MIPRO 2018, May 21-25, 2018, Opatija Croatia

IoT solutions for precision agriculture

Richard Charles Andrew
Department of Mechanical Engineering Science
University of Johannesburg
Johannesburg, South Africa
Email: richard.andrew@minpet.co.za

Reza Malekian
Department of Electrical, Electronic and Computer Engineering
University of Pretoria
Pretoria, South Africa
Email: reza.malekian@ieee.org

Dijana Capeska Bogatinoska
Faculty of Computer Science and Engineering
University of Information Science and Technology St. Paul the Apostle
Ohrid, Republic of Macedonia

***Abstract*—In this paper, precision agriculture is set to provide higher productivity and a better use of resources when compared to traditional methods and this will result in lower costs with higher yields. A crucial activity for crop farming is water irrigation while for livestock farming it is the monitoring of animal health. This paper presents two feasibility studies on IoT solutions for automated irrigation and one study for automated animal monitoring. In each, the proof of concept is verified to operate under normal field conditions.**

***Index Terms*—Internet of Things, precision agriculture, sensor based irrigation, Big Data analytics.**

I. Introduction

Precision agriculture (also known as smart farming) uses internet of things (IoT) solutions together with Big Data methods to provide for more efficient management of resources. It is a significant vertical market [1] that includes the management of crop yields, livestock, seeding, fertilizer use and water. The benefits of precision agriculture (PA) include increased profitability and reduced environmental impact [2].

In the early years, PA consisted mainly of map based technologies using geo-statistical methods like GIS and satellite remote sensing and the main application of PA was to manage fertilizer use [2]. Sensor use was not widespread since sensors were either too costly, too inaccurate or unavailable for the applications required. Surveys during the early 2000's showed that few farmers used PA technologies and the main barriers to the adoption of these methods were the lack of technologies to deal with the large amounts of information, the lack of scientific validation, high costs and no training or technology transfer [2].

This has changed with the development and testing of prototype PA systems, the rapid development of IoT [3] and Big Data [4], and the decreased cost of sensors. IoT solutions in agriculture now form a cycle of i) monitoring through sensors, ii) analysis and planning, and iii) smart control, all linked by a wireless network connected to a cloud service (as shown in Figure. 1) [5]. Big Data analytics [6] and machine learning [6], [7] can be applied to the data to help make informed decisions [8] and the create intelligent control. This paper will consider past feasability studies in irrigation and livestock monitoring [9] and will present the main conclusions found.

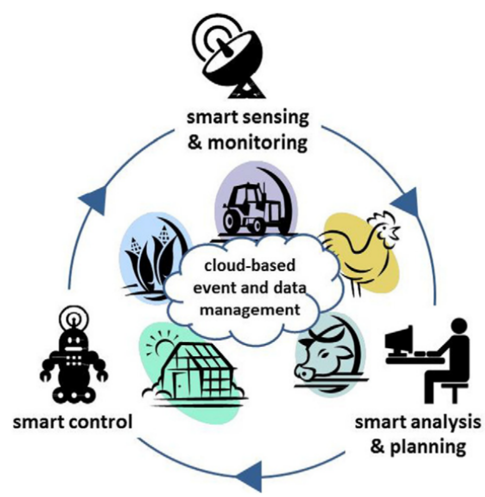

Fig. 1. Precision agriculture IoT wireless system [5]

II. Sensor based Irrigation

The success of crop farming relies on proper irrigation. Under-watering reduces nutrient uptake while over-watering causes leaching which poisons ground water [10]. Early water management [11] relied heavily on projected weather patterns, past farming activities and the manual observation of soil conditions; for instance, McKinion et al. [12] used GIS information [13] (based on soil samples and past farm use) as inputs for crop simulation models to optimize water and nitrogen use on a 201 ha cotton farm. Around the same time an automated irrigation system was prototyped using a central computer control centre [14], [15] linked to field irrigation valves [16].

