MODEL PREDICTIVE CONTROL STRATEGY FOR PRECISION IRRIGATION TOWARDS WATER SAVING AGRICULTURE

ABIOYE ABIODUN EMMANUEL

UNIVERSITI TEKNOLOGI MALAYSIA

MODEL PREDICTIVE CONTROL STRATEGY FOR PRECISION IRRIGATION TOWARDS WATER SAVING AGRICULTURE

ABIOYE ABIODUN EMMANUEL

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

OCTOBER 2021

ACKNOWLEDGEMENT

I want to humbly thank the almighty God, the Kings of Kings and Lord of Lords for his faithfulness, grace and mercies from the beginning of this programme till now. Your faithfulness are new every morning, new every morning. Great is thy faithfulness o Lord, Great is they faithfulness Lord.

I equally express my profound gratitude to my supervisor, Assoc. Prof. Dr. Mohamad Shukri Zainal Abidin for his tutelage, advice, guidance, immense support towards the success of the programme. His entire family members are also appreciated for the relentless supports, especially on the countless get together which tremendously helped me to get used with Malaysian cuisines. Every of those special moments meant a lot and I do cherish them. I equally appreciate my Co Supervisors Assoc. Prof. Dr. Salinda Buyamin and Dr. Mohd Saiful Azimi Mahmud for their mentorship and guidiance. May God reward you abundantly.

I really appreciate entire staff of School of Electrical Engineering (SKE, UTM) is for organizing short courses and training and expert advice. My colleagues in Mobile Robot Laboratory, Khaire Idham, Azwan Ramli, Dr. Hammeda, Dr. Umar Zangina, Hassan Algabray, Balogun Wasiu Adebayo, Dr Hazriq, Dr Izudeeen & Dr Liyana are highly appreciated. Am always motivated by your words of encouragements and kind supports.

I equally appreciate my darling wife, Joy Taiye Bossa Esq and my Son, Abioye Alexander Oluwadarasimi, for their prayers, encouragement, and understanding. She and my lovely Son are great sources of my inspirations not to give up when my morals goes low and things seems uncertain. Alexander, will always say “Daddy weldone”. God added another crown on my head, by blessing us with Abioye Anderson Oluwatimilehin towards the end of my PhD research. To God be the glory for his blessings. I cherish and adore them firmly in my heart. To my parents Daddy & Mummy Reuben Ajayi Abioye, for their efforts in bringing up in the way of the Lord. I also appreciate my mother inlaw, Madam C.Y. Bossa, I am grateful for your love and supports for the family. I have the best siblings and inlaws in the world Mayowa, Ayodele, Mary, Kemi, Kehinde, Emmanuel. I sincerely appreciate you all and your entire family members for your love, prayers and supports. Special thanks Professor M. I. Ajibero, who has also been like a father. My academic journey from first degree to PhD will not be possible if not for God and your efforts. May God reward you abundantly.

My special appreciation also goes to Dr. A. O. Otuoze, Engr. Adeyeye Gbenga, Dr. Bulus Ibrahim, Dr. Obalowu Muhamed, Dr. Olakunle Elijah, who were with me throughout the PhD journey. Your love and kind supports are highly acknowledged.

The management of Akanu Ibiam Federal Polytechnic, Unwana (AIFPU) is duly acknowledged for their kind support for granting me the opportunity for study leave with pay. I also wish to acknowledge the entire staff of the School of Engineering and Technology, AIFPU and especially, those of the Department of Electrical and Electronics Engineering for their encouragements and supports.

ABSTRACT

The field of precision agriculture has widely utilized drip and capillary irrigations for water saving. However, most of the existing controllers for drip irrigation are not capable of adapting to the changing dynamics of soil, plant and weather effect in real-time. Also, investigations have revealed that capillary irrigation has potential for high water saving capability. Moreover, it suffers under-performance due to inaccurate determination and estimation of the water supply depth (Δh) for wetting the root zone of plant. The advent and rapid successes of the internet of things (IoT) and advanced control theory are being integrated for improving monitoring system to achieve precision irrigation. In this thesis, two case studies namely a data-driven model predictive control (MPC) strategy for drip irrigated Cantaloupe plant and a Kalman filter based-PID controller for fibrous capillary irrigated Mustard leaf are proposed. An IoT based cultivation experiment on Cantaloupe plant and Mustard leaf was carried out for data collection on soil, plant, and weather parameters using the drip and capillary irrigations. The data collected are used to develop predictive models using system identification in MATLAB to obtain an accurate model representing the changing dynamics of the systems of both case studies. The predictive model for Cantaloupe cultivation was further used to design MPC and Laguerre network-based MPC for real-time drip irrigation management. To investigate the management of the capillary irrigation system, a Kalman filter based-PID control strategy was developed using the predictive model from Mustard leaf cultivation. The developed model based controllers were then integrated with network of sensor devices using IoT for real-time monitoring of the soil, plant and weather parameters to manipulate the Δh based on plant demand. The effectiveness of the model based controllers was simulated using Simulink and deployed on Raspberry Pi to validate their performance. Three greenhouses (GH1, GH2 and GH3) were used for cultivation experiments to test the performance of the developed control system. The data-driven modelling results for drip irrigation show that the ARX model has better accuracy in terms of MSE of 0.753 with an estimated fit of 91.31%, while a state-space model with an estimated fit of 92.3% was equally identified for the capillary irrigation dynamics. The experimental results show a better performance for the proposed controller deployed in GH2 with 30% savings in water and fertilizer, water productivity index of 23 g/L, and fruit sweetness of 13 Brix greater than existing evapotranspiration-based controller in GH1 for the cultivation of Cantaloupe plant. The Kalman filter based-PID controller for capillary irrigated Mustard leaf in GH3, was able to optimally estimate and control the water supply depth resulting to better water productivity index of 16% and improvement of yield when compared with the fuzzy logic controller deployed in GH3 for benchmarking purpose. Also, the investigation of the computation complexity of the MPC and its suitability for control of irrigation system shows that the Laguerre network-based MPC demonstrated a better computational efficiency when benchmarked with a discrete linear quadratic regulator method for drip irrigation control via simulation. This thesis has contributed to the enhancement of monitoring and advanced control strategies for precision irrigation scheduling towards the realization of improved yield, water saving, and efficient use of fertilizer in agriculture.

