approximately one third of the area is forested, a third is woodland, and the remainder is pasture for grazing (Figure 4.1). The main livestock in this area are beef cattle and sheep, and these provide the majority of economic income for the region. At present, the property is under the management by a farmer we will call Paul. John is an agricultural consultant hired to assist in transferring the latest scientific knowledge to the farmers. Patrick was the scientist for this case study. Patrick contributed his special expertise in the use of EM38 surveying, which is used to measure the conductivity of the soil layers to obtain the soil moisture.

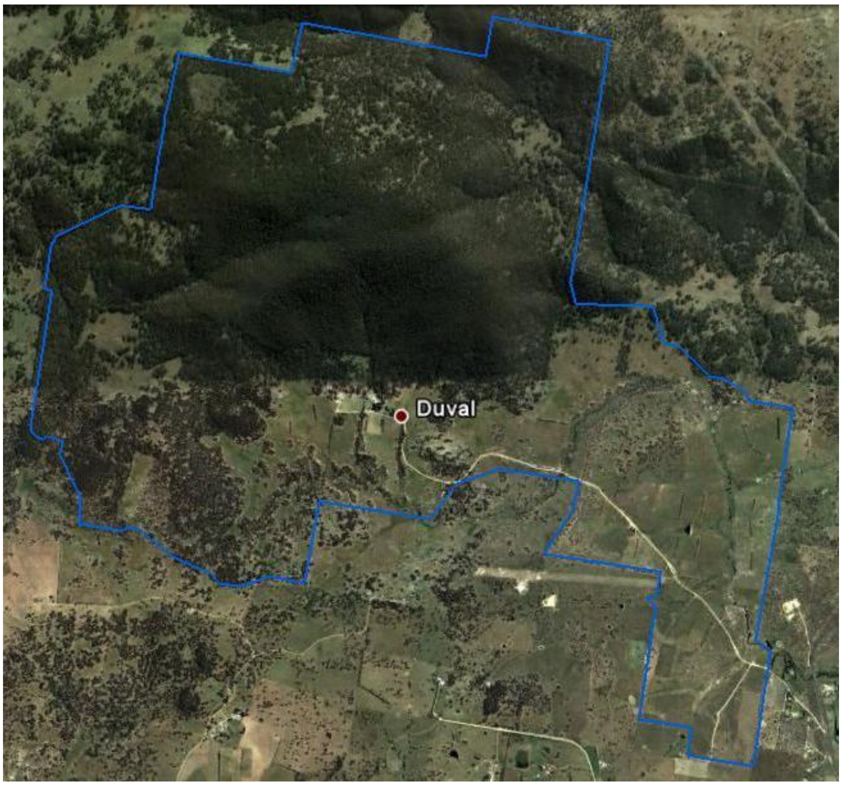


Figure 4.1 Case study area - Newholme

4.2 Case Study Testing and Feedback

As iFarming is based on three-tier architecture, different components can be distributed in different places. The data layer and the service layer are deployed in a physical computer in Melbourne, which is called the server hereafter. The mobile application iFarming-M was installed in farmer’s iPhone™. iFarming-W is a browser application which only needs the installation of Google Earth™ plug-in, so all participants could access it through any computer with internet connection.

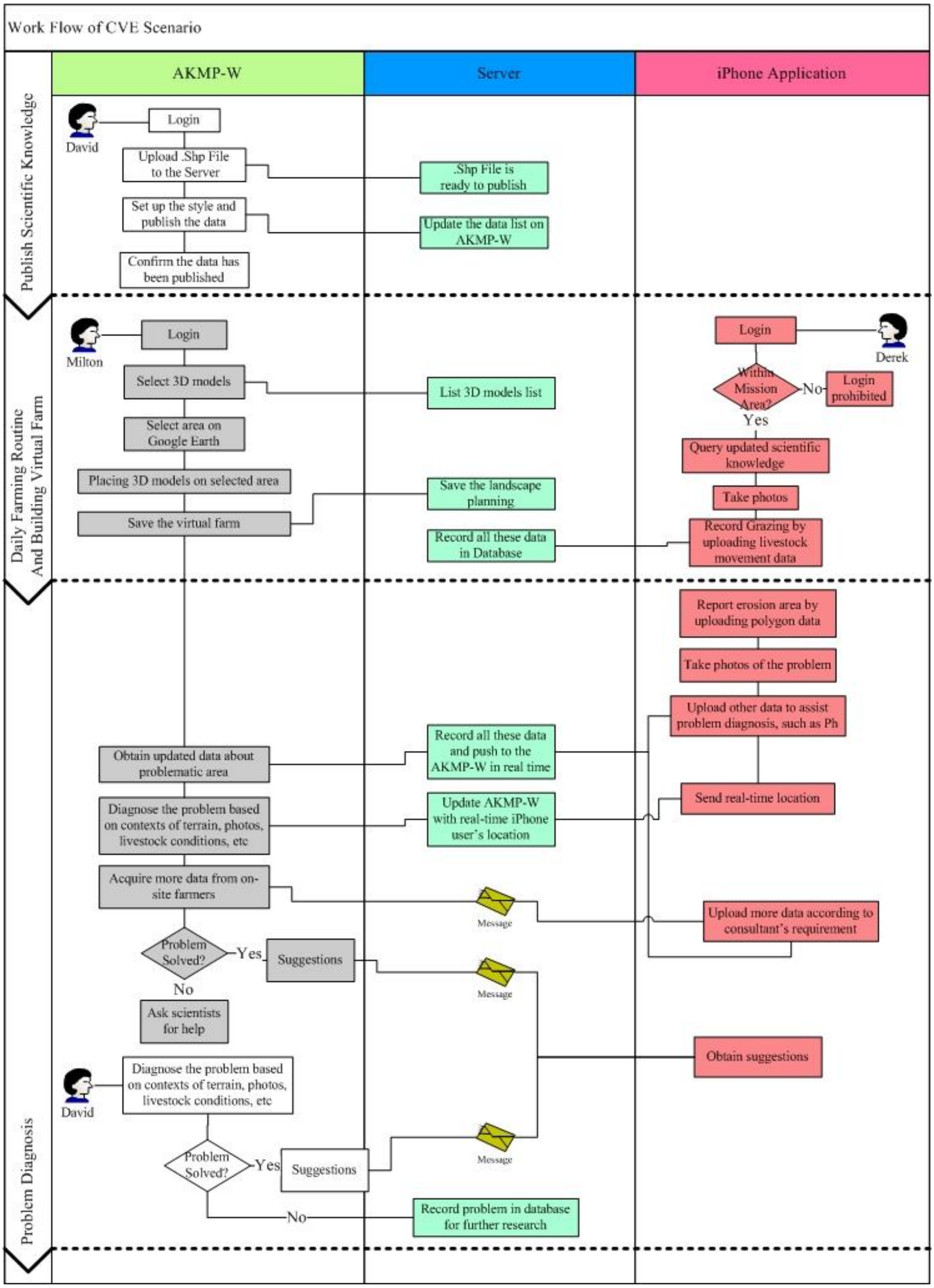
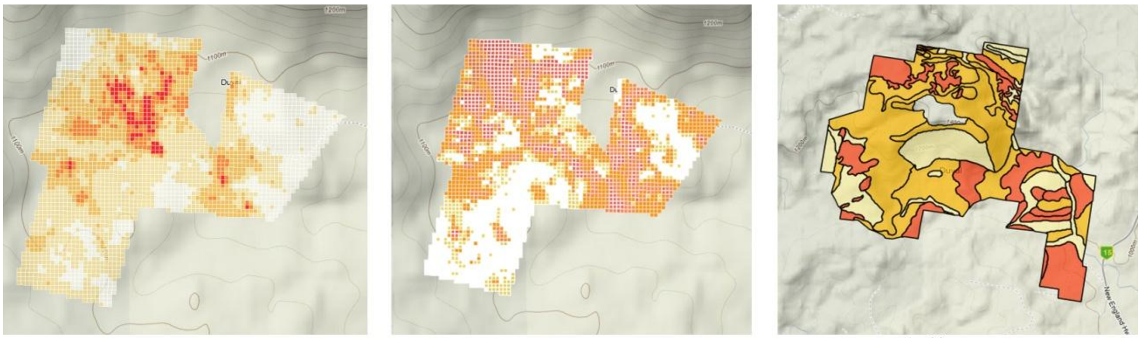


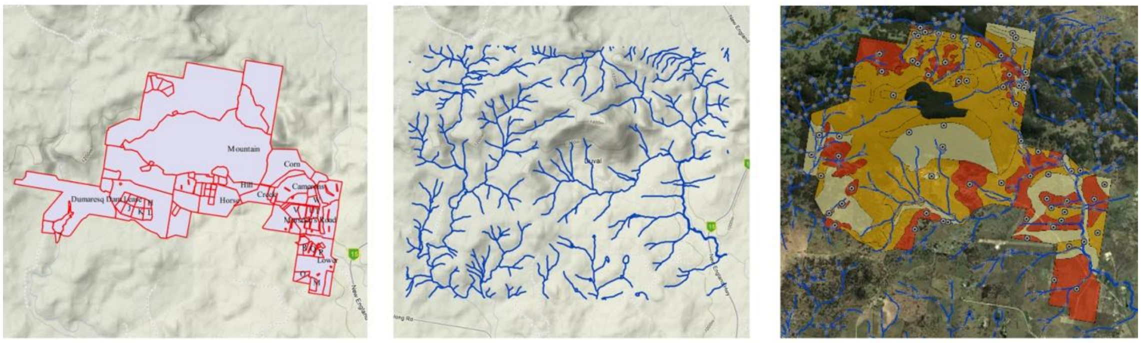
Figure 4.2 Work flow of the scenario for iFarming case study

A workflow was developed (Figure 4.2) based on a day-to-day farm use and management scenario, we introduced iFarming into this scenario to test both the robustness of its functions and also the reactions of the users.

Scientist Patrick and consultant John used iFarming-P for testing function 1: 'publishing scientific knowledge using iFarming-P’. There were 5 data layers uploaded and published through iFarming-P, including EM38, NDVI (Normalized Difference Vegetation Index), soil types, land use, and drainage network (Figure 4.3).



EM38 NDVI Soil types



Land use Drainage network Data layers on iFarming-W

Figure 4.3 Scientific knowledge published

Positive feedback from Patrick and John was that:

- the tool for converting .shp file to geometry types of PostGIS worked reliably and was found to be accurate and effective,
- the ability to automatically recognize projection system of data and convert to WGS84 was convenient, and
- the styler to customize the representations of data was easy to use.

