Internet of Things (IoT), PBL and 3D Holographic modelling for smart agricultural education at The University of Queensland

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The project described in this paper builds on exciting technological developments in real time biophysical data gathering that are currently happening at The University of Queensland (UQ)'s regional campus (UQGatton ~1000ha of prime agricultural land ~85km SW of Brisbane in SE Queensland), via the Internet of Things (IoT) UQ Smart Campus Project.

This paper will describe the development of multifaceted web-based interfaces, problem based learning modules, and 3D modelling using the real time streaming data acquired through the Internet of Things (IoT) technology of the UQGatton Smart Campus Initiative. The idea is to produce innovative teaching and assessment modules for multiple different courses in the UQ Science Faculty, and across 2 Campuses separated by 85kms of highway. The paper describes the technology involved, the challenges and workarounds and a number of examples of using the data collected for problem-based learning modules. Some discussion is included on what these technologies could provide for further Teaching & Learning developments in the "E" space being trialed with partners UQ ITS, Microsoft and Telstra/Readify.

Introduction

The world has a problem. There is a soaring global population, we need to feed more with less resources and food production must become smarter and more sustainable (FAO 2009). Additionally, a very real issue for the agrifood sector as a whole (broadly speaking the category structure of the agrifood industry consists of grain, livestock (beef and dairy), and horticulture), is that the average demographic of people in the production sector across the world has increased significantly over the last 20 years. In Australia the median age of farmers in 2011 was 53 years, compared with 40 years for people in other occupations, and almost a quarter (23%) of farmers were aged 65 years or over, compared with just 3% of people in other occupations. Moreover, the number of farmers in Australia has been declining for many decades as small farmers sell up to large-scale farming operations, and fewer young people take over family farms. (Productivity Commission, 2005).

In essence, it is difficult to get young people into agriculture and related areas because it is perceived as labour intensive, non-academic and lowly paid. Actually, is far from the truth, but the perception is there among young people and their parents (Bryceson 2006) and it is not only frustrating the agrifood industry generally, but also educators in the sector.

A potential solution – or at least part of a potential solution to these problems in the agrifood sector are a combination of: (i) the use of technology for developing smart agricultural practices, and; (ii) the use of technology as a student engagement and teaching tool (Bryceson et al 2016). We believe this to be the case because technology is all pervasive in the business world today and is a strong focus of domestic and international deliberations in the agrifood industry (Australian Farm Institute 2016; Gasiorowski-Denis 2017). Finally, miniaturisation of electronics & automation are key drivers of innovation and are being pursued avidly around the world as a way to 'disruptively' innovate legacy systems in various industry sectors. Indeed, the Australian Farm Institute's 2016 paper and associated Conference "Disruptive technologies in Agriculture, Sydney 2016" refer to disruptive technologies in Agriculture as being key to success for the sector the future.

A disruptive innovation or technology is one that 'disrupts' or 'overturns' traditional business methods and practices and which in the long term leads to the creation of new 'ground-breaking' products (Christensen and Overdorf, 2000). Over the last decade, disruptive technologies in the form of mobile computing (including social media for marketing purposes), Internet of Things (IoT) technologies to collect and transmit real time data, the use of cloud computing to facilitate the analysis of such generated 'Big Data' and Robotics to make use of the data, have been identified as having impacted the agrifood industry in an unprecedented way to create and capture value across the whole chain (Bourlakis et al., 2011; Lehmann et al., 2012, Hall 2016).

In this paper we will describe three technologies that have potential to disrupt agricultural and related education to create engagement in agriculture by young people through more technologically enabled and more realistic learning opportunities for tertiary students. These technologies are the Internet of Things and big data capture and use, "Active" Problem Based Learning in a technologically enhanced learning environment, and 3D Holographic modelling.

The Internet of Things (IoT) & UQ Gatton Smart Campus initiative

The 'Internet of Things' (IoT) is defined as: "A network of physical objects that contain embedded technology to communicate, sense &/or interact with their internal states or the external environment and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction" (Gartner, 2016). In fact we are in the midst of an Internet of Things (IoT) revolution (Xu, et al., 2014). While the smartphone still rules as the de facto Internet connected device, many everyday "things" are becoming connected to the Internet and gaining a cyber-presence. These include not only man-made artefacts but also components of nature such as an individual tree in the landscape in which it resides (Harris, 2015).

