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Streaming and 3D mapping of AGRI-data on mobile devices

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ABSTRACT

Farm monitoring and operations generate heterogeneous AGRI-data from a variety of different sources that have the potential to be delivered to users 'on the go' and in the field to inform farm decision making. A software framework capable of interfacing with existing web mapping services to deliver in-field farm data on commodity mobile hardware was developed and tested. This raised key research challenges related to: robustness of data steaming methods under typical farm connectivity scenarios, and mapping and 3D rendering of AGRI-data in an engaging and intuitive way. The presentation of AGRI-data in a 3D and interactive context was explored using different visualisation techniques; currently the 2D presentation of AGRI- data is the dominant practice, despite the fact that mobile devices can now support sophisticated 3D graphics via programmable pipelines. The testing found that WebSockets were the most reliable streaming method for high resolution image/texture data. From our focus groups there was no single visualisation technique that was preferred demonstrating that a range of methods is a good way to satisfy a large user base. Improved 3D experience on mobile phones is set to revolutionize the multimedia market and a key challenge is identifying useful 3D visualisation methods and navigation tools that support the exploration of data driven 3D interactive visualisation frameworks for AGRI-data.
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1. Introduction

Delivering secure and sustainable provision of food, water and energy, particularly in the face of climate change and reduced carbon targets is a huge challenge. Precision Agriculture (PA) and sustainable intensification has been advocated as a scalable solution to modern global food security challenges by saving time, energy, water and money (Karetsos et al., 2014; Whitacre et al., 2014; Santana et al., 2007). PA stemmed from the desire to manage farms more sustainably. Traditionally PA has been restricted to those that can afford the latest technology, but maturation and ubiquity of enabling digital and mobile technologies are set to transform PA (Whitacre et al., 2014; Karetsos et al., 2014; Butler, 2006). This is supported by various UK, USA and EU strategies for encouraging innovation in agriculture (e.g. UK Agri-Tech Strategy (HM Government, 2013) and associated AGRIMETRICS (Tiffin, 2017) and EUs FIWARE (López-Riquelme et al., 2016) accelerators) supporting a revolution in the use of data science from "farm to fork".

Precision Agriculture (PA) is tightly coupled to the Internet of Things (IoT) and converting big data, originating from heterogeneous sources, into information is a key challenge (Mulla, 2013; Zhang et al., 2002). There is however a growing need for "on the go" decision-making tools for in-field viewing of relevant farm data (Ying et al., 2012; Chittaro, 2006; Pombinho et al., 2007). Mobile technology that interfaces with existing farm servers could deliver data that offers early warnings of potential issues in the field e.g. assessing the risks of disease and pest outbreaks or poor crop performance. The authors see such a mobile tool as complimenting the rich landscape of Farm Management Information System (FMIS) presented by Fountas et al. (2015) and illustrated in Fig. 1. However, to progress there are two technical challenges that need to be addressed:

- Streaming data efficiently from a farm server to a commodity mobile device
- Implementing and evaluating different interactive 2D and 3D visualisation methods for the display of AGRI data on a mobile device

Previous mobile applications (*apps*) have been developed for farmers and agronomists, but these apps are focused on specific

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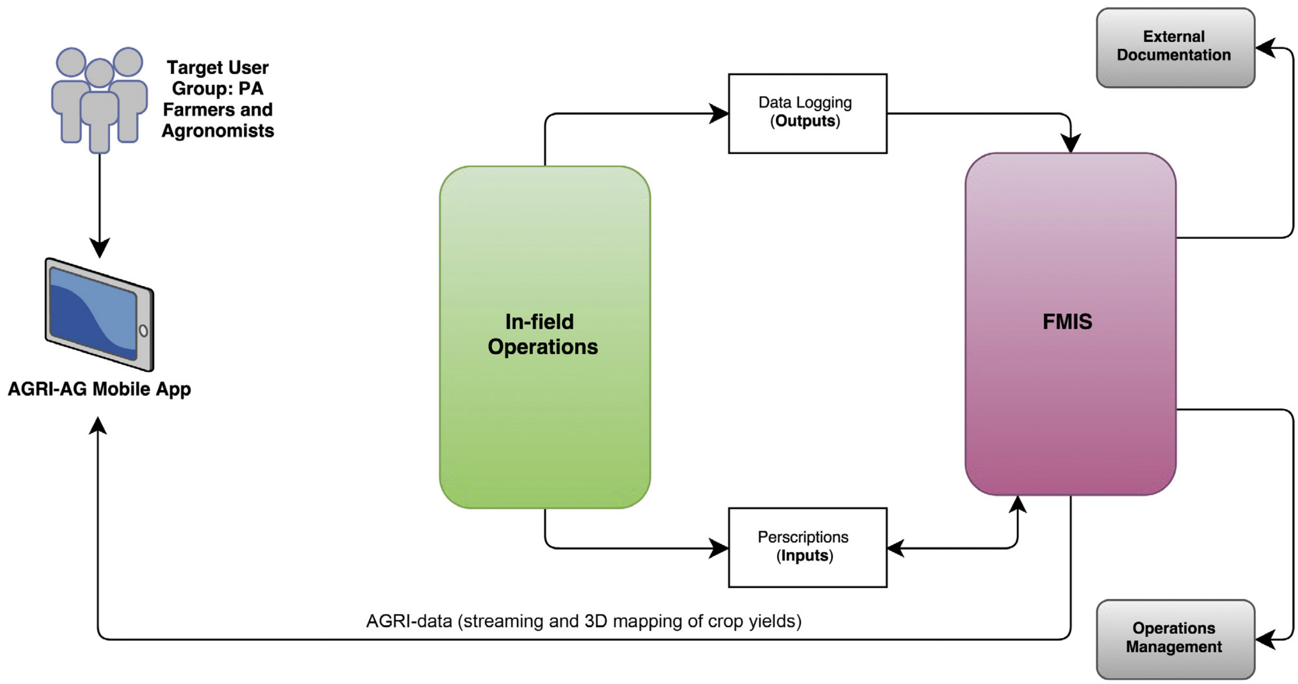