However, they also noted that:

- iFarming-P would be enhanced by a tool for generation of .shp file from their own original files such as AutoCAD file, before uploading to the server.

Such a tool would fully support scientific knowledge publishing. Therefore, future development of iFarming should consider this suggestion.

Consultant John and farmer Paul used iFarming-W for function 2: ‘creating a 3D landscape based on reality or future options’. A virtual farm was built based on the existing conditions of Newholme (Figure 3.10 and Figure 4.4). This included 8,246 trees, 276 livestock models and 14 rural buildings. John spent half hour in learning the tool ‘Plan my farm wizard’. Responses from consultant and farmer were:

- ‘Plan my farm wizard’ was easy to use and a virtual farm was designed and presented in a short time,
- multiple geographically distributed users manipulating the same 3D scenario facilitated the exchange of ideas, especially useful for property planning, and
- the virtual farm looks realistic, so that users have a clear idea of the existing or proposed conditions of the farm.

Less positively:

- iFarming-W would run slowly if the scenario contains too many 3D models, e.g., hundreds of thousands of trees can lead to a system failure.

Figure 4.4 Virtual farm built on iFarming-W

Using iFarming-M in rural area, farmer Paul tested function 3: ‘uploading and querying local knowledge using iFarming-M’. Paul was interested in the EM38 data and the interpreted soil moisture levels, which was new scientific knowledge to him. He walked around the farmland, and queried the EM38 data at a number of locations. At the same time, he took photographs of specific objects or locations, such as the facilities, and livestock conditions. He also uploaded other farming data, such as Ph, nitrogen value and fertilizer amount, based on his observations, recent testing and activities. Paul felt that these data would be crucial for future farm management. Since the entries are permanently stored on the server Paul could find out later how much fertilizer was used in certain areas, and change the strategy according to the pasture or crop outcomes. During this case study, there were totally 45 photos (Figure 4.5) and 38 geographical data entries uploaded including pH, carbon and nitrogen values (Figure 4.6), problematic area (Figure 4.7), and grazing movements (Figure 4.8). Positive feedback from Paul included:

- iFarming-M was a user-friendly application, which was easy to learn and applied to practices.
- As this was a normal portable device, there was no extra piece of equipment to carry around.

However, some deficiencies were also obvious:

- Touch screen technology could be temperamental at times and bright sunshine could make viewing difficult.
- The onscreen keyboard was not ‘fat finger’ friendly.
- Even though the case study area was covered by a 3G network, it still suffered poor network conditions occasionally.
- The short battery life of the iPhone, when using all necessary positioning and communications options, was an issue. Through two in-field tests, it showed that iFarming-M can last up to four hours, and poor network conditions (e.g., forest area) , which required iFarming-M to continually attempt to connect to Google’s data server for downloading map data, were the main reason for this comparatively short battery life.

The issue of battery life could possibly affect the performance of iFarming-M. Through observing Paul’s use habit, I found out that user would not operate on iFarming-M until they found out or reached the place of interest. Therefore, the battery issue can be improved by fine-tuning the programme, including suspending the GPS and the linkage with Google’s data server while iFarming-M doesn't receive any commands over a certain interval (e.g., five minutes).

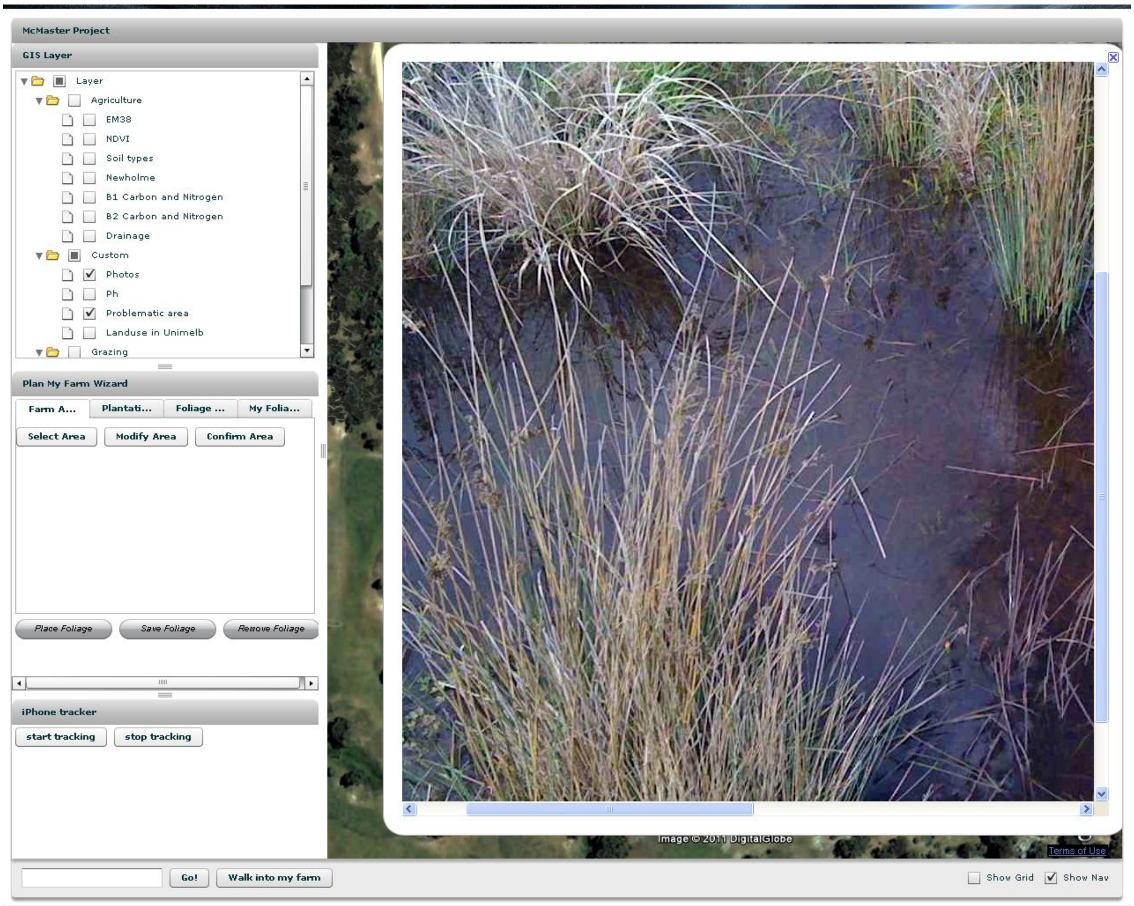
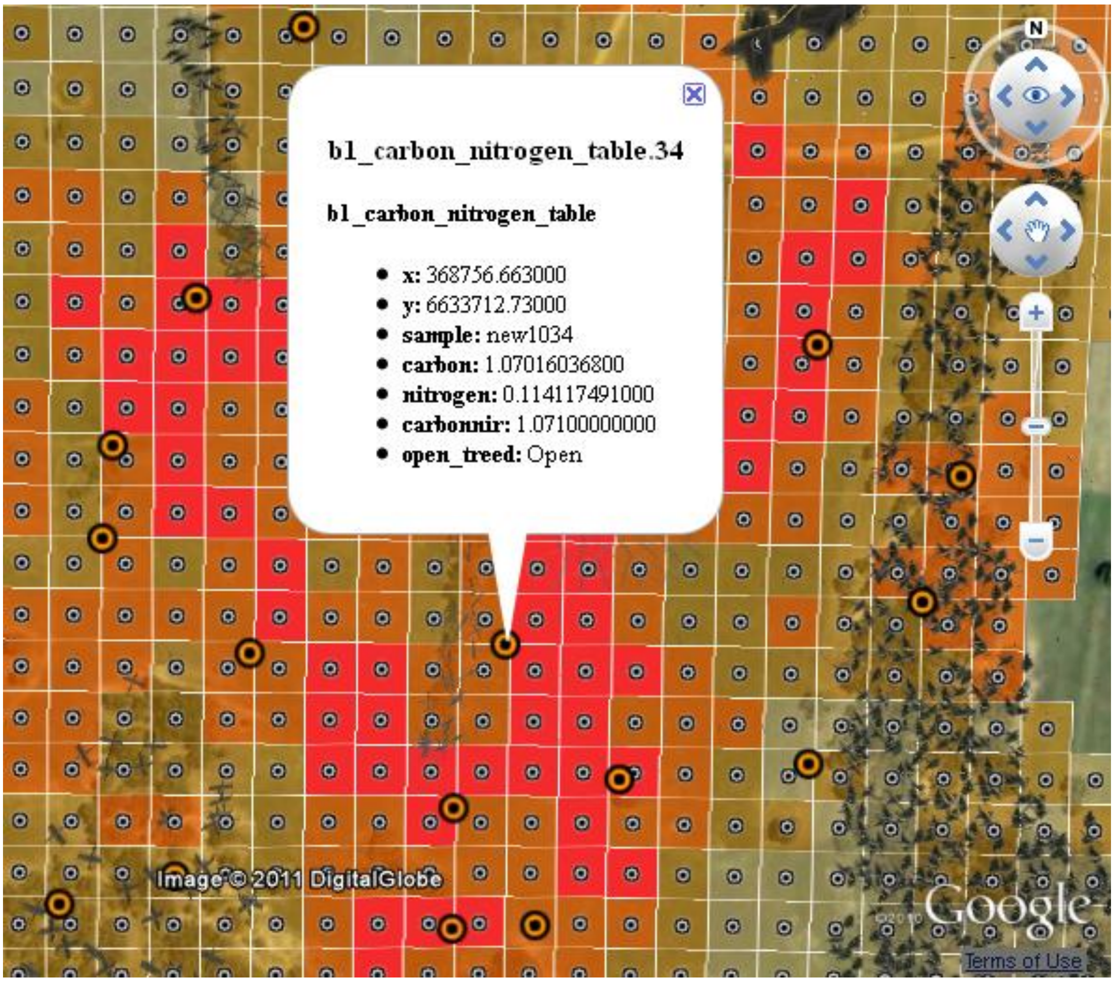