ABSTRAK

Bidang Pertanian Tepat (PA) banyak menggunakan teknik pengairan titisan dan teknik pengairan kapilari berserabut untuk penjimatan air tanaman. Walau bagaimanapun, sebahagian besar sistem kawalan yang digunakan untuk penjadualan sistem pengairan titisan ini tidak mampu mengadaptasi terhadap perubahan dinamik persekitaran seperti kelembapan tanah, tanaman dan cuaca dalam masa nyata. Penyelidikan telah menunjukkan bahawa pengairan kapilari berserabut berpotensi untuk mendapatkan penjimatan air yang tinggi. Walau bagaimanapun, prestasi system ini masih rendah kerana penentuan kawalan mengenai kedalaman air bekalan (Δh) yang tidak tepat kepada zon pembasahan akar tanaman. Kemunculan dan kejayaan 'Internet of Things' (IoT) dan teori kawalan termaju digabungkan untuk pemantauan sistem yang lebih baik untuk mencapai objektif pengairan yang tepat. Dalam tesis ini, dua kajian kes iaitu strategi pengawal Model Ramalan (MPC) berdasarkan data untuk sistem pengairan titisan tanaman tembikai dan pengawal berasaskan penapis Kalman-PID untuk tanaman sawi yang disiram kapilari berserat dicadangkan. Ujikaji penanaman berasaskan IoT pada tanaman tembikai dan sawi dilakukan untuk pengumpulan data berkaitan kelembapan tanah, tumbesaran tanaman, dan cuaca daripada sistem pengairan titisan dan kapilari. Data yang dikumpul digunakan untuk mengembangkan model ramalan menggunakan kaedah Pengenalpastian Sistem (SI) menggunakan MATLAB untuk mendapatkan model yang tepat yang mewakili perubahan dinamik sistem bagi kedua-dua model tersebut. Model ramalan yang dikembangkan selanjutnya bagi tanaman tembikai digunakan untuk merancang MPC berasaskan jaringan Laguerre untuk pengurusan pengairan titisan masa nyata. Untuk menyiasat pengurusan sistem pengairan kapilari berserabut, strategi kawalan PID berasaskan penapis Kalman dikembangkan menggunakan model ramalan dari penanaman sawi. Pengawal berdasarkan model yang dikembangkan ini kemudian digabungkan dengan rangkaian alatan sensor menggunakan IoT untuk pemantauan waktu nyata terhadap parameter tanah, tanaman dan cuaca. Keberkesanan sistem kawalan berdasarkan model yang dirancang disimulasikan menggunakan Simulink dan diuji pada Raspberry Pi untuk mengesahkan prestasi pengawal yang dikembangkan. Tiga rumah hijau (GH1, GH2 dan GH3) digunakan dalam ujikaji penanaman untuk menguji prestasi sistem kawalan yang dihasilkan. Hasil pemodelan berdasarkan data untuk pengairan titisan menunjukkan bahawa model ARX mempunyai ketepatan yang lebih baik dari segi MSE iaitu 0.773 dengan anggaran ketepatan 91.31%, sementara model ruang-keadaan dengan anggaran ketepatan 92.3% dikenal pasti serupa dengan dinamik pengairan kapilari. Hasil ujikaji yang diperolehi menunjukkan prestasi yang lebih baik untuk sistem kawalan yang dicadangkan yang digunakan dalam GH2 dengan penjimatan sebanyak 30% untuk air dan baja, indeks produktiviti air 23 g/L, dan kemanisan buah 13 Brix lebih tinggi daripada pengawal berasaskan evapotranspirasi di GH1 untuk penanaman tanaman tembikai. Pengawal berasaskan penapis Kalman-PID untuk tanaman sawi mengunakan sistem kapilari dalam GH3, dapat menganggarkan dan mengawal kedalaman air bekalan (Δh) secara optimum sehingga menghasilkan indeks produktiviti air yang lebih baik sehingga 16% dan peningkatan hasil jika dibandingkan dengan pengawal logik fuzzy yang digunakan di GH3 sebagai penanda aras. Juga, penyiasatan kerumitan pemprosesan MPC dan kesesuaiannya untuk mengendalikan sistem kawalan pengairan menunjukkan bahawa MPC berasaskan rangkaian Laguerre menghasilkan kecekapan pemprosesan yang lebih baik apabila dibandingkan dengan kaedah pengatur Linear Kuadratik Diskret untuk kawalan pengairan titisan melalui simulasi. Tesis ini telah menyumbang kepada peningkatan strategi pemantauan dan pengendalian lanjutan untuk penjadualan pengairan yang tepat ke arah meningkatkan hasil pertanian, penjimatan air dan penggunaan baja yang lebih baik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DLQR	-	Discrete Linear Quadratic Regulator
GH	-	Greenhouse
IAE	-	Integral Absolute Error
IASE	-	Integral Absolute Square Error
ANOVA	-	Analysis of Variance
UV	-	Ultra Violet
TWU	-	Total Water Use
WPI	-	Water Productivity Index
DMPC	-	Discrete Model Predictive Control
NDVI	-	Normalized Difference Vegetation Index
BP	-	Back Propagation
ES	-	Expert System
EC	-	Electro Conductivity
POR	-	Peak Overshoot Ratio
DR	-	Decay Ratio
TDR	-	Time Domain Reflectometry
VWC	-	Volumetric Water Content
GSM	-	Global System for Mobile Communication
ISFET	-	Ion-Sensitive Field-Effect Transistor
PH	-	Potential Hydrogen
UAV	-	Unmanned Aerial Vehicles
CMOS	-	Complementary Metal Oxide Semi Conductor
LAI	-	Leaf Area Index
PAR	-	Photosynthetically Active Radiation
PWM	-	Pulse-Width Modulated
RTC	-	Real-Time Clock
RFID	-	Radio Frequency Identification Device
SSID	-	Service Set Identifier
HTTP	-	Hypertext Transfer Protocol
RSSI	-	Received Signal Strength Indication
ICT	-	Information Communication Technology
DSS	-	Decision Support System
LWPA	-	Low Power Wide Area

LoRa	-	Long Range
TDR	-	Time Domain Reflectometry
FAO	-	Food Agriculture Organization
RTC	-	Real-Time Clock
DC	-	Direct Current
AC	-	Alternating Current
SVM	-	Support vector machines
TSDI-ES	-	Technical Specification of Drip Irrigation-Expert System
ELM	-	Extreme Machine Learning
IGA	-	Improved Genetic Algorithm
SMLA	-	Shark Machine Learning Algorithm
GAPSO	-	Genetic Algorithm Particle Swarm Optimization
ADSS	-	Adaptive Decision Support System
LEPA	-	Low Energy Precision Application
SS-VRI	-	Site-Specific Variable Rate Irrigation
WS	-	Weather Station
MIMO	-	Multi-Input Multi-Output
GPC	-	Generalized Predictive Control
KNN	-	K Nearest Neighbour
SVR	-	Support Vector Regression
TWU	-	Total Water Use
MV.		Manipulated Variable