This system by Damas et al. had the hallmarks of a modern IoT solution [17], [18] since it was made up of rudimentary sensors measuring water pressure and flow volume, simple

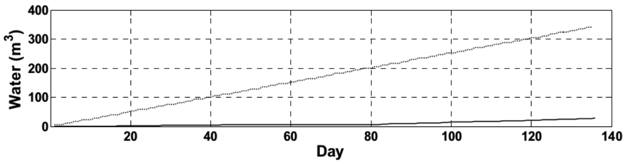

Fig. 2. Water volume for the greenhouse irrigation system (bottom line) as compared to traditional methods (top line) [23]

solenoids controlling the irrigation valves, and a central computer management system [19], [20] all linked together with a network of omni directional UHF radio antennas. 1500 ha of irrigated land was covered with an irrigation system comprised of 1850 valves, 1850 meters and 32 pressure sensors. The management software monitored the sensors [21], controlled the valves while assessing water use to correctly bill the supplied communities. Although the system could more efficiently distribute water to irrigation users it was not fully automated since it lacked control feedback from the fields. This requires the use of soil and moisture sensors [22, 1].

Such an experimental system was developed by Gutirrez et al. [23] to irrigate sage crops in a greenhouse. The main components of the system were sensor units joined to a central micro controller through a ZigBee network. A General Packet Radio Service unit relayed the sensor data over a cellular network to a server with a database. Each sensor unit is comprised of a temperature sensor, a moisture sensor, solar power cells with rechargeable batteries with a ZigBee radio unit. The unit is low-power with a sleep mode to reduce consumption. ZigBee unit was chosen due to its low price and efficient power consumption. The micro controller sends data to the server and receives instructions to activate irrigation. It also directly processes sensor data to implement automatic irrigation. Lastly the irrigation pumping system consists of two pumps activated by relays. A web application is used for monitoring and determination of an irrigation schedule. It is also used to set threshold values on the WIU for the automated scheduling. A SQL database is used for storage.

Testing was done over 136 days to compare it to the traditional irrigation method that used human supervision. Both methods used the same flow rate per drip hole during irrigation. The traditional irrigation schedule consisted of watering 42 production beds for 5 hours three times per week. The automated system watered 14 beds for only 35 min/week for the first 6 weeks then 35 min every three weeks along with automatic watering triggered by the sensor feedback of temperature and soil moisture. Threshold values to trigger automatic irrigation were set based on the producers experience. The total water use (for 14 beds) shown in Figure. 2 show a $\sim 90\%$ reduction in water use using the automated system as compared to human supervision.

Advantages of the system are low power consumption, reasonable cost, long power life due to the solar cells and efficient water management. The study showed that a wireless sensor based irrigation system is an effective solution to cut water use.

An outdoor system was developed by Coates et al. [24] to irrigate outdoor nurseries and orchards. It used a commercial system developed by MEMSIC (Andover, Mass., USA) consisting of soil moisture sensors that communicated over a low power, IEEE 802.15.4 standard mesh network to a base station connected to a computer with a SQL database. The system shares many features with the previous greenhouse system such as solar panels and control relays except everything is geared towards outdoor field irrigation. The actuator units contained a micro controller that received sensor data and controlled irrigation valves with latching solenoids. The application software monitored sensor and actuator operation and sent control instructions to the actuators units based on a preprogrammed schedule or irrigation rules based on sensor information. Advantages of this system are long range connectivity, outdoor design, a grid network enabling communication between nodes and long power life due to solar cells. The estimated cost of a working system with 10 sensor nodes with 1 actuator along with the estimated savings per year due to the reduced labor, fertilizer use and water use costs meant that cost recovery would take about 4.5 years.

The system was tested for network and valve actuator robustness. The network tests shown in Figure. 3 show that nodes connectivity depended on line of sight conditions a ranged from 100 m to 170 m. It was also noted that once the node successfully joined the network, communication remained stable. The actuator stress tests showed that the system withstood over 11000 normal actuations and over 6000 short circuit events. Short circuit testing was crucial since short circuiting valve wires is a common mistake made in the field. Further field testing done for nursery, landscaping and orchard applications revealed no major mis functions. The system showed that a commercially available sensor network could be used to actuate valves for a large scale irrigation system under normal operating conditions.