Figure 4.5 Photo shown on iFarming-W

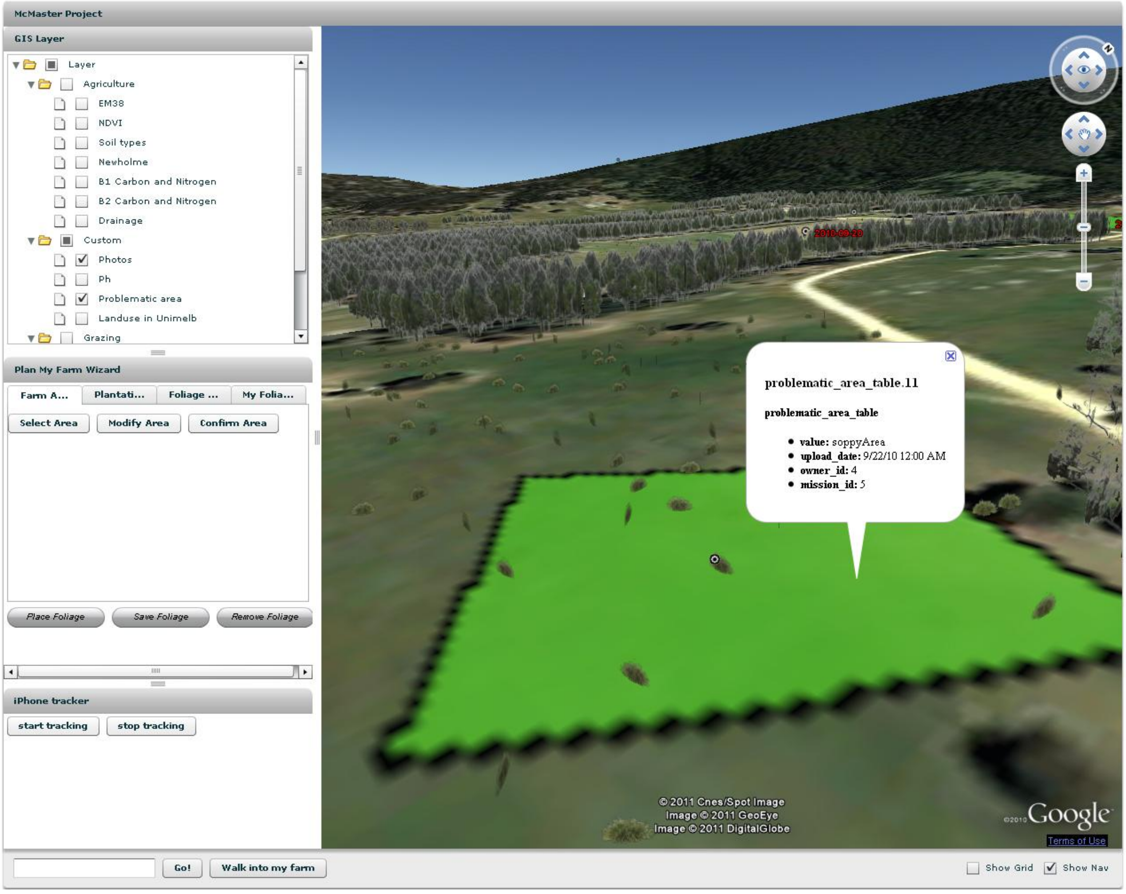


b1_carbon_nitrogen_table.34

b1_carbon_nitrogen_table

- **x:** 368756.663000
- **y:** 6633712.73000
- **sample:** new1034
- **carbon:** 1.07016036800
- **nitrogen:** 0.114117491000
- **carbonnir:** 1.07100000000
- **open_treed:** Open

Figure 4.6 Carbon and nitrogen value in iFarming-W (light colour indicates low EM38 area, while dark colour indicates high EM38 area)



problematic_area_table.11

problematic_area_table

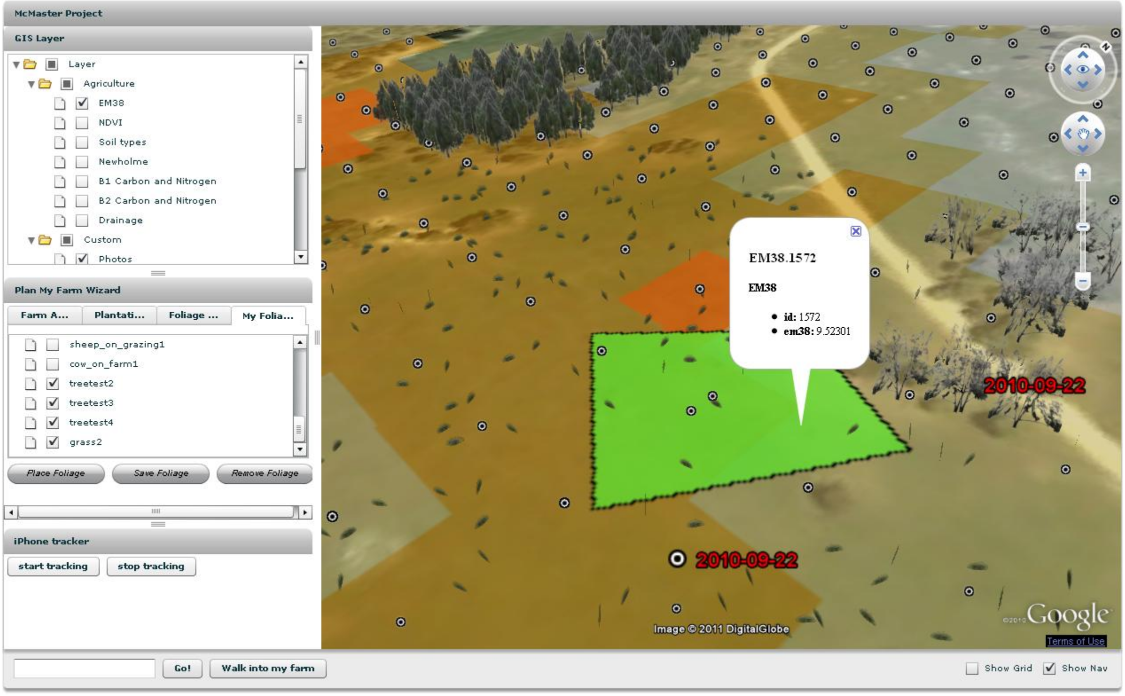
- **value:** soppyArea
- **upload_date:** 9/22/10 12:00 AM
- **owner_id:** 4
- **mission_id:** 5

Figure 4.7 Problematic area in iFarming-W (green colour indicates soaking area)

Farmer, consultant and scientist used iFarming-W for function 4: 'Interacting with the 3D scenario using iFarming-W, to review the uploaded knowledge and communicate with distant users to solve specific problem’.

Agricultural consultants, John, who was hired by Paul, worked in a distant office. He used iFarming-W to assist him to diagnose any in-field problems. In the stage of problem diagnosis, Paul found out that there were some serious soaking areas. He collected some data, including images (Figure 4.5) and the extent of the problematic area (Figure 4.7) for John to diagnose. At the same time, John researched the data uploaded, and considered other contextual elements such as terrain, drainage network, existing livestock conditions and EM38 to analyse the problem. Considering the lighter colour indicating the lower EM38 value (Figure 4.8), he found that the soaking area had low EM38 value compared to the surroundings, which meant this area had low conductivity. He believed that this area was the low point of a small local catchment, so he suggested that the farmer not apply fertilizer, which would be not effective, and this area should potentially become a new farm dam. When he had developed a proposed solution, he sent the details to Paul using conventional media.

During the trial, iFarming was proved to be an adaptable system. Paul identified the requirement of monitoring livestock movements. This was easily accommodated in iFarming by adding one more data layer in the database to allow iFarming-M to perform this task, and the corresponding records of movements were visualized on iFarming-W instantly (Figure 4.9).



- ■ Layer
  - ■ Agriculture
    - ☑ EM38
    - ☐ NDVI
    - ☐ Soil types
    - ☐ Newholme
    - ☐ B1 Carbon and Nitrogen
    - ☐ B2 Carbon and Nitrogen
    - ☐ Drainage
  - ■ Custom
    - ☑ Photos

☐ sheep_on_grazing1
☐ cow_on_farm1
☑ treetest2
☑ treetest3
☑ treetest4
☑ grass2

EM38.1572

EM38

- **id:** 1572
- **em38:** 9.52301

☐ Show Grid ☑ Show Nav

Figure 4.8 Problem diagnosis in iFarming-W

2010-09-20

mob_moveout_table

- **mission_id:** 5
- **value:** 20Rams
- **upload_date:** 9/20/10 12:00 AM
- **latitude:** -30.42046500
- **longitude:** 151.63692800
- **owner_id:** 4

Figure 4.9 Grazing movements in iFarming-W

The spatio-temporal knowledge database provides first-hand in-field data for scientist to perform further research. Farmer's inputs potentially create a large amount of data in time series. In this case study, the farmer uploaded the nitrogen data collected. As shown in Figure 4.6, the orange spots indicate the distribution of the nitrogen data collected, and the grids in the background show the EM38 value. Through spatial query services, a scientist obtained the nitrogen data in KML format, which can be post-processed to standard GIS data. Based on these nitrogen data and combining other inputs, including EM38 mapping, weather records, and rainfall, the scientist evaluated the potential soil performance in response to the fertilizer, and formulated a better fertilizing strategy for this area to increase gross margins. As use continues a longer time series will develop and scientists can follow the changes of the soil, and adjust the fertilizer and other management strategies to achieve more sustainable agriculture. If the scientists, or the consultants, have access to more farms across a region the comparisons can be made and the value of the possible findings grows.

Responses to this procedure included:

- Data was instantly available to all users whether in the paddock or office.

- The capacity to store the data into the database results in a complete farming history for users to follow.
- The capacity to visualize data in 3D context provides users with comprehensive contextual knowledge for problem diagnosis and concept exchange (e.g., EM38).
- Historical knowledge database providing farming records in time series benefits scientific research.

Negative feedback was:

- Lack of an interaction with other external data sources or scientific research systems, such as Matlab™.
- Adding or adjusting the data layers now was relying on software developers. Ideally farmers or their consultants would have a simple mechanism for adding and specifying a data layer (e.g. Locust tracking).

Providing an interaction interface to external data sources and systems (such as data held by local or state government agencies) would also possibly increase data and knowledge availability, and further streamline the contribution to scientific research. Providing users with a flexible data layer controller would allow them to adjust the knowledge management strategy without frequent interaction with developers. These suggestions should be considered when designing a mature product for broader usage.

4.3 iFarming Workshop

Main question of this research is whether or not a CVE can support a new communications paradigm by reducing the geographical distance and cognitive distance of knowledge management in a distributed environment. To determine if the new paradigm of agricultural knowledge management (Figure 4) is achievable, by recruitment of other farmers, consultants and scientists, a group of people was invited in a workshop. The best practices that occurred during the case study were demonstrated, and participants were asked to give general comments via an evaluation form (7.1: Appendix 1).