t_s	-	Settling time
d		Delay
Ho	-	Null hypothesis
ET_O	-	Reference evapotranspiration (mm day^{-1})
R_n	-	Soil surface solar radiation at the crop surface (MJ m^{-2} day^{-1})
U_2	-	Speed of the wind measured at 2m height (ms^{-1})
T	-	Daily mean temperature of the air
G	-	Soil heat flux density(MJ m^{-2} day^{-1})
$e_s - e_a$	-	Saturation vapour pressure deficit (kPa)
γ	-	Psychrometric constant (kPa $^0C^{-1}$)
Δ	-	Gradient of the pressure curve (kPa $^0C^{-1}$)
F_T	-	F Statistics
MS_E	-	Mean Square for Error
MS_T	-	Mean Square for Treatment
ESS	-	Error for sum of square
$df(e)$	-	Error for the degree of freedom
TSS	-	Total sum of square
TrSS	-	Treatment sum of square
Y_{ij}	-	Grand mean
Δh	-	Water Supply Depth
R^2	-	Regression Coefficient
$\propto$	-	Confidence Level
ζ	-	Inverse z-transform
R_f	-	Reference Trajectory
Y_{Pr}	-	Predicted Output
ΔU	-	Predicted Output
EI_{max}	-	Optimal Control Signal
δ	-	Effective Irrigation Effort
a	-	Dirac delta function
$L(k$	-	Scaling factor
$I(k)$	-	Discrete-time Laguerre functions
χ	-	Impulse Response
	-	Chi

LIST OF APPENDICES

In a conventional irrigation system, farmers apply uniform irrigation across every part of the farm without considering the variabilities on the field and the water need for the crop. Therefore, this method has a lesser water-saving capability and can cause over-irrigation in some parts of the farm while other parts are under irrigated which often leads to water stress on the plant (Al-Karadsheh *et al.*, 2002; Munoth *et al.*, 2016; Li *et al.*, 2018). Also, most of the commercial irrigation controllers available in the market are pre-programmed to supply water at predefined intervals which offer fixed irrigation scheduling based on empirical knowledge of dynamics of weather variables, as well as soil and plant characteristics (Lozoya, Mendoza, Mejía, *et al.*, 2014). Since conventional irrigation systems often result to insufficient water supply to plant which causes yield loss and plants wilting, while too much water supply will result in wasted water and root disease, there is need to adopt a precision irrigation concept with advanced control strategies for optimal irrigation scheduling, water-saving, and better crop yield.

Drip and capillary irrigation is often practiced irrigation methods, which has potential for high water saving, but suffers a lot of operational and environmental problems. Drip irrigation is one of the surface irrigation methods which supplies water slowly through narrow emitter tubes to provide water to the soil near the plant roots (Seyfi and Rashidi, 2007). While fibrous capillary is subsurface irrigation that works based on the action of gradually supplying water from source directly to the root area by through a capillary medium using a negative pressure. One of the major challenge to achieve precise management of both irrigation methods is the disturbance in terms of water loss associated with the process and the need to compensate for it. The disturbance may include change in irrigation water flow, air and canopy temperature, water loss for soil and plant etc., and may lead to undesirable consequences on plant performance. For example, an abrupt increase or decrease in temperature and water loss in a tropical environment may have severe implications on the yield, if there is no proper real time monitoring and control of water resources to effectively manage such environmental effect. There is therefore need to sense and monitor crop response to water deficit often caused by disturbance due to water loss, in order to precisely irrigate the plants cultivated using both irrigation methods.

Precision irrigation is the integration of information, communication, and control technologies in the irrigation process to obtain optimal usage of water resources while minimising environmental impact (Shibusawa, 2001; Zacepins *et al.*, 2012). Precision irrigation takes into account the spatial and temporal soil variation, soil structure and hydraulic properties, plant responses to water deficit, changing weather variables through effective monitoring via internet of things (IoT), to make better irrigation decisions that has the potential to help achieve high water saving and improved yield (Bitella *et al.*, 2014; Capraro *et al.*, 2018). Precision irrigation is an excellent water-saving technique for maximising yield and providing water at the correct location based on the water needs of the plant (Evett *et al.*, 2009; Smith and Baillie, 2009; Niu *et al.*, 2015). Also implied is the idea that the system will be managed to achieve a specific target by aiding the delivery of nutrient and water directly to the roots of each plant and keeping the soil moisture at optimal levels to eliminate surface run-off and deep percolation as the design process is conducted based on the ability of the soil to absorb water and the amount of crop water demand (Daccache *et al.*, 2015). Therefore, this method results in increased productivity and improved quality of yield while ensuring maximum water use efficiency (Tropea, 2014). However, to provide efficient precision irrigation, the integration of the internet of things (IoT) for data acquisition as well as monitoring, control theory, and decision support technologies ought to be considered in irrigation management (Smith *et al.*, 2010; Pham and Stack, 2018; Zamora-izquierdo *et al.*, 2018).

This research focuses on advance monitoring and predictive control strategies for precision irrigation with the integration of IoT based irrigation monitoring methods. Control theory is an aspect of engineering and mathematics which deals with the dynamical behaviour of systems. In the context of precision irrigation, control is the ability to reallocate inputs and adjustment of irrigation management according to the crop response deficit while ensuring optimal water-saving and mitigating the effects of disturbance and uncertainties (De Baerdemaeker, 2000; Smith and Baillie, 2009). Therefore, in most cases, there will be a need to sense the response of a plant to the applied water at a scale appropriate for management, decide for improved irrigation using both the real-time and historical information for subsequent irrigation applications at a proper spatial level (Shashi *et al.*, 2017). Therefore, in this thesis, an improved monitoring system for soil, plant, and weather variables is proposed for both drip and fibrous capillary irrigation experiments. The data collected using the IoT framework is used for data driven modelling. Also, the models were further used to design more advanced controllers for optimal irrigation decisions and water saving.

1.2 Problem Statement

The significant losses in agriculture are mostly due to low-efficiency irrigation control and inaccurate weather monitoring and prediction methods. It is desirable to irrigate to meet specific plant water demands at the right time and volume while avoiding over and under irrigation. Excessive irrigation often affects plants health, have negative environmental impact and often results in high water and energy usage. Most of the commercial automated irrigation systems for drip irrigation are preprogramed to water at specific time intervals and apply a fixed irrigation volume, hence this method cannot provide crop water need with the changing dynamics of soil, plant and weather conditions. A number of these systems are also programmed to irrigate after a predefined soil moisture threshold is reached. Due to their open-loop structure, these methods may not guarantee optimum irrigation scheduling decisions resulting in suboptimal plant health and low efficiency in water use. As a result, the overall system may not be robust to external disturbance in terms of actual evapotranspiration and other environmental factors.