With the growing popularity of the Internet of Things (IoT) technology, (which includes both smart wireless network technology and sensor nodes), there has been extensive research on the use of wireless sensor networks or IoT in agricultural research studies, ranging from on farm through to market and into agricultural education. For example, IoT systems have been set up for real time biophysical data collection for use in environmental monitoring, precision farming, precision irrigation, precision livestock and cold chain logistics. Of great interest in a world of changing climate is efficient waste water management practices which can be facilitated by the use of IoT technologies. Vellidis et al., (2008) developed a smart sensor system integrating moisture sensors, thermocouples and RFID tags for scheduling irrigation in cotton. Kim et al., (2008) reported a wireless sensor network for controlling irrigation interfaced using low-cost Bluetooth wireless radio communication with the base station. Sensors attached to a can be used for monitoring the presence and concentration of toxic substances near rivers and aquifers, where chemical runoff can contaminate drinking water supplies.

The 'Smart Campus' project at UQ commenced in December 2014 and was aimed at developing an IoT multisensory mesh network encompassing everywhere on The University of Queensland's rural 1000ha campus at Gatton (Figure 1) and which is covered by Wi-Fi and/or LORA radio technologies.

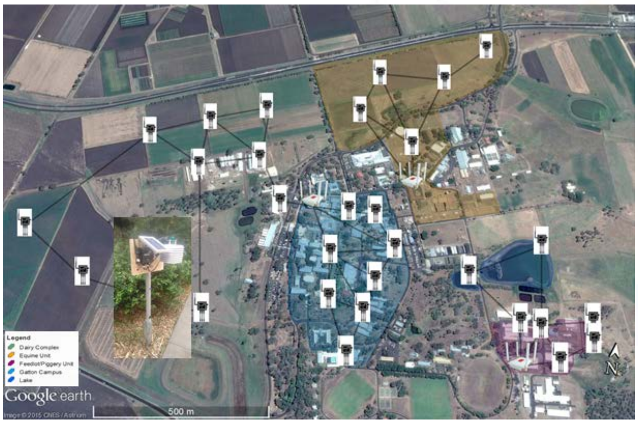

Figure 1: UQ Gatton Campus with identified multi-sensor nodes located on a Google Map image of the area

The specific areas covered by the network include: cattle backgrounding paddocks and feedlot, horticultural fields, equine foaling unit and collocated equine paddocks, piggery, dairy and the "built environment" (particularly for radiance, dust, noise etc). The mesh network also includes sensors capable of measuring the water level and chemical content of the farm ring tanks, dams and the piggery effluent and associated waste water management lakes (Figures 2 and 3). Data is collected continuously in real time and stored in the Australian National Research Infrastructure Cloud (Nectar).

Figure 2: Libelium Smart Agriculture, Water, Environment, and Security Models used in UQSmart Campus initiative 2016. Images of models from Libelium webpage - http://www.libelium.com/products/plug-sense/models/ and a list of sensors being used at UQGatton from Libelium http://www.libelium.com/products/plug-sense/models/

Figure 3a): Multisensor Mesh physical set up on farm; Figure 3b) Smart Water node on UQGatton Environmental Management lake – Lake Galletely

IoT technology as a sustainable educational infrastructure for delivering real time biophysical data

The UQGatton IoT network comprises approximately 40-60 multisensor nodes (dependant on academics' needs) in a wireless enabled network, was originally set up for agricultural and environmental biophysical data collection in the managed landscape, mainly for research purposes. The data collected amounts to a big data set (a collection of data from traditional and digital sources). Appropriately analysed, it can improve visibility (Barratt & Oke, 2007) and sustainability performance (Schoenherr & Speier-Pero, 2015).

A significant amount of time went into the design of the IoT mesh network and in choosing the technologies involved. The main requirements were that we had a large area to cover so needed a network typology that was flexible, self-configuring, self-healing (ie fault tolerant) and able to relay data over long distances, we chose a mesh multi-hop network (Zawawi et al., 2012), (Fig 4). We also needed a wide choice of sensors enabling many problem scenarios to be developed and the network needed to be robust & have low set up and maintenance needs and costs.

Figure 4: Waspmote mesh network typology

The Waspmote technology of Libelium addressed these needs with the added benefit that each node is solar powered (imperative for field implemented technology), with 12+ hours of backup power and the UQ network link failure protection in place to ensure data integrity. When using Wi-Fi the system is connected to Eduroam.

The system has modular embedded "Plug & Play" components and sensors that are compatible with standard interfaces and protocols, e.g. RS-232, RS-485, Modbus which are capable of reading & transmitting as many as 20+ variables (most of ours currently = 6+). The nodes are autonomous with a smart CPU and all are remote wireless programmable using Arduino-like software (IDE) (Arduino 2016) which is also compatible with what is currently being taught as part of the Australian High School curriculum.