The results of this workshop are not statistically significant, involving just 9 people, but most of them were experienced in farming, and able to offer insights into how other farmers, consultants and scientists may perceive iFarming, in particular, whether they would be willing to adopt the new knowledge management options in daily farming practices.

A series of questions regarding the value of iFarming in reducing geographical distance and cognitive distance were formulated in the evaluation form. Participants could select not useful, not very useful, neutral, useful, or very useful in response to each question.

The individual sections of the demonstration and questionnaire were: 1) knowledge publishing and retrieval, 2) onsite data collection, 3) farm planning, 4) problem diagnosis, 5) assisting decision making, and 6) further usage of data.

4.3.1 Knowledge publishing and retrieval

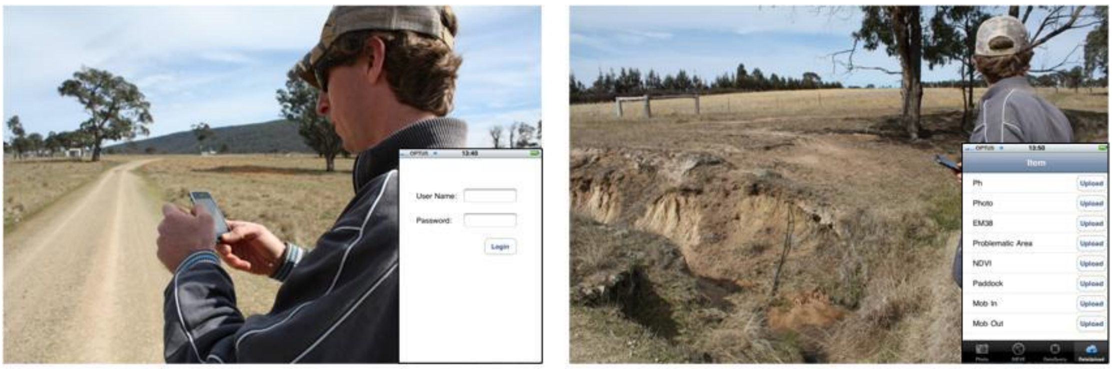
The first part of the workshop showed iFarming-P for demonstrating knowledge publishing (Figure 4.3), and iFarming-W and iFarming-M for knowledge retrieval (Figure 4.8). Afterwards, the group was asked how useful iFarming is for access to the latest knowledge. Only 1 out of 4 farm managers believed it is not very useful, compared to other two believing useful and one believing very useful. The one who selected not very useful stated: ‘knowledge would be more complicated in representation than only polygon and point data, which should be complimented with other materials for reference’. The one who selected very useful was a farm manager from that farming region, who stated that: ‘data displayed in 3D context offers more information than text’. The difference between these two answers may be caused by their different cognitive positions, that the latter has a better idea of the pilot area, which facilitates him to absorb the knowledge published. Both two academics and one consultant believed that iFarming is useful in helping users to access to latest knowledge. However, they were worried about the knowledge quality, as iFarming currently does not have a mechanism to control it. One of them stated: ‘subjective data with personal intention may be populated into database’. This opinion is useful in developing a data quality control mechanism in the future. Both students selected neutral, as they stated ‘to prepare standard GIS format before publishing to iFarming-P was demanding’. Their shortage of GIS knowledge impacts the procedure of data publishing, even though they have advanced education backgrounds. Moreover, a farmer manager noticed that iFarming-M, when querying data, didn’t indicate the owner of the data, which was visible in iFarming-W. This feature should be implemented in iFarming-M in the future, as it respects the contribution of the users.

In conclusion, 6 out of 9 audiences believed iFarming is useful or very useful for accessing the latest knowledge. This feature of iFarming facilitates resource sharing between different users, decreasing their geographical distance. However, it still suffered some issues caused by cognitive distance, including: 1) representation of knowledge was limited (point data and polygon data were the only data format supported), and 2) data preparation is a demanding task even for people with advanced education backgrounds.

4.3.2 In-field data collection

The second part showed the procedure of farmer collecting in-field data (Figure 4.10), and corresponding data displayed on iFarming-W. Afterwards, the group was asked how useful iFarming is for collection of on-site information. Seven people believed that it was very useful, compared to one believing useful and one neutral. The one who selected neutral is an academic, stating that ‘iPhone technology is handy, but uploading polygon data covering large area would be a time-consuming job’. More specifically, he worried that using iFarming-M to survey the whole land use conditions would cost much more time than another method, such as by analyzing a satellite image. This suggested a more convenient data upload solution, where iFarming-M utilizes user’s driving route to indicate the boundary of each polygon, instead of marking vertex by vertex. The one who selected useful is a consultant, worrying that ‘it may face competition with other applications on the market, such as PAM™ for Palm Top, having similar in-field data collecting capacity’. Compared to other applications, iFarming-M has its own advantages, including 1) real-time knowledge transfer and 2) permanent data storage. The former can establish a virtual board room, where user working on site and in an office can share data in real time and communicate their issues and ideas; the latter ensures data storing in database would not be lost, while PAM™ for Palm Top requires post-data entry into other systems. Those who selected very useful believed that data stored in a database is very important for farm management, such as designing a sustainable fertilization strategy based on the fertilizer usage history. Moreover, they agreed that iFarming-M was convenient to use, as it allows a farmer lacking GIS background to contribute their knowledge to the server.

In conclusion, most audiences believed the in-field data collection capacity of iFarming can help user to share knowledge and communicate ideas with distant user, and it allows farmers to produce professional agricultural data. This feature reduces both geographical distance and cognitive distance and support the new paradigm of distributed communications.



Login

Select layers for upload

Upload problematic area

Upload photos

Figure 4.10 Collection of in-field data

4.3.3 Farm planning

One of the creative applications of iFarming is online farm planning. Traditionally, a consultant formulates a farm planning by 2D maps (Figure 4.11), which indicate the existing conditions, such as land use, soil types, locations of fences, buildings, dams, roads, and propose improvements, such as sheds, dams and proposed farming practices (DPI, 2011). As discussed in Chapter 2, 3D data can offer more information than a 2D map. In this regard, iFarming provides a feature for users to build up a 3D virtual farm. The group was shown the process of 3D farm planning on iFarming-W, and the virtual farm built during the case study. Afterwards, they were asked to consider how useful iFarming is for farm planning. There were 5 people believing it was useful, and 2 believing very useful, while 1 selected neutral. The one who selected neutral is an academic, stating that ‘3D farm planning tool may be useful for demonstrating the landscape, but it didn’t provide more details than a 2D map’. As an experienced agricultural researcher, he believed he can interpret a 2D map well enough to master the existing conditions. Others choosing useful or very useful believed it can offer more information than 2D maps, such as showing the terrain, especially for a user lacking advanced map-reading skills. One of them said ‘looks realistic for me’, believing the 3D view can give an idea of the landscape before plantings or building construction. Some of them thought it could even help problem diagnosis, as it provides user with an intuitive image. A consultant selecting useful, said ‘through it, I can provide clients living in England with an online 3D farm, and afterwards share ideas based on it’. However, he worried that some distant rural areas would not be covered with high resolution satellite images by Google Earth™, which would possibly impact the look and feel of the virtual farm. Most audiences thought the tool was easy to use, making it possible for a virtual farm to be constructed in a short time.

In conclusion, most of the group believed the farm planning tool of iFarming was useful for presenting an intuitive virtual farm. As the virtual farm was accessible online, consultant and farmer can share the same scenario and communicate ideas instantly, which reduces the geographical distance between them. Moreover, as the virtual farm looks realistic to users, it can help them to understand the knowledge. For example, the area with high EM38 value was covered with dense grasses, compared to the area with low EM38 value (Figure 4.8), which helps the farmer to understand which area is of high nutrition. This feature therefore also reduces cognitive distance.

Figure 4.11 2D map showing farm planning (DPI, 2011)

4.3.4 Problem diagnosis

This part of the workshop showed how the consultant diagnosed a problem through reviewing data uploaded by the farmer and findings published by the scientist. The group was asked how useful iFarming was for problem diagnosis. There were 3 farm managers and 1 student believing useful, compared to 2 academics believing very useful, and 1 student and 1 farm manager selecting neutral. The latter were worried that the data used for problem diagnosis were not sophisticated enough for fully understanding the problem, which may cause a wrong or incomplete solution. They suggested that I initiate a long-term collaboration with consultants to obtain data categories, which are sufficient for problem diagnosis. The process of problem diagnosis is complicated, so this suggestion should be considered in a future development plan. Others selecting useful or very useful thought this feature ensures in-field problems can be reported instantly, and saves time and money of consultant for travelling. However, those who selecting useful also felt that not all problems could be fully interpreted only through reviewing the data in iFarming-W. More tests need to be performed to assess the capability of this feature in problem solving.

In conclusion, compared to traditional methods of in-field problem diagnosis, which requires a consultant to travel to the farm, this practice showed iFarming was capable of reducing the geographical distance between farmer and consultant. However, data provided for reference may not be sufficient for fully interpreting the problem, most participants were not confident to fully rely on iFarming.