Irrigation management for Cantaloupe plant cultivation are mostly based on empirical or heuristic knowledge. Typically, drip irrigation strategies for Cantaloupe cultivation are often carried out by farmers in total ignorance of the actual soil water content, weather, as well as plant consideration. Such strategies are called open-loop irrigation strategy. The main drawback of open-loop irrigation for Cantaloupe is the difficulty in delivering the precise irrigation amount, which could lead to either a waste of irrigation water or insufficient watering which can cause root asphyxiation leading to root rot, low yield and fruit quality or even plant death. Due to the inefficiency of open-loop irrigation and the emerging water crisis, there has been an increasing interest in the research of model based closed-loop irrigation strategy.

i. To model the dynamics of the soil-plant-weather system through system identification using data from IoT-based experimental cultivations of Cantaloupe plant.
ii. To model the dynamics of the soil-plant-weather system through system identification using data from IoT-based experimental cultivations of capillary irrigated Mustard leaf.
iii. To design a MPC and Laguerre network based MPC controller for drip irrigation and implement it experimentally on Raspberry Pi for Cantaloupe plant cultivation.
iv. To design a Kalman filter-PID controller for water supply depth (Δh) of fibrous capillary irrigation and deploy on Raspberry Pi for Mustard leaf cultivation experiment.

1.4 Scope

The main scopes in conducting this research which is stated as follows:

i. Only three greenhouses are selected for the experimental work, namely GH1 and GH2 for drip irrigation, and GH3 for fibrous capillary irrigation.
ii. Matlab/Simulink and Python software are used for modelling and simulation of all the algorithms.
iii. The model structures use to fit the data are ARX, ARMX, SS, and BJ.
iv. Vertical and horizontal interface are used for the capillary irrigation system.
v. Cantaloupe plant and Mustard leaf plant are selected as test crops for this study.
vi. Liquid fertilizer (AB) is used to aid the plant growth.

1.5 Contribution of the Research Work

In this thesis, a data-driven predictive model is used to design an optimal irrigation control for drip and fibrous capillary irrigation systems in achieving water-saving agriculture. The real-time implementation of the model predictive irrigation control algorithm on the target hardware and integration of IoT monitoring will be a novel approach to improve water use efficiency and crop yield. Specifically, the contribution of this research are as follows:

(a) Development of different predictive models to represent the changing dynamics soil, plant and weather

An open loop and improved IoT based cultivation experiment on drip irrigated Cantaloupe and fibrous capillary irrigated Mustard leaf was carried out for data collection of soil, plant and weather variables. Through system identification, a state space model structure was use to fit the experimental input and output data. This results to a state space model that captured the dynamics of the plant.

(b) Formulation of control law based on MPC and Laguerre networks MPC for drip irrigation system.

Using the predictive model formulated, an MPC and Laguerre networks MPC for drip irrigations was formulated, simulated, and implemented on Raspberry Pi in a greenhouse experimental cultivation for high water saving and improved yield. The MPC controller was benchmarked experimentally with a model base automatic evapotranspiration (ET) controller.

(c) Improved management of water supply depth for fibrous capillary irrigation using Kalman filter-PID controller

Toward ensuring an extreme water saving Agriculture, a Kalman filter-PID control strategy for determining optimal Δh to ensure enhanced wetting of the root zone of plant was tested through simulation and bench marked experimentally with a fuzzy logic controller.

1.6 Thesis Organization

This thesis is organized in six chapters. Chapter 1 gives the overview of the whole thesis. It contains a general background of the study, the problem statement with the existing research gaps, the set objectives, the scopes of the work and limitations, and contribution of the research.

Chapter 2 presents a comprehensive and critical literature review of the theoretical background on precision irrigation concept, different irrigation system, monitoring and advanced control strategies for precision irrigation. The existing monitoring approach, issues associated with different irrigation method were highlighted.

Chapter 3 proposes the methodology used to achieve the objectives of this thesis in phases. The adopted methodology for the modelling presented in each of the phases are comprehensively discussed. In the monitoring phase, the IoT implementation for data collection and processing were equally presented. This is followed by the explanation of dynamic modelling for soil moisture prediction. The experimental performance comparison between drip and capillary irrigation systems for Cantaloupe plant cultivation is also presented.

Chapter 4 presents more detailed methodology on the formulation of control law for controller design for both drip irrigation. It also discusses the proposed controller as well as the implementation of the developed models for the design of both data driven MPC in Simulink and Laguerre networks based MPC controller on Raspberry Pi for Cantaloupe plant cultivation.

Chapter 5 discusses the design and implementation of Kalman filter-PID controller for fibrous capillary irrigation management for the cultivation of Mustard leaf is carried out.

Chapter 6 contains the results of the predictive modelling and model predictive controller design as well as implementation for both drip and capillary irrigation experiments. Finally, the results of the experimental performance comparison between drip and capillary irrigation systems for Cantaloupe plant cultivation is also explained.

Chapter 7 draws the overall conclusions of the remarkable achievements of the research. In addition, recommendations for future studies is presented. This thesis is closed with list of references, appendices as well as list of publications during the period of the research.

REFERENCES

Abdul Rahim, H., Ibrahim, F. and Taib, M. N. (2010) 'System identification of nonlinear autoregressive models in monitoring dengue infection', *International Journal on Smart Sensing and Intelligent Systems*, 3(4), pp. 783–806.

Abidin, M. S. B. Z. (2014) *Capillary-Based Subsurface Irrigation System for Water-Saving Agriculture*. Tokyo University of Agriculture and Technology.

Abidin, M. S. B. Z. *et al.* (2015) 'Intelligent control of capillary irrigation system for water-saving cultivation', in *2015 10th Asian Control Conference: Emerging Control Techniques for a Sustainable World, ASCC 2015*, pp. 2–6.

Abioye, E. A., Abidin, M. S. Z., Mahmud, M. S. A., Buyamin, S., Ishak, M. H. I., *et al.* (2020) 'A review on monitoring and advanced control strategies for precision irrigation', *Computers and Electronics in Agriculture*. Elsevier, 173, p. 105441.

Abioye, E. A. *et al.* (2021) 'A model predictive controller for precision irrigation using discrete lagurre networks', *Computers and Electronics in Agriculture*. Elsevier B.V., 181(November 2020), p. 105953.

Adeyemi, O. *et al.* (2017) 'Advanced Monitoring and Management Systems for Improving Sustainability in Precision Irrigation', *Sustainability- MDPI*, 9(353), pp. 1–29.

Adeyemi, O. *et al.* (2018a) 'Dynamic modelling of lettuce transpiration for status monitoring', *Computers and Electronics in Agriculture*. Elsevier, 1 55(September), pp. 50–57.

Adeyemi, O. *et al.* (2018b) 'Dynamic modelling of the baseline temperatures for computation of the crop water stress index (CWSI) of a greenhouse cultivated lettuce crop', *Computers and Electronics in Agriculture*. Elsevier, 153(January), pp. 102–114.

Adeyemi, O. *et al.* (2018c) 'Dynamic Neural Network Modelling of Soil Moisture Content for Predictive Irrigation Scheduling', *Sensors*, 18(10), p. 3408.

Afshar, M. H. and Rajabpour, R. (2007) 'Optimal design and operation of irrigation pumping systems using particle swarm optimization algorithm', *International Journal of Civil Engineerng*, 5(4), pp. 302–311.