III. Sensor based Livestock behavior Monitoring

Animal farms require healthy stock to provide maximum profits. Many detectors have been developed to monitor the individual health of animals. These wearable sensors monitor various health indicators to identify disease and infection [25]. For instance sensors that monitor body temperature and humidity are used to detect stress levels in animals [26]. Another indicator of animal health is the identification of various animal behaviors such as movement and eating/drinking patterns. Analyzing these patterns can indicate if an animal is in distress and requires medical intervention.

Nadimi et al. [27] developed an experimental system that monitored animal head movements which were analysed by a trained neural network to identify movement modes of individual animals. The system consisted of a ZigBee mesh wireless network connected to temperature and accelerometer sensors in sensor nodes from Crossbow Technology, Inc. The network transfered data to a cellular modem which connected

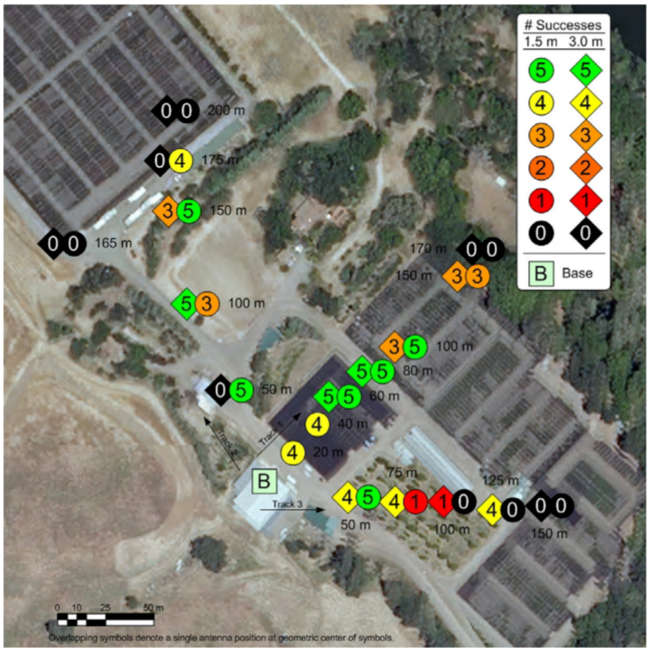

Fig. 3. Network connectivity tests for nodes mounted at differing heights [24].

to a cloud server. Four main movement modes were identified (grazing,lying down, standing and walking) and these were monitored for an eleven sheep flock in both field and barn conditions for 9 hrs a day for five days. The resulting 1782000 measurements were split 75/25 into training and testing datasets and used to train a feed-forward backpropogation 5-layered network. Testing was done to evaluate network health (see Table. I) and the accuracy of the machine learning algorithm (see Table. II). They found that the total packet loss on average was 14.8% which is a significant improvement to previous studies by Nadimi et al. [28]. Similarly, movement mode identification accuracy was better than previous studies using a Kalman filter with a multiple-model adaptive estimation technique [29] and one using decision tress [28]. The study showed the effectiveness of combining a sensor network with predictive data analysis.

IV. Conclusions

The sensor network systems presented here all share the same basic features: a wireless sensor/actuator network connected to a server and database. The studies showed that the wireless sensor networks were feasable with an improvement over traditional methods. Each system generated vaste quantities of data which could be analyzed with Big Data analytics to find trends and correlations. In the case of irrigation, data on irrigation events would be integrated into the systems that control agricultural machinery to improve crop yields and fertilizer use. Time trends would be used to plan future farming strategies based on recorded outcomes. Animal monitoring would flag abnormal animal behavior and make predictions on the possible cause. This data would be used to inform veterinary services about the nature of the health problem to initiate a call-out.

These IoT solutions will improve farming methods and result in more productivity and a better use of resources.