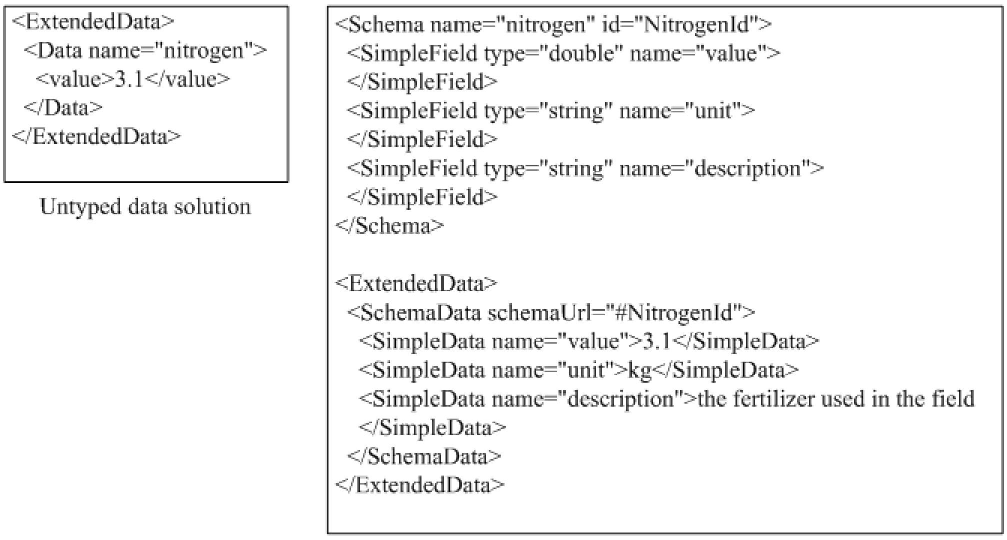
4.3.5 Assisting decision-making

During the case study, the consultant provided a solution of the problem reported by the farmer. Afterwards, the farmer realized that the area with high EM38 value indicated rich nutrition composition, and he decided not to apply fertilizer to this area. The group was shown these processes and asked how useful iFarming was for supporting decision-making. There was 1 farm manager selecting neutral, who stated 'iFarming provides users with contextual knowledge to refer, but decision-making needs more supports from outside, including fertilizer and production prices, and consideration of risks resulted from changing farming strategy'. As iFarming does not offer risk assessment of proposed farming practices, farmers would possibly be cautious in using the system. In this regard, predicting outcomes based on proposed practices, and introducing real time market information are two possible major improvements of iFarming in the future. There were 2 students, 1 academic, 1 farm manager and 1 consultant selecting useful. Among these, the academic said 'iFarming was useful for making some basic decisions, such as building a dam in a natural catchment'. However, he had the same concern as those selecting neutral that decision-making involves more information which iFarming cannot provide. There were 1 academic and 2 farm managers who were confident in using iFarming for decision-making. They believed knowledge represented in a 3D context was more intuitive than 2D data, which facilitates the user to interpret in-field problems and make proper decisions. Moreover, reported problems may occur in other area with similar contexts, such as similar soil condition, terrain, weather, and land use. Therefore corresponding solutions can become references for others. For example, an erosion problem which happened in a dry area with high EM38 value and intense farming intervention may also occur in other area with similar conditions, so the solution applied to the former may also be functional to the latter. They thought iFarming allows users who do not have equivalent expertise, to study other people's experiences in applying the new technologies or innovations, to ultimately adopt them in their own farms.

Traditionally, farmers would prefer to share their faming experiences in the local community. With the support of iFarming, a central knowledge database which stores contextual knowledge or experiences provides best practices to which others can refer. Therefore, iFarming can reduce cognitive distance between users.

4.3.6 Further usage of data

The group was shown 1) how the farmer used iFarming-M to upload grazing records and review them on iFarming-W (Figure 4.9), to adjust the grazing strategy, and 2) how the scientist analyzed the nitrogen data uploaded by the farmer and combined other modelling results, to formulate a proper fertilizing strategy for this area. Afterwards, they were asked how useful the knowledge database was for helping future research. The results showed that most participants expected iFarming to be very useful in this facet, except 2 who selected useful. Those who selected useful were 1 student and 1 farm manager, worrying that even though the knowledge database can offer large amount of data from both users, it would only benefit scientists rather than farmers, without a built-in analysis tool. ‘Raw data would not make senses to us, but analysis reports are what we want’, stated the farm manager. It was realized that the generation of reports based on scientific modellings is important to the less science-trained users. However, as addressed in Section 2.6, incorporating complicated modelling and analysis tools into iFarming could divert the interest and involvement of farmers. Instead of introducing a complicated modelling module, future development should: 1) integrates running basic models (Section 5.5.2), and 2) provide a more sophisticated and flexible data interface for users to refer or export the data of interest. For example, a farmer can refer the in-field fertilizer usage statistics and production data to his consultant for a cost-benefit analysis report, or download the data as an Excel™ file and transfer this to another software program for analysis. To implement such data interface in iFarming, the spatial interoperability mechanism which is used to transfer data between components should be adjusted. The untyped data solution of KML, which was used by iFarming, was not suffieient to describe the data itself for data sharing. Lacking a *schema* to describe the meanings and the units of the data, untyped data is not easily understood when shared with external users. Figure 4.12 demonstrates the difference between the untyped data and typed data solution of KML in describing nitrogen usage data. Based on the tag of <schema>, the typed data solution indicates the unit and meaning of the data itself, which would then be easily understood by external data users. To enable iFarming to provide meaningful data for external users, future research would implement a typed data solution.



```
<ExtendedData>
  <Data name="nitrogen">
    <value>3.1</value>
  </Data>
</ExtendedData>
```

Untyped data solution

```
<Schema name="nitrogen" id="NitrogenId">
  <SimpleField type="double" name="value">
  </SimpleField>
  <SimpleField type="string" name="unit">
  </SimpleField>
  <SimpleField type="string" name="description">
  </SimpleField>
</Schema>

<ExtendedData>
  <SchemaData schemaUrl="#NitrogenId">
    <SimpleData name="value">3.1</SimpleData>
    <SimpleData name="unit">kg</SimpleData>
    <SimpleData name="description">the fertilizer used in the field
    </SimpleData>
  </SchemaData>
</ExtendedData>
```

Typed data solution

Figure 4.12 Untyped and typed data solution

Moreover, the student thought a database only relying on users’ inputs may not be able to provide sufficient data for modelling and analysis. Therefore, in the future iFarming should introduce third-party data inputs, such as rainfall, other weather records, digital terrain model (DEM), and governmental policies. Other audiences selecting very useful believed the knowledge database was an important new attempt to centralize scientific knowledge and local knowledge. From a farmer's view, it can provide long term histories of their properties, for them to formulate better farm management plans. From academics’ view, it can provide first-hand local data for scientific research, saving time and money in communicating with farmers and consultants. From the consultant’s view, it can save time in preparing and summarizing in-field data from farmer for reporting.

In conclusion, the knowledge database can potentially benefit all users. However, it needs certain steps to make it practical and acceptable, including a data interface and integration of external data sources. It appeared to be more welcome by the academics in this feature, as first-hand in-field data are important materials for their research. The knowledge database can decrease geographical distance between users, especially farmer and scientist.

4.3.7 System Acceptance

The proposed new paradigm for agricultural knowledge management using iFarming could possibly affect users' day-to-day farming practices. To evaluate the system acceptance by users, the group was asked three questions: 1) if iFarming was available for day-to-day farming practices, how likely would they be to employ it, 2) if introducing iFarming into daily farming practices, how useful it would be, and 3) how much it would affect their ways of farming. The third question was supposed to indicate if user would spend too much time and money in learning and utilizing the new tools. However, the results of this question were found to be ambiguous, as when it was asked, it didn't explicitly indicate that the intended effect was negative. Therefore, the third question was not used for this evaluation. The first two questions, however, have already given us an overall idea of how audiences perceive iFarming.

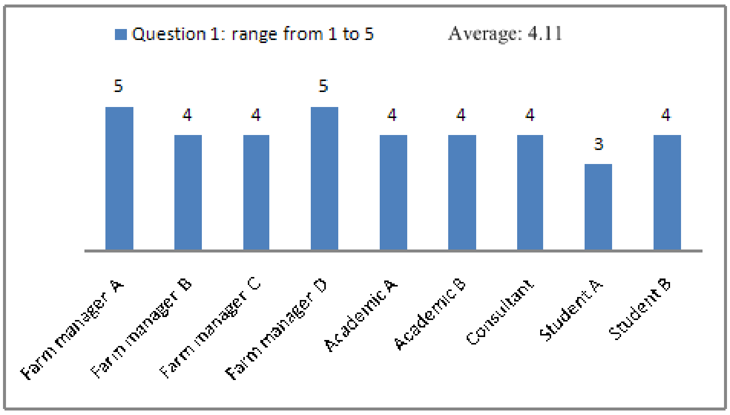


Figure 4.13 The result of question 1: if iFarming was available for day-to-day farming practices, how likely would they be to employ it?

Through Figure 4.13, it appeared that farm managers were very willing to adopt iFarming in farming practices, with 2 out of 4 selecting strongly agree. Others also thought they would adopt it, except one student selecting neutral.

When asked how useful iFarming would be, 1 student and 1 farm manager selected neutral, and others thought it would be useful or very useful (Figure 4.14).

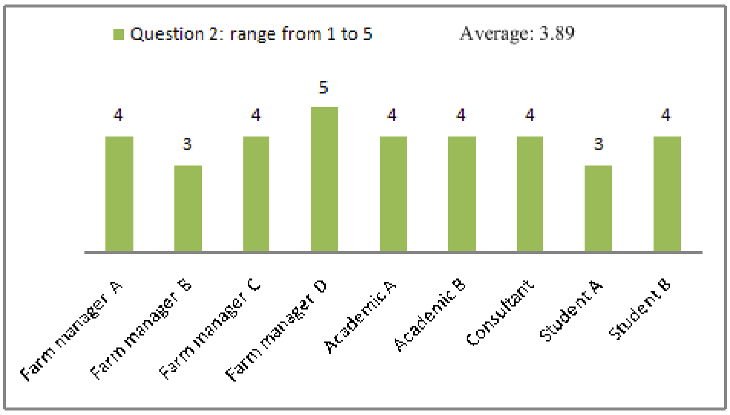


Figure 4.14 The result of question 2: if introducing iFarming into daily farming practices, how useful it would be?

In conclusion, most audiences were optimistic towards the new technology, averaging 4.11 for the first question, and 3.89 for the second one. Amongst them, Student A and Farm manager B both doubted the value of iFarming in their daily farming practices. However, they had different attitudes to the adoption of this new technology, Farm manager B would be likely to adopt it, Student A was cautious.

Even though the third question ‘how iFarming would possibly affect farming practices’ was not considered in the quantitative evaluation, the comments from the audiences about it are still relevant for future development. Some worried: 1) farmer would not have time to use it during certain days, especially harvest season, 2) if there were questions about usage, frequent communications with developers would disturb users, 3) legal issues would become more significant when private data grows, and 4) iFarming was still in prototype stage, some functions would be not stable, which may harm user’s patience.

4.3.8 Demonstration Summary

While the demonstration was only given to a small group, 9 people with various backgrounds, gaining their feedback was still instructive. The findings relevant to iFarming are listed below.

With regard to using iFarming for reducing geographical distance, it was found:

- Knowledge publishing/retrieval and onsite data collection facilitates resource sharing and knowledge transfer between geographically distributed
- Farm planning module allows geographical distributed users to share and manipulate the same 3D virtual farm, where ideas and concepts can be communicated.
- iFarming provides a centralized knowledge platform for consultant to diagnose the basic onsite problems, which saves them large amount of time and money for travelling.
- The central knowledge database centralizes onsite data and scientific data, to provide scientists with first-hand research material and famers with long term farm history, and enable knowledge transfer between farmer and scientist to be bidirectional.