Agency, U. S. E. P. (2017) *Soil Moisture-Based Irrigation Control Technologies : WaterSense ® Specification Update*. EPA WaterSense.

Al-Ali, A. R. *et al.* (2015) 'ZigBee-based irrigation system for home gardens', in *2015 International Conference on Communications, Signal Processing, and Their Applications, ICCSPA 2015*, pp. 0–4.

Al-Karadsheh, E., Sourell, H. and Krause, R. (2002) 'Precision Irrigation: New strategy irrigation water management', in *Conference on International Agricultural Research for Development*, pp. 1–7. doi: C:\staging\3DAAD18D-5BDB-AB96\in\3DAAD18D-5BDB-AB96.doc.

Aleotti, J. *et al.* (2018) 'A Smart Precision-Agriculture Platform for Linear Irrigation Systems', in *26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*. University of Split, FESB, pp. 1–6.

Ali, M. H. and Abustan, I. (2013) 'Irrigation management strategies for winter wheat using AquaCrop model', *Journal of Natural Resources and Development*, 3, pp. 106–113.

Allawi, M. F. *et al.* (2018) 'Synchronizing Artificial Intelligence Models for Operating the Dam and Reservoir System', *Water Resour Manage (2018) 32:3373–3389 https://doi.org/10.1007/s11269-018-1996-3 Synchronizing*. Water Resources Management, pp. 3373–3389.

Alomar, B. (2018) 'A Smart Irrigation System Using IoT and Fuzzy Logic Controller', *2018 Fifth HCT Information Technology Trends (ITT)*. IEEE, pp. 175–179.

Andrew, R. C., Malekian, R. and Bogatinoska, D. C. (2018) 'IoT solutions for precision agriculture', in *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics, MIPRO 2018 - Proceedings*. Croatian Society MIPRO, pp. 345–349.

Anjos, W. L. F. dos and Tello, R. J. M. G. (2017) 'Validation of an Unrestricted DMC Controller Implemented on Raspberry PI III', *International Journal of Research in Engineering and Science (IJRES*, 5(11), pp. 32–36.

Arriaga *et al.* (2014) 'Modeling, simulation and control of irrigation on young almond trees', in *Proc. VIIth IS on Irrigation of Horticultural -CropsActa Horticulturae*, pp. 479–486.

Auernhammer, H. and Demmel, M. (2016) 'State of the Art and Future Requirements', in *Precision Technology Agriculture For Crop Farming*, pp. 1009–1010.

Awang, Y. *et al.* (2009) 'Chemical and physical characteristics of cocopeat-based media mixtures and their effects on the growth and development of celosia cristata', *American Journal of Agricultural and Biological Science*, 4(1), pp. 63–71.

De Baerdemaeker, J. (2000) 'Process Monitoring and Control for Precision Agriculture', *IFAC Proceedings Volumes*. Elsevier, 33(29), pp. 23–30.

Bah, A., Balasundram, S. K. and Husni, M. H. A. (2012) 'Sensor technologies for precision soil nutrient management and monitoring', *American Journal of Agricultural and Biological Science*, 7(1), pp. 43–49.

Balbis, L. and Jassim, A. (2018) 'Dynamic model of soil moisture for smart irrigation systems', *2018 International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies, 3ICT 2018*. IEEE, pp. 1–4.

Balbis, L., Kateb, R. and Ordys, A. W. (2006) 'Model predictive control design for industrial applications', in *UKACC International Conference on Control*. University of Strathclyde, Glasgow.Uk, pp. 1–6.

Bauer, J. and Aschenbruck, N. (2018) 'Design and implementation of an agricultural monitoring system for smart farming', in *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IoT Tuscany 2018*. IEEE, pp. 1–6.

Bemani, A. *et al.* (2013) 'Optimal water allocation in irrigation networks based on real time climatic data', *Agricultural Water Management*. Elsevier B.V., 117, pp. 1–8.

Bhalage, P., Jadia, B. B. and Sangale, S. T. (2015) 'Case Studies of Innovative Irrigation Management Techniques', *International Conference On Water Resources, Coastal And Ocean Engineering (ICWRCOE 2015)*. Elsevier B.V., 4(Icwrcoe), pp. 1197–1202.

Bi, P. and Zheng, J. (2014) 'Study on Application of Grey Prediction Fuzzy PID Control in Water and Fertilizer Precision Irrigation', in *2014 IEEE International Conference on Computer and Information Technology*. IEEE, pp. 789–791.

Bitella, G. *et al.* (2014) 'A Novel Low-Cost Open-Hardware Platform for Monitoring Soil Water Content and Multiple Soil-Air-Vegetation Parameters', *mdpi sensors journal*, 14, pp. 19639–19659.

Bogue, R. (2017) 'Sensors key to advances in precision agriculture', *Sensor Review,Emerald Publishing Limited*, 37(1), pp. 1–6.

Boman, B., Smith, S. and Tullos, B. (2015) ‘Control and Automation in Citrus Microirrigation Systems’, *Agricultural and Biological Engineering Department, UF/IFAS Extension*, pp. 1–15.

Bordons, E. F. C. and C. (2003) *Model Predictive Control*. Second Edi. London: Springer.

Bosschaerts, W. *et al.* (2017) ‘Development of a Model Based Predictive Control System for Heating Buildings’, *Energy Procedia*. Elsevier B.V., 112(October 2016), pp. 519–528.

Bralts, V. and Edwards, D. (1987) ‘Drip Irrigation Design and Evaluation Based on the Statistical Uniformity Concept’, *ACADEMIC PRESS, INC.*, Vol 4.

Brouwer *et al.* (1990) *Surface irrigation systems*, *FAO - Food and Agriculture Organization of the United Nations*.
Available at: http://www.fao.org/3/T0231E/t0231e04.htm (Accessed: 17 June 2019).

Brouwer, C. *et al.* (1990) *Drip Irrigation*, *FAO - Food and Agriculture Organization of the United Nations*. Available at: http://www.fao.org/3/S8684E/s8684e07.htm (Accessed: 17 June 2019).

Cai, P, W. and L, Z. (2017) ‘Simulation of soil water movement under subsurface irrigation with porous ceramic emitter’, *Agric Water Management*, 192, pp. 244–256.

Çam, Z. G., Çimen, S. and Yildirim, T. (2015) ‘Learning parameter optimization of multi-layer perceptron using artificial bee colony, genetic algorithm and particle swarm optimization’, in *SAMI 2015 - IEEE 13th International Symposium on Applied Machine Intelligence and Informatics, Proceedings*, pp. 329–332.

Capraro, F. *et al.* (2018) ‘Web-Based System for the Remote Monitoring and Management of Precision Irrigation : A Case Study in’, *Sensors MDPI*.