References

[1] A. Rayes and S. Salam, *Internet of Things - From Hype to Reality: The Road to Digitization*. Springer International Publishing, 2017, p. 227.

[2] N. Zhang, M. Wang, and N. Wang, "Precision agriculture* a worldwide overview," *Computers and Electronics in Agriculture*, vol. 36, pp. 113–132, 2002.

[3] B. B. L. Kgotlaetsile M. Modieginyane, "Software defined wireless sensor networks (sdwsns) application opportunities for efficient network management: A survey," *Computers Electrical Engineering*, vol. 66, no. 1, pp. 274–287, 2018.

[4] A. C. Jose, "Improving smart home security; integrating logical sensing into smart home," *IEEE Sensors Journal*, vol. 17, no. 1, pp. 4269–4286, 2017.

[5] J. Wolfert, C. Srensen, and D. Goense, "A future internet collaboration platform for safe and healthy food from farm to fork," in *2014 Annual SRII. IEEE*, 2014, pp. 266–273.

[6] N. Y. Zhongqin Wang, "Trackt: Accurate tracking of rfid tags with mm-level accuracy using first-order taylor series approximation," *AD Hoc Networks*, vol. 53, no. 1, pp. 132–144, 2016.

[7] M. W. Guijie Liu, "Research on flow field perception based on artificial lateral line sensor system," *Sensors*, vol. 18, no. 3, pp. 1–24, 2018.

[8] A. C. Jose, "Improving home automation security; integrating device fingerprinting into smart home," *IEEE Access*, vol. 4, pp. 5776–5787, 2016.

[9] P. C. Tianhe Gong, Haiping Huang, "Secure two-party distance computation protocol based on privacy homomorphism and scalar product in wireless sensor networks," *Tsinghua Science and Technology (IEEE)*, vol. 21, no. 4, pp. 385–396, 2016.

[10] Q. Y. Baojun Qu, "A new concentration detection system for sfn mixture gas in extraultra high voltage power transmission systems," *IEEE Sensors Journal*, vol. 18, no. 9, pp. 3806–3812, 2018.

[11] B. Su, "Electrical anisotropic response of water conducted fractured zone in the mining goaf," *IEEE Access*, vol. 4, pp. 6216–6224, 2016.

[12] J. McKinion, J. Jenkins, D. Akins, S. Turner, J. Willers, E. Jallas, and F. Whisler, "Analysis of a precision agriculture approach to cotton production," *Computers and Electronics in Agriculture*, vol. 32, pp. 213–228, 2001.

[13] M. Yu Bie, "Effect of phase transition temperature and thermal conductivity on the performance of latent heat storage system," *Applied Thermal Engineering*, vol. 135, pp. 218–227, 201.

[14] J. Wannenburg, "Physical activity recognition from smartphone accelerometer data for user context aware-

TABLE I
NETWORK HEALTH STATISTICS [27].

node number	Forwarded packets (%)	Dropped packets (%)	Retry packets (%)	Transmit quality (%)	Receive quality (%)	Retransmission rate (%)
1	31.4	14.1	56	86.6	73.3	6.68
2	45.7	4.3	2.2	80	86.6	5.8
3	42.5	14.2	23	84.3	71.2	25.06
4	44.3	11.8	25.2	73.4	63	44.3
5	30	12.3	50	97.7	93	5.4
6	19.3	17	32.5	100	93	8.58
7	13	7	33	47	100	15.1
8	47.5	14.4	17	80	66	26.1
9	52.5	14	12	72.1	62.4	68.9
10	30.3	11	44.2	100	100	5.8
14	59.3	9.8	22.7	100	100	5.2
16	65.3	3.9	71.4	100	100	8.18

TABLE II
MACHINE LEARNING ACCURACY [27].