With regard to iFarming for reducing cognitive distance, it was found:

- Onsite data collection enables users who are lack of advanced GIS skills to contribute local knowledge with professional data format.
- Knowledge represented in 3D context, provides more information than 2D to facilitate interpretations towards knowledge itself.

- The central knowledge database collecting knowledge from users of different cognitive positions can provide contextual knowledge for decision making.

5. Discussion, Conclusions and Future Work

5.1 Introduction

When sources and recipients of knowledge are geographically distributed, finding ways to collect, share, and reuse this collective knowledge to obtain a competitive advantage has become one of the most important challenges for modern organizations. When different backgrounds and sources of knowledge are involved an additional challenge is the cognitive distance between individuals. Geographical distance and cognitive distance are the two main impediments to effective distributed knowledge management. To reduce these two distances, I designed and developed iFarming, a knowledge management system based on a collaborative virtual environment. I also proposed a new paradigm for distributed communication and enhanced knowledge management. A case study with farmers, scientists and consultants demonstrated that iFarming worked as expected, was easy to adopt and was able to reduce both distances to some degree.

This chapter revisits the research objectives, outlines the contributions made by this thesis, summarises its limitations, and suggests future directions for research.

5.2 Research Objectives Revisited

The overall objective of this thesis was to provide a new paradigm for distributed communications by developing a system that reduces the geographical and cognitive distances between the users involved. Through analysis of the issues caused by geographical and cognitive distance, system requirements were formulated in Chapter 2. More specifically, iFarming was designed to:

- offer a collaborative working environment, where geographically dispersed users, who may lack advanced computer skills, are able to manipulate the same virtual scenario and share knowledge in the 3D context.

- provide a contextual knowledge database for sharing of knowledge and best practices to ultimately advance knowledge propagation. Contributions were gathered from both users trained in the sciences, to users who were more practically orientated.

To achieve such a DKMS, I employed the concept of Web 2.0 and the technologies of CVE and smartphones. Three key research and development problems arose:

- CVEs have emerged as training platforms but are not typically configured for knowledge management

- While iFarming employs various technologies, spatial heterogeneity issues between components may exist, and

- CVEs have already been recognized as effective in facilitating communication and resource sharing, which addresses the issues of geographical distance. Can iFarming, which is based on CVE and enriched by Web 2.0 and smartphones, be useful in reducing cognitive distance?

While this research is carried out in the context of agriculture through provision of a central spatial database and multiple user-interfaces to access the knowledge repository, the CVE is working as a DKMS for agricultural knowledge management. Moreover, this thesis proposed and implemented a spatial interoperability mechanism to allow various technologies to smoothly work together in an effort to reduce development time and provide users with familiar user-interfaces, such as Google

Earth™ and iPhone™. Besides offering a communication and resource sharing platform to reduce geographical distance, iFarming also provides users with other features to decrease the cognitive distance, including 1) representing knowledge in 3D contexts which facilitate understanding, 2) onsite data collection which allows users who lack advanced GIS skills to contribute local knowledge in a professional format, and 3) a central knowledge database which provides contextual knowledge from users can learn from and which becomes a knowledge archive and a source of material for further research.

The next section summarizes the success and limitations in achieving a system that addresses these research issues.

5.3 Summary of Findings

5.3.1 CVE for knowledge management

A CVE is not normally configured for knowledge management. I considered the technical and logical limitations of existing CVEs, and used available systems to develop an enriched CVE with new features to support knowledge management. The following sections address the achievements and limitations of these features.

5.3.1.1 Knowledge storage

In Chapter 2, the review of empirical studies demonstrated that existing CVEs lack the support of knowledge storage, which is the basis of knowledge management. In this regard, iFarming adopted a central spatial database, storing scientific knowledge from scientists and local knowledge from farmers. This data was tagged with location information, timestamps, and the names of the owners. Through querying these tags, a user can access and understand the farming history of a certain area.

5.3.1.2 Spatial interoperability mechanism

As iFarming integrates various technologies, I proposed a spatial interoperability mechanism to coordinate them to work together smoothly. This mechanism solves heterogeneity issues at the levels of *Network Protocols*, *Hardware* & *OS*, *Spatial data files*, and *Data model*. After comparing KML and GML in terms of functionality and complexity, KML was selected as the data transfer protocol. In iFarming, KML proved to be a light-weight and flexible data format to transfer geographic information between components to overcome the heterogeneity issues of *Network Protocols*, *Hardware* & *OS*, and *Spatial data files*. However, as iFarming was expected to integrate an external data source, and provide a data interface for users to download data (Section 4.3.6), the *untyped data* solution of KML (Section 3.3.2), which iFarming used, was not sufficient for describing all the details of the data. Therefore, iFarming should use *typed data* of KML, as this contains a *Schema* to assist data requesters to interpret the data. Accordingly, the ISDS (Section 3.3.3), which was used to overcome heterogeneity in *Data models*, should also be adjusted to contain this *Schema* and *Schema Data*.

A Spatially Intelligent Naming Mechanism (SINM) was proposed to overcome the issue of Naming Heterogeneity (Section 3.3.4). This can be a significant difficulty when geographically dispersed farmers and scientists seek to share knowledge, with SINM possibly helping users obtain the proper names of certain species according to their locations. However, a practical SINM needs a complete taxonomic synonyms database, where synonyms are marked with geographic locations and corresponding area codes. Unfortunately, I was lacking such a database, and therefore, I was unable to implement SINM in iFarming. As a result, the heterogeneity of *application semantics* remained unresolved.

5.3.1.3 Web 2.0 and Smartphone for knowledge transfer

The advantages of iFarming over existing CVEs in dealing with knowledge management also include: 1) by adopting the concept of Web 2.0, iFarming allows a larger numbers of users covering larger areas of interest to be involved in knowledge management, and 2) using a smartphone as one of its user-interfaces enables users who lack advanced GIS skills to contribute their local knowledge.

iFarming’s iPhone™ application, iFarming-M, could be made available as a free application in Apple’s App Store. Ideally, iFarming-M works in areas covered by mobile Internet. As iFarming provides users with free services as described in the case study in Chapter 4, innovators and early adopters according to Rogers (2003), may be willing to try this new technology. Unlike participatory research undertaken by CSIRO and APSRU (Section 2.3.3) that requests specific users to attend short-term programmes, iFarming may attract those *knowledge activists* to spontaneously contribute to knowledge management, and in turn, this may motivate their local communities to follow. However, as addressed in Section 4.3.1, iFarming lacks a data quality control mechanism, which may not prevent the central knowledge database from being fed with subjective or erroneous data from people with certain intentions. Data quality control significantly affects the trust of users towards the whole system. Therefore, further research should consider this issue.

The integration of a mobile user-interface into the computer-based structure of traditional CVEs was particularly innovative of this research. In the case study, the portable application, iFarming-M, demonstrates that it allows in-field users to upload and query remote knowledge via mobile Internet. Through interviews with potential users and a responsive design with an easy-to-use interface, iFarming-M allows users who lack advanced GIS skills to contribute their local knowledge in professional format. However, this was affected by three main issues; short battery life, occasional poor network conditions and, importantly, user complaint that the touch screen technology was not always user-friendly. In this regard, further research could be conducted to improve the programme to reduce battery use, and with contributions from users, a more user-friendly interface could be designed.

5.3.2 A new paradigm for distributed communication

The traditional agricultural knowledge management paradigm was discussed in Chapter 2. Involved members face a series of issues caused by geographical and cognitive distances (Section 2.3.3). In this regard, I proposed a new paradigm for distributed communication in order to reduce both distances. To test if this new paradigm achieved its objective, a case study involving a farmer, scientist, and consultant was carried out. While both distances were reduced by this new paradigm, the main achievements revealed by this evaluation process included:

- Coordination costs were effectively reduced as knowledge flowed smoothly between geographically distributed users. This benefits: 1) consultants, who save time and money in travelling to diagnose in-field problems and who also offer property planning, 2) farmers, who obtain the latest scientific knowledge through using iFarming-M, and 3) scientists, who publish their knowledge through iFarming-P, and who also obtain first-hand local knowledge.

- Bidirectional interactions between involved users advance knowledge propagation. The main advantage of this new paradigm is establishing a bridge between scientists and farmers. As knowledge is instantly available to both sides, scientists can access more in-field information than before, which enables them to have a better understanding of on-farm situations, and also enables them to adjust their scientific knowledge based on this information. In turn, realizing that scientific knowledge is based in part on their local knowledge, farmers may be more willing to trust and then adopt scientific knowledge.

- Collective intelligence may be achieved. By setting up a central knowledge database that stores contextual knowledge in the 3D context similar to other Web 2.0 applications, iFarming allows larger numbers of users to contribute and learn best-practices. These spontaneous contributions by knowledge practitioners with diverse backgrounds are the source of novelty and innovation in scientific research.

The case study also revealed the defects of iFarming, which are summarized below.

- Representation of knowledge was limited (Section 4.3.1) which may prevent users from publishing knowledge in forms that iFarming doesn’t support, such as document, audio and video. iFarming should integrate these formats of data and represent them in its user-interfaces.

- The available data may not be sufficient for a consultant or scientist to fully understand in-field situations (Section 4.3.4). This is a significant problem as it can affect the procedure of problem diagnosis. However, this could be improved by long-term collaboration with consultants to obtain additional data categories that are sufficient for problem diagnosis.

- While the concept of Web 2.0 opens up the opportunity for collective intelligence, it also causes issues related to data, such as data privacy and data quality. Users may fear that the knowledge downloaded may breach legal requirements.

In conclusion, the development of software to support a new paradigm for distributed communication and knowledge management has been the main achievement of this thesis. Based on this, different parties involved in farming can be brought closer together than ever before, and enriched by the latest knowledge to overcome challenges in the context of globalization and climate change (Section 2.3.1). This new paradigm is also applicable in other contexts related to land and environmental management, where geographically dispersed users also face issues caused by geographical and cognitive distances. However, to apply iFarming into these contexts, a few more steps need to be taken, including analysis of the existing knowledge management pattern, adjusting the data content of interest, and fine-tuning the mobile application according to the user's needs.