Chate, B. K. and Rana, P. J. G. (2016) ‘Smart irrigation system using raspberry pi’, *Internation Research Journal of Engineering and Technology (IRJET)*, 3(5), pp. 247–249.

Chen, W. *et al.* (2011) ‘Improved Nonlinear Model Predictive Control Based on Genetic Algorithm’, in *Advanced Model Predictive Control*. InTech, pp. 1–19.

Chieochan, O., Saokaew, A. and Boonchieng, E. (2017) ‘Internet of things (IoT) for smart solar energy: A case study of the smart farm at Maejo University’, in

International Conference on Control, Automation and Information Sciences, ICCAIS 2017, pp. 262–267.

Clemmens, A. J. (2011) ‘Water-level difference controller for main canals’, *Journal of Irrigation and Drainage Engineering*, 138(1), pp. 1–8.

Cong, D. *et al.* (2017) ‘Optimization of irrigation scheduling using ant colony algorithms and an advanced cropping system model’, *Environmental Modelling and Software*. Elsevier Ltd, 97, pp. 32–45.

Dela Cruz, J. R. *et al.* (2017) ‘Design of a fuzzy-based automated organic irrigation system for smart farm’, in *HNICEM 2017 - 9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management*.

Daccache, A. *et al.* (2015) ‘Implementing precision irrigation in a humid climate – Recent experiences and on-going challenges’, *Elsevier -Agricultural Water Management*. Elsevier B.V., 147, pp. 135–143.

Dean, S. *et al.* (2019) ‘On the Sample Complexity of the Linear Quadratic Regulator’, in *Foundations of Computational Mathematics*. Springer US.

Debauche, O., Moulat, M. El and Mahmoudi, S. (2018) ‘Irrigation Pivot-Center Connected At Low Cost For The Reduction Of Crop Water Requirements’, in *2018 International Conference on Advanced Communication Technologies and Networking (CommNet)*.

Delgoda, D., Malano, H., *et al.* (2016) ‘Irrigation control based on model predictive control (MPC): Formulation of theory and validation using weather forecast data and AQUACROP model’, *Environmental Modelling and Software*. Elsevier Ltd, 78, pp. 40–53.

Delgoda, D., Saleem, S. K., *et al.* (2016) ‘Root zone soil moisture prediction models based on system identification: Formulation of the theory and validation using field and AQUACROP data’, *Agricultural Water Management*. Elsevier B.V., 163(November 2017), pp. 344–353.

Deng, X., Dou, Y. and Hu, D. (2018) ‘Robust closed-loop control of vegetable production in plant factory’, *Computers and Electronics in Agriculture*. Elsevier, 155(September 2017), pp. 244–250.

Difallah, W. *et al.* (2018) ‘Intelligent Irrigation Management System’, *(IJACSA) International Journal of Advanced Computer Science and Applications*, 9(9), pp. 429–433.

Dimitriadis, S. and Goumopoulos, C. (2008) 'Applying machine learning to extract new knowledge in precision agriculture applications', *Proceedings - 12th Pan-Hellenic Conference on Informatics, PCI*, pp. 100–104.

Ding, Y. *et al.* (2018) 'Model predictive control and its application in agriculture: A review', *Computers and Electronics in Agriculture*. Elsevier, 151(December 2017), pp. 104–117.

Divya, Y. (2019) 'Smart Water Monitoring System using Cloud Service', *International Journal of Trend in Scientific Research and Development (IJTSRD)*, 3(2), pp. 406–408.

Dubravko Ćulibrk *et al.* (2014) *Sensing Technologies For Precision Irrigation*. Springer New York Heidelberg Dordrecht London Library.

Eid, S. and Abdrabbo, M. (2018) 'Developments of an Expert System for On-Farm Irrigation Water Management Under Arid Conditions', *Journal of Soil Sciences and Agricultural Engineering*, 9(1), pp. 69–76.

Elasbah, R. *et al.* (2019) 'Modeling of Fertilizer Transport for Various Fertigation Scenarios under Drip Irrigation', *MDPI-Water*. Multidisciplinary Digital Publishing Institute, 11(5), pp. 878–893.

Elijah, O. *et al.* (2018) 'Enabling smart agriculture in Nigeria: Application of IoT and data analytics', *2017 IEEE 3rd International Conference on Electro-Technology for National Development, NIGERCON 2017*, 2018-Janua, pp. 762–766.

Esmaeilzadeh, B. and Sattari, M. T. (2015) 'Monthly Evapotranspiration Modeling using Intelligent Systems in Tabriz , Iran', *Agriculture Science Developments*, 4(3), pp. 35–40. Available at: www.tijournals.com.

Espinoza, J. *et al.* (2018) 'Real-Time Implementation of Model Predictive Control in a Low-Cost Embedded Device', *Systemics, Cybernetics and Informatics*, 16(2), pp. 72–77.

eTape TM (2020) *Continuous Fluid Level Sensor Operating Instructions and Application Notes*. Available at: www.milonetech.com.

Evans, R. G., Iversen, W. M. and Kim, Y. (2012a) 'Integrated Decision Support, Sensor Networks, and Adaptive Control for Wireless Site-Specific Sprinkler Irrigation', *Applied Engineering in Agriculture, American Society of Agricultural and Biological Engineers*, 28(3), pp. 377–387.

Evans, R. G., Iversen, W. M. and Kim, Y. (2012b) 'Integrated Decision Support, Sensor

Networks, and Adaptive Control for Wireless Site-Specific Sprinkler Irrigation', in *Applied Engineering in Agriculture 2012 American Society of Agricultural and Biological Engineers ISSN 0883-854*, pp. 377–387.

Evans, R. G. and King, B. A. (2012) 'Site-specific sprinkler irrigation in a water-limited future', *Transactions of the ASABE 2012 American Society of Agricultural and Biological Engineers ISSN 2151-0032*, 55(2), pp. 493–504.

Evans, R. G. and Sadler, E. J. (2008) 'Methods and technologies to improve efficiency of water use', *Water Rources Research*, 44(July), pp. 1–15.

Evett, S., Shaughnessy, S. A. O. and Colaizzi, P. (2009) 'Advanced irrigation engineering : Precision and precise', *Dahlia Greidinger International Symposium*, (January), pp. 338–353.

Fandika, I. R., Stirzaker, R. and Chipula, G. (2019) 'Promoting Social Learning in Soil Water and Nutrients Management Using Farmer — Friendly', in *MDPI-Proceedings at the third International Tropical Agriculture Conference (TROPAG 2019), Brisbane, Australia*, p. 3390.

Fernández-Pacheco, D. G. *et al.* (2014) 'A digital image-processing-based method for determining the crop coefficient of lettuce crops inthe southeast of Spain', *Biosystems Engineering*, 117(C), pp. 23–34.

Fernando, F., Marcuzzo, N. and Wendland, E. C. (2014) 'The Optimization of Irrigation Networks Using Genetic Algorithms', *Journal of Water Resource and Protection*, 6(September), pp. 1124–1138.