Fig. 1. Example integration of the AGRI-AG app, and related app inputs, into an existing FMIS. Adapted from Fountas et al. (2015).

needs (e.g. soil nutrient approximation), and utilise 2D visualisation methods (Hopkins, 2013). Mobile devices (tablets and/or smart phones) are now ubiquitous with more memory, faster processors and feature a programmable Graphic Processing Unit (GPU) (Shebanow, 2013). GPUs can be programmed via special programs called *shaders*, which permit sophisticated mobile graphics once reserved for video games and PC-based visual simulations (Akenine-Möller et al., 2008; Falconer and Houston, 2015). Mobile graphics hardware is designed to work with texture data efficiently. The benefits of using high resolution aerial photography (Lange, 2001) and interactive 3D landscapes (Lovett et al., 2015; Falconer et al., 2015) for enhancing user engagement has been highlighted. Additionally mobile GPS hardware can be exploited to ensure relevant data is delivered to users by linking GPS to the Field of View (FoV) (Burigat and Chittaro, 2007; Tsiropoulos and Fountas, 2015).

Recently (PIX 4D, 2016) released software to construct 3D textured Digital Elevation Models (DEM) of FARM DATA, captured using unmanned aerial drone, or using sensors. There is a growing recognition in the AGRI sector that 3D visualisation is a useful tool as exemplified by Gepiel et al. (2015), where a PC-based 3D visualisation of in-field sensor data is created. A review of ICT-AGRI ERA-NET EU funded projects for 2010 to 2015 features few utilising 3D content with the exception of VAROS (Jordan, 2016). Further, there is a paucity of mobile applications for PA with interactive 3D visualisation and this is primarily a consequence of two issues. Firstly, the skills set associated with 3D graphics does not intersect with the traditional AGRI sector. Secondly, the real benefits of mobile 3D content have yet to be discovered in this sector. At the time of writing, the authors were not able to find a specific example of a 3D visualisation specifically for crop yield analysis on a mobile platform.

A software framework for streaming and rendering data in 3D, with potential applications to crop scouting, is presented based on mobile game technology. The software framework combines virtual texturing and streamed farm data to inform 'on the go' decision making. The technology is demonstrated using crop yield data and high resolution aerial photography although it can in principle display other AGRI data. The proposed AGRI-AG mobile app, enabled only by the multidisciplinary convergence of game technology with AGRI data, has the potential to transform in-field crop monitoring and inform early decision-making by growers to improve efficiency/profitability of the farming industry, providing healthier, more affordable food for the future.

2. Software development

2.1. Application

The Model Viewer Controller (MVC) is a common and well documented software design pattern (Vlissides et al., 1995) and this methodology guided the development of the app. The MVC pattern is widely used and suitable for applications that require user input via a graphical user interface (GUI). The MVC pattern is also the default and recommended software design pattern for developing Android applications (Phillips and Hardy, 2013).

Fig. 1 illustrates how the AGRI-AG app can integrate into the existing FMIS landscape, which is reviewed in Fountas et al. (2015), to support crop monitoring illustrated here by delivering *yield maps*.

Fig. 2 shows the components of the AGRI-AG application, implemented as an Android mobile app and highlighting the data streaming, processing and rendering stages.

AGRI-AG user input is facilitated through the mobile app's user interface as well as GPS functionality. Users can navigate the 3D scene using gestures for zooming, rotating and panning the 3D scene. The GPS coordinates are used to centre the users view in the 3D scene, which acts as a virtual camera so that users can freely navigate the scene. The different methods for AGRI-data presentation is by the toggling of radio buttons.

The 3D scene comprise a textured Digital Elevation Model (DEM) and different methods to present yield data (in 2D and 3D). Two streaming methods delivering large textures e.g. high resolution aerial photography from UAV, but this could also be satellite infrared imagery for assessing crop health, are investigated. Although the desire is to integrate the mobile technology with

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