5.4 Discussion - is iFarming building a Utopia?

The greater the number of *knowledge activists* that contribute to iFarming, the better the potential of contextual knowledge to serve farming communities. In this regard, the success of the new paradigm of AKM is highly dependent on whether the farming practitioners are willing to share their knowledge to a broader community, which includes strangers. In reality, knowledge is always regarded as a tradable entity, especially from the point of view of consultants, who provide knowledge for their living. This brings forward a controversial but fundamental topic about knowledge management: "Why should I share?" (Cabrera & Cabrera, 2002; Wasko & Samer, 2005) Empirical studies have indicated, especially after the emergence of online communities, that individuals are willing to share mostly because 1) they feel happy to help others, and 2) it enhances their professional reputations (Allen, 2010; Ardichvili, Page, & Wentling, 2003; Janzik, 2010; Wasko & Samer, 2005). These two main incentives, both regarded as altruistic motivations and self-centred motivations (Allen, 2010), have induced the success of recent Web 2.0 communities, including Wikipedia, Facebook, StackOverflow, Digg, Wordpress, Yelp, TripAdvisor and Craigslist. The example of Wikipedia has shown that even without significant reward or reputation building, individuals are still willing to contribute (Wagner & Prasarnphanich, 2007). Wasko and Samer (2005) also pointed out that individual virtual reputations could be even more salient when linked to physical professional networks, e.g., an outstanding contributor from the online code sharing community, StackOverflow, could be viewed as a top quality programmer by companies. Although research has suggested that altruism can lead to reciprocated networks of practice, it doesn’t necessarily apply to the farming industry because of its competitive nature. Therefore, as Wasko and Samer (2005) assumed, along with other Web 2.0 communities, extrinsic incentives, including material rewards, e.g., monetary compensation, coupons, free products or free services, and immaterial motives, e.g., peer recognition, self-marketing, career opportunities (Allen, 2010; Janzik, 2010) could be applied to motivate users to share. The following section discusses such incentives in the context of three farming parties: farmers, consultants and scientists.

While social capital is recognized to be the main benefit of online knowledge sharing and an important source of competence for both organzations and individuals (Wasko & Samer, 2005), risks to privacy and the ‘incorrect’ behaviour of users is a reality, e.g., data spying, gaming the system, spam and fraud (Allen, 2010). However, Allen (2010) investigated successful Web 2.0 applications and believed appropriate mechanisms could solve these risks to some extent and prevent a contributor's enthusiasm from waning in regard to sharing.

5.4.1 The incentives for online sharing

According to *Diffusion of Innovations* theory, scientists, whether supported by profit or non-profit organizations, need to disseminate their research results to generate interest in their adoption. Therefore, the incentive for scientists to share knowledge is mainly diffusion of their latest knowledge or technology. In this scenario, there is no further rewarding mechanism needed to motivate scientists. However, there are also confidentiality protocols or intellectual property (IP) policies for each research project which may restrict the diffusion (Blakeney, 2002). Therefore, iFarming needs to provide users with the settings as to where and how a specific data record may be shared. These data privacy settings are discussed in Section 5.4.2.

Within the local farming community, some innovative farmers have always shared their experiences with others (Carolan, 2006). According to Lave (1991) and Wenger (1998), within this community of practice, members know each other and meet face-to-face to communicate and directly share information. These joint sense-making and problem solving practices build strong interpersonal ties and create direct reciprocity between members. In contrast, iFarming allows networks of practices, where geographically distributed members do not know each other nor meet face-to-face (Brown & Duguid, 2001), and therefore, have lower expectations of the immediate benefits when contributing (Wasko & Samer, 2005). Moreover, free-riders in this virtual community can access the same knowledge as everyone else (Wasko & Samer, 2005), and this has been regarded as a barrier to online sharing in general. However, networks of professional practices, e.g., legal knowledge exchanging (Wasko & Samer, 2005) and programming knowledge sharing (Stackoverflow, 2011), have proved that knowledge sharing practices in virtual communities exist across highly competitive industries. Innovative farmers gain their competence against others within the local community by keeping pace with the latest market information and technologies. Through building up reputations, individuals can have more opportunities to interact with scientists and consequently obtain external resources or support. Web 2.0 applications, such as StackOverflow, Sencha, Google Code and iPhone Dev SDK, award their contributing users with virtual points or “badges”. Accordingly, those outstanding users were given free services or rewarded with monetary compensation (Janzik, 2010), e.g., Google provides users with monetary rewards who report bugs in its products (Google, 2010). Similarly, respected farmers may gain opportunities to join participatory research programs, obtain the latest knowledge or even funding or compensation in return. As iFarming bases knowledge transfer on best practice sharing between farmers, in order to build their reputation as a farmer, it should allow learners to rate the value of the provided best practices in terms of data accuracy, completeness, and replication difficulty. Moreover, access by free-riders can also be taken into account. Therefore, contributors’ virtual points may be calculated based on those ratings and their accessing rates. This reward mechanism implies that government or research organizations should encourage contributing farmers by providing allowances or technical support to those with high points.

Traditionally, consultants gain contracts based on their reputation or ability to showcase past best practices. iFarming provides an open platform for them to demonstrate their success supported by a user-based rating system to build up their reputation in online communities. Consultants may worry that sharing their showcase projects may harm their own business, however there are difficulties in directly copying those revealed practices from farm to farm given that farming conditions do not fully coincide and some best practices need a third-party data provider, e.g., a survey of EM38. In this regard, consultants can share their best practices without supplying too many details. Similar to scientists, consultants may also be restricted by research confidentiality protocols and IP policies. The corresponding settings for data privacy are addressed in Section 5.4.2.

5.4.2 Group settings

Inappropriate user behaviour and privacy are two main issues for most Web 2.0 communities (Allen, 2010; Kumar & Kumar, 2010). The settings of the group, either direct (e.g., friendship, trading relationships and professional associations) or indirect (e.g., users reviewing the same posts), are both formed through sharing practices in online communities (Lai & Turban, 2008) and have played key roles in coping with ‘incorrect’ user behaviour (Allen, 2010). Group members either report inappropriate content for removal by the site providers, or organize themselves to edit and remove the content (Allen, 2010). These group-assisted or group-driven policies leverage users’ pursuit for high quality content, and eventually construct a sustainable content checking mechanism. In this regard, iFarming should also allow users to report inappropriate user behaviours or report practices, e.g., provision of obviously incorrect farming outputs or inappropriate fertilizer usage.

Group settings also play an important role in coping with privacy issues. Facebook has utilized group settings to prevent privacy intrusion by a ‘spy’ (Kumar & Kumar, 2010). Users can limit their content to only be accessible by their friends group. Similar settings have appeared in other online communities, e.g., Linkedin allows users to control visibility and accessibility of content to specific groups (Linkedin, 2011). As such, Linkedin has been regarded as the free-of-controversy site (Allen, 2010). As addressed in Section 2.3, local farming communities are common farming groups in Australia. These groups are formed either by geographic proximity or by common interest, e.g., cattle group or cotton group. Accordingly, iFarming could utilize these group settings in its design. Similar to Linkedin, the group coordinator would have the right to open a group in iFarming. Users who want to join the group, such as scientists, consultants and farmers, should be approved by the group coordinator. Knowledge published by individual users may be monitored, edited or removed by those who manage the group. Therefore, confidentiality protocols and IP can also be applied in the group regulations. Consultants and farmers specified in a certain group can control the accessibility of their content by either opening to the public or only to members of the group. Through the explicit formation of groups, iFarming can provide an adaptable knowledge-sharing mechanism for different users' needs. Innovative users can demonstrate their IP-free experiences to the public, e.g., how they manage grazing, while group users can keep their knowledge within the group, e.g., fertilizer usage records in a certain area. The group settings imply that iFarming-M should allow in-field users to login to the system wherever they are, but their read and write access to farm data should be authorized by the data owner, e.g., a farmer belonging to a cattle group could access the grazing data published and authorized by other group members, but could not access crops data secured by another group.

While the group settings can solve privacy and trade secret issues within the Web 2.0 communities, the motivation for sharing may be affected as they require additional input from users.

5.4.3 Conclusion

Knowledge, regarded as the core competence of an individual or an organization, has traditionally been protected within an organization, however the emergence of Web 2.0 communities has shown that sharing knowledge with strangers does not harm an industry, and in fact can bring wider prosperity, e.g., code-sharing allows faster development time for everyone. In the farming industry, knowledge sharing within local communities has existed for a long period due to the expectation of building interpersonal ties and immediate reciprocity. iFarming seldom brings those immediate benefits to the contributory users, but does provide other advantages, such as opportunities to showcase and build reputations. These indirect benefits bring users long-term rewards, such as diffusion of innovative technologies, additional supports from research units, and contracts from other users. Therefore, agricultural knowledge sharing across the virtual communities may share in the great success of other Web 2.0 communities.

5.5 Further Research

Rogers' *Diffusion of Innovations Theory* (2003) suggests that the innovators and early adopters, who in most cases are the *opinion leaders* in the diffusion process, have significant influence in spreading either positive or negative information about innovation in their local communities. The involved farming parties and audiences attending the case study and workshop, also recognized as the *opinion leaders*, provided valuable opinions on the prototype system, iFarming. Their opinions gave guidance to furthering the new knowledge management paradigm offered by iFarming.

5.5.1 Integration of external data source

As suggested in the case study, integration of external data sources may enrich the content of iFarming and provide more information for in-field users. This implies an investigation of the existing data sources may be available for integration and an analysis whether or not these data providers comply with the industrial standards, which in this case are the OGC's protocols. For example, the Bureau of Meteorology (2011) is an ideal data provider as they supply data regarding water and land services. It complies with the OWS framework, which is based on the weather data that can be retrieved by Web Map Service (WMS), Web Feature Service (WFS) and KML. Through sending a Http request with the required parameters, such as region area and layer names, a user can obtain images or geographical features from the data provider. To utilize this data source, iFarming needs to configure the service layer to support this external Http request and develop a module to request and parse the external data source. Accordingly, iFarming-W and iFarming-M would allow users to select interesting external data sources already configured by iFarming for display. The process is demonstrated in Figure 5.1.