However, the IoT system has since been further developed to create a multifaceted web-based interface to the data (Data Dashboard) and problem based learning modules using the real time streaming data from the IoT to produce more engaging and active learning based teaching tools (Figure 5).

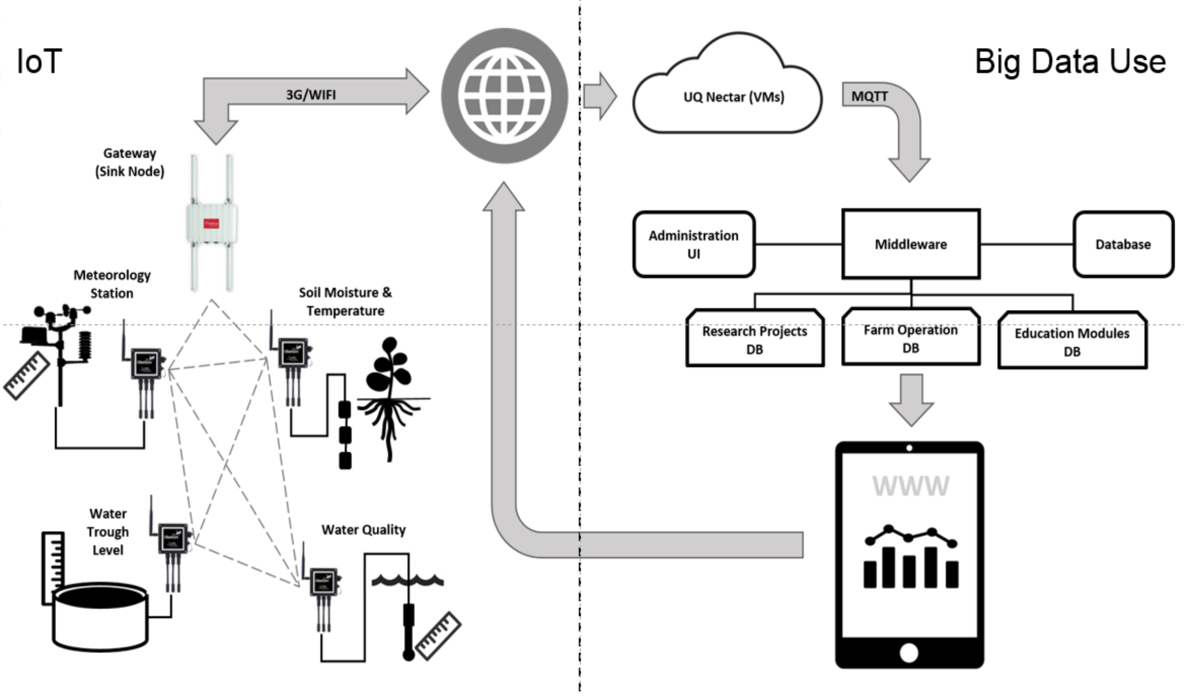

Figure 5: UQGatton IoT multisensory mesh network development and Big Data use in 2017

Technology Enhanced Learning (TEL) Project

The TEL project has a pedagogical philosophy of 'active learning' which is generally defined as any instructional method that engages students in the learning process and where students are required to do meaningful learning activities and think about what they are doing rather than just listen: they must read, write, discuss, or be engaged in solving problems through higher order thinking tasks such as analysis, synthesis, and evaluation (Bonwell & Eison, 1991).

Of the three active learning scenarios defined by Prince (2004), (collaborative learning, collective learning and problem-based learning) this project addresses the development and use of in-context problem based learning (PBL) where relevant problems are introduced during instruction and are then used to provide the motivation for the learning of other material. Wood (2003) identifies how the learning takes place in a PBL approach when she says: "*In problem based learning (PBL) students use "triggers" from the problem case or scenario to define their own learning objectives. Subsequently they do independent, self-directed study before returning to the group to discuss and refine their acquired knowledge. Thus, PBL is not about problem solving per se, but rather it uses appropriate problems to increase knowledge and understanding".*

To value add to the PBL approach this project is using real time data streaming in from a range of biophysical sensors located around the UQGatton Campus and associated farms as the basis for agricultural and environmental problem solving exercises for students in a range of courses across the Faculty of Science at UQ (for example Agronomy, Agribusiness, Equine Science, Animal Production (various aspects), Maths and Statistics, Waste water science and management, Soil science, Chemistry, Wildlife Monitoring, Animal Reproduction, Sustainability monitoring, Plant pathology, etc etc). The idea being to engage students in real world issues that they will have to deal with when employed, using the current fascination of young people with the ubiquitous 'e' enabled environment of today, to provide the source of learning.