Ferrández-Pastor, F. J. *et al.* (2018) 'Precision agriculture design method using a distributed computing architecture on internet of things context', *MDPI, Sensors (Switzerland)*, 18(6), pp. 1710–1731.

Ferrarezi RS, T. R. (2016) 'Performance of wick irrigation system using self-compensating troughs with substrates for lettuce production', *J Plant Nutrition*, 39(1), pp. 147–161. doi: 10.1080/01904167.2014.983127.

Fuentes, B. S. and Tongson, E. (2018) 'Advances and requirements for machine learning and artificial intelligence applications in viticulture', *Wine & Viticulture Journal*, pp. 47–51.

Fujimaki, H. *et al.* (2018) 'Salinity management under a capillary-driven automatic irrigation system', *Journal of Arid Land Studies*, 118, pp. 115–118.

Garg, A., Munoth, P. and Goyal, R. (2016) 'Application of Soil Moisture Sensors in Agriculture: a Review', in *Proceedings of International Conference on*

Hydraulics, Water Resources and Coastal Engineering (Hydro2016), CWPRS Pune, India, pp. 1662–1672.

Ghodake, M. R. G. and Mulani, M. A. O. (2016) 'Sensor Based Automatic Drip Irrigation System', *Journal for Research*, 02(02), pp. 53–56.

Gillies, M. (2017) *Modernisation of furrow irrigation in the sugar industry : final report 2014 / 079*. Sugar Research Australia Ltd.

Goldstein, A. *et al.* (2018) 'Applying machine learning on sensor data for irrigation recommendations: revealing the agronomist's tacit knowledge', *Precision Agriculture*. Springer US, 19(3), pp. 421–444.

Goodchild, M. S. *et al.* (2015) 'A Method for Precision Closed-loop Irrigation Using a Modified PID Control Algorithm', *Sensors & Transducers*, 188(5), pp. 61–68.

Gu, J. *et al.* (2017) 'An improved back propagation neural network prediction model for subsurface drip irrigation system', *Computers and Electrical Engineering*. Elsevier Ltd, 60, pp. 58–65.

Hamouda, Y. E. M. (2017) 'Smart Irrigation Decision Support based on Fuzzy Logic using Wireless Sensor Network', in *International Conference on Promising Electronic Technologies*, pp. 109–113.

Hang, L. and Kim, D. (2018) 'Enhanced Model-Based Predictive Control System Based on Fuzzy Logic for Maintaining Thermal Comfort in IoT Smart Space', *MDPI-Applied Sciences*, 8(1031).

Harper, S. (2017) *Real-Time Control of Soil Moisture for Efficient Irrigation*. doi: 10.1111/icad.12044.

Harun, A. N. *et al.* (2015) 'Precision Irrigation using Wireless Sensor Network', in *International Conference on Smart Sensors and Application (ICSSA)*. IEEE, pp. 71–75. doi: 10.1109/ICSSA.2015.7322513.

Harun, A. N. *et al.* (2019) 'Improved Internet of Things (IoT)monitoring system for growth optimization of Brassica chinensis', *Computers and Electronics in Agriculture*, 164, pp. 1–11.

Hasan, F. *et al.* (2018) 'Implementation of Fuzzy Logic in Autonomous Irrigation System for Efficient Use of Water', *Joint 7th International Conference on Informatics, Electronics & Vision (ICIEV) and 2nd International Conference on Imaging, Vision & Pattern Recognition (icIVPR)*. IEEE, pp. 234–238.

He, Q. *et al.* (2019) 'Humidity control strategies for solid-state fermentation: Capillary water supply by water-retention materials and negative-pressure auto-controlled irrigation', *Frontiers in Bioengineering and Biotechnology*, 7(OCT), pp. 1–13.

Hebbar, S. and Golla, V. P. (2017) 'Automatic Water Supply System for Plants by using Wireless Sensor Network', in *International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2017) Automatic*, pp. 742–745.

Hemming, S. *et al.* (2019) 'Remote Control of Greenhouse Vegetable Production Irrigation , and Crop Production', *MDPI-sensors Article*, 19, pp. 1785–1807.

Horvath, K., Valentin, M. G. and Rodellar, J. (2013) 'The effect of the choice of the control variables of the water level control of open channels', in *10th IEEE International Conference on Networking, Sensing and Control, ICNSC 2013*. IEEE, pp. 621–626.

Hussain, M. H. *et al.* (2011) 'Fuzzy Logic Controller for Automation of Greenhouse Irrigation System', in *3rd CUTSE International Conference (CUTSE 2011)*.

Hussain, M. N. M., Omar, A. M. and Samat, A. A. A. (2011) 'Identification of Multiple Input-Single Output (MISO) model for MPPT of photovoltaic system', *Proceedings - 2011 IEEE International Conference on Control System, Computing and Engineering, ICCSCE 2011*. IEEE, pp. 49–53.

Hussan, E. and Hamouda, A. (2014) 'Implementation Fuzzy Irrigation Controller (Mamdani and Sugeno Performance Comparison)', *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 03(11), pp. 12819–12824.

Huuskonen, J. and Oksanen, T. (2018) 'Soil sampling with drones and augmented reality in precision agriculture', *Computers and Electronics in Agriculture*. Elsevier, 154(September), pp. 25–35.

Idham, A. R. M. K. *et al.* (2018) 'Analysis of Fibrous Interface Capillary Irrigation System Using HYDRUS 2D / 3D for High Water Saving Agriculture', in *MSAE Conference, Serdang, Selangor D.E.*, pp. 1–8.

Izzuddin, T. A. *et al.* (2018) 'Smart irrigation using fuzzy logic method', *ARPN Journal of Engineering and Applied Sciences*, 13(2), pp. 517–522.

Isık, M. F. *et al.* (2017) 'Precision Irrigation System (PIS) Using Sensor Network Technology Integrated with IoS/Android Application', *MDPI-Applied Sciences*, 7(9), pp. 1–14.

Jawad, H. M., Nordin, R. and Gharghan, S. K. (2017) 'Energy-Efficient Wireless Sensor Networks for Precision Agriculture : A Review', *Sensors-MDPI*, 17.

Jayaraman, P. *et al.* (2016) ‘Internet of Things Platform for Smart Farming :Experiences and Lessons Learnt’, *Sensors MDPI*, pp. 1–17.

Jha, R. K. *et al.* (2017) ‘Field Monitoring Using IoT in Agriculture’, in *2017 International Conference on Intelligent Computing,Instrumentation and Control Technologies (ICICICT*, pp. 1417–1420.

Jia, X. *et al.* (2019) ‘Research on water and fertilizer irrigation system of tea plantation’, *International Journal of Distributed Sensor Networks*, 15(3).