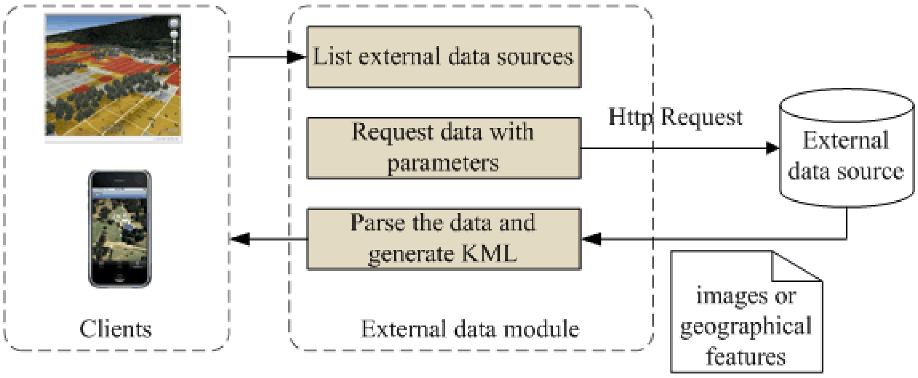


Figure 5.1 Process of utilizing external data source

5.5.2 Modelling tools

As addressed in Section 2.6 and Section 4.3.6, integrating modelling tools in iFarming could add knowledge of process to the developed approach to knowledge of form. This would ultimately advance knowledge application. This is achievable within the existing development because iFarming is based on a three-tier structure, where components communicate with each other through transmitting KML strings. This architecture allows each component to be developed independently but linked seamlessly, e.g., JTS Topology Suite is developed by Vivid Solution Inc., but offering advanced spatial analysis for iFarming-M. Components in the service layer are .jar files either developed by this research or retrieved externally. MATLAB™ Builder JA enables compiled MATLAB programs to be exported as .jar files which can be incorporated into iFarming through its service layer (MathWorks, 2011). This implies that models developed by an external modelling tool, e.g., MATLAB™, could be seamlessly integrated into the service layer of iFarming to provide computation services.

5.5.3 Data exporter

iFarming supports data export in KML format for analysis or modelling tools. This requires users to have advanced technological skill. For example, HARTT (Hydrograph

Analysis - Rainfall and Time Trend software), provided by the Department of Agriculture and Food in Western Australia (DAF Western Australia, 2010), is a software program that statistically estimates trends in groundwater levels. It requires users to manually input on-farm rainfall and groundwater level data in time series into an Excel™ file. When iFarming is able to store this type of historical data, the process will become more convenient if iFarming supports the transfer of such data into the standard Excel™ file required by HARTT. The development of this feature may be included along with the investigation of popular farming software to obtain the proper formats for the transfer of data. As iFarming-W supports data visualization on a map, a user can select data of interest, draw the region, and export the data in a specific format. As the case study suggests, if this feature is developed, iFarming data can be further analysed by other agricultural models to generate familiar reports for farmers.

5.5.4 Context finder

iFarming gives users the opportunity to compare their own the situation with that of other users with matching contexts, e.g., a user who runs a farm growing oats and is suffering high temperature and drought problems (indicated by low EM38 value) may be interested in the best practices of another farmer in a similar context. When stored knowledge grows due to the input of more and more users, context comparing may become a demanding task. In this regard, further research should develop a context finder to search similar contexts according to the inputs of the user. The example above has shown that there are three keywords available for context finding: oats, high temperature, and low EM38 value. By searching these keywords in the database, iFarming may find farms that share similar situations, or are able to visualize their farming histories, such as fertilizer usage and production data on iFarming-W. To achieve this feature, iFarming needs to list the available keywords for a user to select, and index the database according to these keywords for faster context finding. Besides finding a similar context, this feature should also sort a ranking of the best practices according to a user’s ratings, which may indicate if a best practice is applicable and effective.

5.5.5 Extension to other mobile platforms

As suggested above, saving battery life and designing a more user-friendly interface would be the main improvements to iFarming-M for better user-experiences. Moreover, as users may already use various mobile platforms (Table 3.1), iFarming-M should be extended to these platforms. In this regard, further research needs to investigate if these platforms support the KML protocol, and development applications.

5.5.6 Conclusion

The features proposed above can effectively improve the user-experience of iFarming and accelerate its diffusion. However, to achieve this, and as suggested by one of the users, this would involve a long-term collaboration with a larger group of users who can evaluate the limitations and strengths. Options for such an evaluation process will be investigated for future research. Moreover, built as a Web 2.0 application, iFarming should expand its users to larger numbers to achieve its best potential regarding collective intelligence. This requires iFarming to continually provide free services to the users; however this depends on an appropriate business model that may involve data providers.

5.6 Conclusion

This research has taken an important step forward in bridging the geographical and cognitive distance for distributed knowledge management. This research was made possible by both the emergence of smartphone technology and collaborative virtual environments, and acceptance of the concept of Web 2.0 by the public. The incentive for the research was to provide a new paradigm for distributed communication to improve existing knowledge management patterns. iFarming is a distributed knowledge management system developed for involved farming parties, farmers, consultants and scientists to better share knowledge. This research has brought all of these groups closer than ever before, with the purpose of overcoming the challenges in the context of globalization and climate change.

More specifically, iFarming, which offers a collaborative working environment for geographically dispersed users to share knowledge, provides a contextual knowledge database for experiences and best practices learning to ultimately advance the propagation of knowledge.

This thesis was inspired the work of Carolan's (2006). Carolan interviewed a farmer, Steve, who said:

'They, university researchers, seemed genuinely interested in what we had to say. I remember one time a farmer doing something, I think he was growing a herb, that a researcher didn't think would work given his soil type, but it was working. A lot of the time researchers' assumptions were challenged like that.'

In this instance, if the farmer and the researcher were given access to systems such as iFarming and its descendents, they could share their experiences with each other to ultimately improve scientific research and farming practice.

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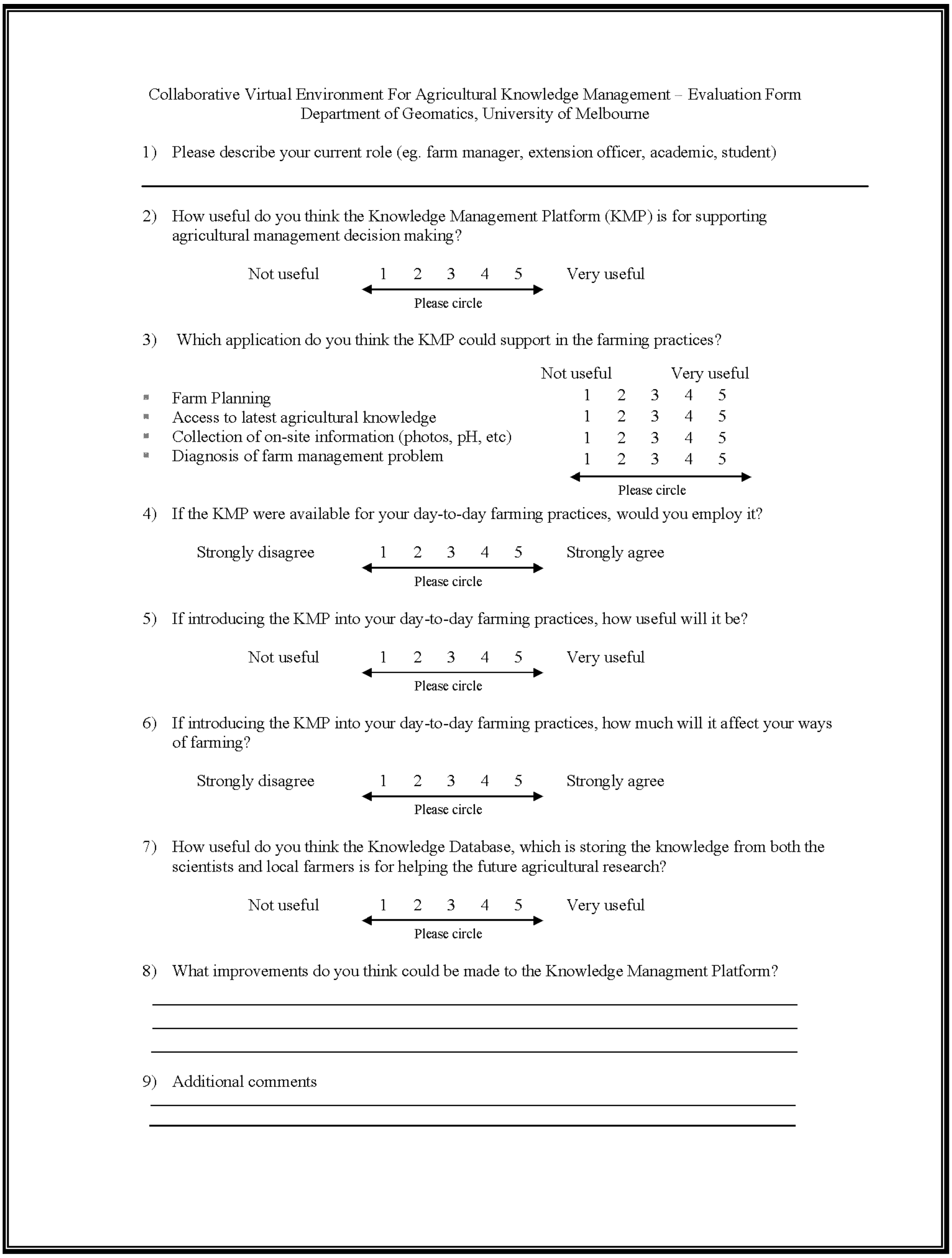
7. Appendices

7.1 Appendix 1: iFarming Evaluation Form



Collaborative Virtual Environment For Agricultural Knowledge Management – Evaluation Form
Department of Geomatics, University of Melbourne

1) Please describe your current role (eg. farm manager, extension officer, academic, student)

2) How useful do you think the Knowledge Management Platform (KMP) is for supporting agricultural management decision making?

Not useful 1 2 3 4 5 Very useful
Please circle

3) Which application do you think the KMP could support in the farming practices?

	Not useful				Very useful
▪ Farm Planning	1	2	3	4	5
▪ Access to latest agricultural knowledge	1	2	3	4	5
▪ Collection of on-site information (photos, pH, etc)	1	2	3	4	5
▪ Diagnosis of farm management problem	1	2	3	4	5
	Please circle				

4) If the KMP were available for your day-to-day farming practices, would you employ it?

Strongly disagree 1 2 3 4 5 Strongly agree
Please circle

5) If introducing the KMP into your day-to-day farming practices, how useful will it be?

Not useful 1 2 3 4 5 Very useful
Please circle

6) If introducing the KMP into your day-to-day farming practices, how much will it affect your ways of farming?

Strongly disagree 1 2 3 4 5 Strongly agree
Please circle

7) How useful do you think the Knowledge Database, which is storing the knowledge from both the scientists and local farmers is for helping the future agricultural research?

Not useful 1 2 3 4 5 Very useful
Please circle

8) What improvements do you think could be made to the Knowledge Managment Platform?

9) Additional comments

7.2 Appendix 2: Publications resulting from and related to this research

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