Wood (2003) points out that PBL is successful only if the scenarios are of high quality and suggests that for this to occur the following should be adhered to:

- Learning objectives of the problem to be presented should be consistent with the course learning objectives
- Problems should be appropriate to the stage of the curriculum and the level of the students' understanding
- Scenarios should have sufficient intrinsic interest for the students or relevance to future practice
- Basic science should be presented in the context of the scenario to encourage integration of knowledge
- Scenarios should contain cues to stimulate discussion and encourage students to seek explanations for the issues presented
- The problem should be sufficiently open, so that discussion is not curtailed too early in the process

- Scenarios should promote participation by the students in seeking information from various learning resources

The PBL design process that is being used is a simple step based approach to the development of each PBL module following a modified design process of the Frey & Sutton (2010) Step Multi-media design approach:

Step 1. Define the instructional goals, objectives, and audience
Step 2. Review and investigate existing options (e.g. in our case system software)
Step 3. Determine the content, activities, and assessment strategies
Step 4. Develop the flowchart, site map, and/or storyboard for each module
Step 5. Develop a prototype
Step 6. Perform a formative evaluation (does it do what you want it to do)
Step 7. Complete the design.

The PBL scenarios within this project are/will be delivered online and will be useful for a number of years without necessarily needing updating or changing. This is because the data changes in real time so that problems developed, while the same for each year, will have different outcomes dependent on a specific year's data. Given this, we suggest that functional aspects of the delivery, and the interface with the technology such as software, applications system and graphics design, are very important to 'get right' in order to provide a sustainable quality learning experience.

Technology enhanced learning system

The proposed system consists of several software modules that will enable the creation of multifaceted applications from real-time biophysical sensor data collected at the UQ Gatton campus. Primary among these software modules is an Internet of things (IoT) middleware whose main purpose is to act as a hub which connects heterogeneous sensor devices and data gathered by them to multiple applications (Fig 5). The existing IoT platform is being leveraged for this purpose and provides the following functionality:

- Receive sensor data in real-time from the Gateways (i.e. Meshliums) and make them available to applications and store them in a database in a flexible format.
- Provide APIs (Application Programming Interfaces) which can be used to build applications that make use of real-time and historical sensor data.
- Be robust and scalable as number of devices, data volume and application usage grows.
- Maintain a registry of sensor devices and thereby provide device management capabilities.

Having evaluated several IoT platforms we have chosen the SiteWhere open source IoT platform. While communication with the current Libelium devices is done using the IoT specific machine-to-machine protocol MQTT (http://mqtt.org/) the middleware allows use of other protocols if needed. We intend to build multiple applications which feed off the UQ Gatton sensor data. These will connect to the REST APIs exposed by the middleware module.

The existing applications include a generic Data Dashboard dashboard app to visualise sensor data in real-time via charts and a mapping tool, plus multiple other eLearning applications which can provide course focused visualisations and assessments. As part of the dashboard app, users have the option of downloading raw sensor data (e.g. in CSV format) for use with external applications such as Excel or the statistics package 'R'. We have also have an app to enable an existing gamified crop fungal development program to use the IoT data, the development of an online 'fishtank' linked into the IoT that represents a water chemistry scenario and a Waste Water Management module which we detail below.

Further possibilities include applications which will perform business-oriented data analysis and provide more relevant information for the likes of farmers, land managers etc.

Waste Water Management PBL

In the water management PBL the basic scenario is that of a Waste Water Management issue associated with a Piggery effluent system – in particular managing the development of algal blooms that are an indicator of poor nutrient management.

In Fig 6 there are four Smart Water Nodes with sensors measuring chemical variables in the water, distributed throughout a series of Lakes and Ponds that make up the Piggery Effluent Management System at UQGatton. Piggery effluent gets released into Lake Galletly from effluent settling ponds directly below the piggery. Smart Water Node 1 is located at the entry point of effluent into the Lake. The effluent gets diluted as it is moved through Lake Galletly by water aerators and pumped out into Mac's Pond where Smart Water Node 2 is recording incoming chemical content of water. The effluent is further diluted in Mac's Pond over x time period and allowed to move via gravity through a bio-filter (small native forest and grassland), to Lake Lenore where Smart Water Node 3 is recording water quality. Water then overflows into Lake Galletly and moves (without aerators turned on) towards the outlet pump at top right hand side of image where it will be pumped out onto the paddocks surrounding the piggery as irrigation water. This water then seeps down and back into Lake Galletly (which is a constructed lake).