Sheep number	Grazing (%)	Lying down (%)	Walking (%)	Standing (%)	Other (%)
1	85.4	83.7	70.2	72.5	53.2
2	80.5	81.4	73.5	68.4	61.8
3	83.9	80.7	69.3	66.7	55
4	79.7	80.1	75.5	71.1	73.3
5	80	79.3	72.1	70	66.5
6	88.3	85.6	77.4	73.5	71.7
7	81.8	82	71.7	75.6	74.3
8	84	89	79.9	77.9	81.2
9	88.5	82.4	73	68.4	73.2
10	82.2	84.9	73.3	71.3	65.6
11	87.6	87	76.8	75	77.9
mean	83.8	83.2	73.8	71.8	68.5
S.D.	3.2	3	3.2	3.4	9

ness sensing," *IEEE Transactions on Systems, Man and Cybernetics: Systems*, vol. 47, no. 12, pp. 3142–3149, 2017.

[15] J. Yu, "Modeling of whole-space transient electromagnetic responses based on fdtd and its application in the mining industry," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 2974–2982, 2017.

[16] M. Damas, A. Prados, F. Gomez, and G. Olivares, "Hidrobus system: fieldbus for integrated management of extensive areas of irrigated land," *Microprocessors and Microsystems*, vol. 25, pp. 177–184, 2001.

[17] N. M. R. Malekian, "Design and implementation of a wireless obd ii fleet management system," *IEEE Sensors Journal*, vol. 17, no. 4, pp. 1154–1164, 2017.

[18] Z. W. Ning Ye, "A method for driving route predictions based on hidden markov model," *Mathematical Problems in Engineering*, vol. 2015, pp. 1–12, 2015.

[19] J. S. Xiangjun Jin, "Modeling of nonlinear system based on deep learning framework," *Nonlinear Dynamics*, vol. 84, no. 3, pp. 1327–134, 2016.

[20] D. C. B. R. Malekian, "A novel smart eco model for energy consumption optimization," *Elektronika ir Elektrotechnika*, vol. 21, no. 6, pp. 75–80, 2015.

[21] Z. Ramudzuli, ""'design of rfid system to track laboratory animals for behavior analysis purposes," *Wireless Personal Communications*, vol. 95, no. 4, pp. 3883–3903, 2017.

[22] V. Adamchuk, J. Hummel, M. Morgan, and S. Upadhyaya, "On-the-go soil sensors for precision agriculture," *Computers and Electronics in Agriculture*, vol. 44, pp. 71–91, 2004.

[23] J. Gutirrez, J. F. Villa-Medina, A. Nieto-Garibay, and M. ngel Porta-Gndara, "Automated irrigation system using a wireless sensor network and gprs module," *IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT*, vol. 63, no. 1, pp. 166–176, 2014.

[24] R. W. Coates, M. J. Delwiche, A. Broad, and M. Holler, "Wireless sensor network with irrigation valve control," *Computers and Electronics in Agriculture*, vol. 96, pp. 13–22, 2013.

[25] S. Neethirajan, S. K. Tuteja, S.-T. Huang, and D. Kelton, "Recent advancement in biosensors technology for animal and livestock health management," *Biosensors and Bioelectronics*, vol. 98, pp. 398–407, 2017.

[26] A. Kumar and G. P. Hancke, "A zigbee-based animal health monitoring system," *IEEE SENSORS JOURNAL*,

vol. 15, no. 1, pp. 610–617, 2015.

[27] E. Nadimi, R. Jrgensen, and V. B.-V. ans S. Christensen, “Monitoring and classifying animal behavior using zigbee-based mobile ad hoc wireless sensor networks and artificial neural networks,” *Computers and Electronics in Agriculture*, vol. 82, pp. 44–54, 2012.

[28] E. Nadimi, H. Sggard, and T. Bak, “Zigbee-based wireless sensor networks for classifying the behaviour of a herd of animals using classification trees,” *Biosystems Engineering*, vol. 100, no. 2, pp. 176–176, 2008.

[29] E. Nadimi and H. Sggard, “Observer kalman filter identification and multiple-model adaptive estimation technique for classifying animal behaviour using wireless sensor networks,” *Computers and Electronics in Agriculture*, vol. 68, no. 1, pp. 9–17, 2009.