Various scenarios can be developed and storyboarded around monitoring chemical content of water and management practices: for example changes over time, changes around the Lakes and Pond systems, diurnal fluctuations, impact of events such as effluent input and natural rain input allowing nuances in chemical content to be analysed and questioned in relation to management practices. The mesh network does also allow both the aerators and the pumps to be turned on and off if required - however as this is a working piggery and waste water management system, these services these services will only be available to the Farm staff – and will NOT be available to students other than in a simulation.

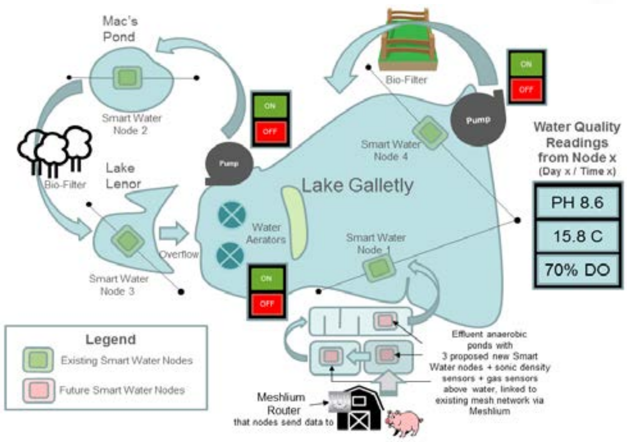

Figure 6: Piggery Effluent and Waste Water Management Scenario

Waste Water Management PBL Module in Augmented Reality
This module is currently being further developed as part of a project investigating the value of other online educational tools including Augmented Reality, Virtual Reality and Mixed Reality (Bonde et al., 2014; Makransky, et al., 2016; Thisgaard & Makransky, 2017). A single water unit in the waste water management system (Lake Galletly) is being developed into a 3D holographic model (both above and below water) using IoT data from the physical environs of the Lake (e.g. rainfall and temperature) and chemical data from below the surface of the Lake as input into the model.

A rules based model of the various chemical systems working in the Lake (e.g. nutrient acquisition, dissolved oxygen build up or decline, phytoplankton build up/decline and fish health as a result) was first developed in STELLA (agent based deterministic modelling software) and then further developed using UNITY (a "game engine in a box") (Infante, 2017), and CSharp to build the 3D assets. The scenario being storyboarded is that of a Fish Farm that has befallen a disaster of dead and dying fish and what does the student do about it?

The idea is for students to interact with the holographic model to pull apart the system using Microsoft's Augmented Reality technology, the Hololens (https://www.microsoft.com/en-au/hololens). This technology will provide a very different (disruptive) teaching tool by providing an immersive experience for students that is not possible with standard lectures and practicals (Christian, 2016). Evaluation of the Project in terms of student learning outcomes, student enjoyment and feasibility over the long term will be available by the end of November 2017.

Challenges and conclusions to date of IoT + TEL project

There have been a number of challenges associated with TEL project. These include:

Technological

- Managing costs and ensuring sustainability of the overarching system by keeping the system design based around freeware (i.e. no long term costs for ongoing software licences).
- The development of appropriate design rules for the system around data management and storage so that additional PBL modules can be developed easily and quickly as they come to mind or as other organisations wish to build them from the UQGatton datasets for their own students.
- Creating assets in UNITY so academics can develop their own teaching scenarios using off the dashboard data and tools.

Pedagogical

- Getting academics to visualise how they can use real time data in an online or web-based format in their courses for adding value to the learning experience.
- Finessing the storyboarding for each PBL and developing challenging assignments associated with them is key to providing quality learning outcomes.
- A particular challenge in developing eLearning applications using real-time sensor data are that assessments need to match the conditions represented by the data. Possible solutions include:
  - Creating generic questions that do not depend on the trends displayed by the data.
  - Incorporating into the application, the ability for the student to deduce the correct answer from the real-time data provided.
  - Providing a snapshot of the data together with the student's answer so that the teacher can make use of it in marking.

- Including a simulation (as discussed in the waste water management example above) of an 'event' or 'hazard' or 'disaster of management issue' that uses real time data in order for students to develop a solution.

In conclusion - we have had good interest from academics across a range of disciplines with the idea of using real time data for developing PBL modules for their courses. An unexpected benefit is that while most academics started their involvement with the project with a strong discipline focus, it is pleasing to note that many are now talking about integration across the broad spectrum of content to better enable students to see the relevance of an individual course in the context of their whole Program/ learning experience.

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