Jianfeng, Z. *et al.* (2018) ‘Developing a Long Short-Term Memory (LSTM) based model for predicting water table depth in agricultural areas’, *Journal of Hydrology*. Elsevier, 561(April), pp. 918–929.

Joly, M. *et al.* (2017) ‘Multimodal Probe Based on ISFET Electrochemical Microsensors for In-Situ Monitoring of Soil Nutrients in Agriculture’, *Proceedings*, 1(10), p. 420.

Jones, J. W. *et al.* (2003) ‘The DSSAT cropping system model’, *Elsevier Science, Europ. J. Agronomy*, 18.

Mousa, A., S. Croock, M. and N. Abdullah, M. (2014) ‘Fuzzy based Decision Support Model for Irrigation System Management’, *International Journal of Computer Applications*, 104(9), pp. 14–20.

Kale, A. P. and Sonavane, S. P. (2019) ‘IoT based Smart Farming : Feature subset selection for optimized high- dimensional data using improved GA based approach for ELM’, *Computers and Electronics in Agriculture*. Elsevier, 161(November 2018), pp. 225–232.

Kamal, R., Muhammed, H. H. and Mojid, M. A. (2019) ‘Two-dimensional Modeling of Water Distribution under Capillary Wick Irrigation System’, *Science & TechnologY, Pertanika J. Sci. & Technol. 27 (1): 205 - 223 (2019) SCIENCE*, 27(1), pp. 205–223.

Karim, Foughali, Karim, Fathalah and Ali, F. (2017) ‘Monitoring system using web of things in precision agriculture’, in *The 12th International Conference on Future Networks and Communications (FNC 2017)*. Elsevier B.V., pp. 402–409.

Keesman, K. J. (2011) *System Identification :An Introduction*. Springer-Verlag London Limited.

Kelley, J. and Pardyjak, E. R. (2019) ‘Using Neural Networks to Estimate Site-Specific Crop Evapotranspiration with Low-Cost Sensors’, *MDPI agronomy Article,* 9(108), pp. 1–17.

Keswani, B. *et al.* (2018) ‘Adapting weather conditions based IoT enabled smart irrigation technique in precision agriculture mechanisms’, *Neural Computing and Applications*. Springer London, 1, pp. 1–16.

Khairie, M., Bin, I. and Rahman, A. B. D. (2018) *Development of an Adaptive Control Strategy in Fibrous Capillary Irrigation System for Water Saving Agriculture*. Universiti Teknologi Malaysia.

Khamkar, M. N. U. (2014) *Design and Implementation of Expert System in Irrigation of Sugarcane : Conceptual Study*. Sinhgad Institute.

Khoshhal, J. and Mokarram, M. (2012) ‘Model for Prediction of Evapotranspiration Using MLP Neural Network’, *International Journal Of Environmental Sciences*, 3(3), pp. 1000–1009.

Kinoshita, T. *et al.* (2010) ‘Application of Controlled- release Fertilizer to Forcing Culture of Tomato Using Root-proof Capillary Wick’, *Hortic Resources.*, 9(1), pp. 39–46.

Kisekka, I. *et al.* (2016) ‘Evapotranspiration-Based Irrigation Scheduling for Agriculture’, *UF IFAS Extension, University of Florida*, AE457, pp. 1–5.

Klein, L. J. *et al.* (2018) ‘Closed Loop Controlled Precision Irrigation Sensor Network’, *IEEE Internet of Things Journal*. IEEE, 5(6), pp. 4580–4588.

Koech, R. and Langat, P. (2018) ‘Improving irrigation water use efficiency: A review of advances, challenges and opportunities in the Australian context’, *MDPI Journal-Water (Switzerland)*, 10(12), pp. 1754–1771.

Kong, L. *et al.* (2019) ‘A model predictivewater-level difference control method for automatic control of irrigation canals’, *Water (Switzerland)*, 11(4).

Kothawade, S. N. *et al.* (2016) ‘Efficient Water Management for Greenland using Soil Moisture Sensor’, in *1st IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES-2016)*, pp. 1–4.

Krishna, K. L. (2017) ‘Internet of Things Application for Implementation of Smart Agriculture System’, *International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2017) Fig.*, pp. 54–59.

Kumar, A. *et al.* (2017) ‘Internet of Things Based Smart Irrigation Using Regression Algorithm’, *2017 International Conference on Intelligent Computing,Instrumentation and Control Technologies (ICICICT) Internet*, pp. 1652–1657.

Kumar, V. *et al.* (2017) 'Implementation of IoT in Smart Irrigation System Using Arduino Processor', *International Journal of Civil Engineering and Technology (IJCIET)*, 8(10), pp. 1304–1314.

Kranthi Kumar, M. and Srenivasa Ravi, K. (2016) 'Automation of irrigation system based on Wi-Fi technology and IOT', *Indian Journal of Science and Technology*, 9(17), pp. 1–5. doi: 10.17485/ijst/2016/v9i17/93048.

Kushwaha, D. S., Taram, M. and Taram, A. (2015) 'A Framework for Technologically Advanced Smart Agriculture Scenario in India based on Internet of Things Model', *International Journal of Engineering Trends and Technology (IJETT)*, 27(4), pp. 182–185.

Kwon, W. H. and Han, S. (2005) *Receding Horizon Control: model predictive control for state models*. Springer-Verlag London Limited.

Lakhiar, I. A. *et al.* (2018) 'Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques : A Review of the Aeroponic System', *Hindawi Journal of Sensors*, 2018, pp. 1–18.

Ławry´nczuk, M. (2013) *Computationally Efficient Model Predictive Control Algorithms A Neural Network Approach*. 3rd edn. Springer International Publishing Switzerland.

Lee, J. B. *et al.* (2016) 'Shaping the MPC Cost Function for Superior Automated Glucose Control', *IFAC-PapersOnLine*. Elsevier B.V., 49(7), pp. 779–784.

Lefkowitz, M. (2019) *Smart irrigation model predicts rainfall to conserve water*, *Cornell University*. Available at: https://phys.org/news/2019-07-smart-irrigation-rainfall.html (Accessed: 26 July 2019).

Levidow, L. *et al.* (2014) 'Improving water-efficient irrigation : Prospects and difficulties of innovative practices', *Agricultural Water Management*. Elsevier B.V., 146, pp. 84–94.

Li, Q. *et al.* (2018) 'Water Use Efficiency of Precision Irrigation System under Critical Water-saving Condition', in *14th International Conference on Precision Agriculture June*. Montreal, Quebec, Canada, pp. 1–7.

Li, Z. *et al.* (2017) 'Design of an Intelligent Management System for Agricultural Greenhouses Based on the Internet of Things', in *IEEE International Conference on Computational Science and Engineering and IEEE/IFIP International Conference on Embedded and Ubiquitous Computing, CSE and EUC*, pp. 154–160.

Liakos, K. G. *et al.* (2018) 'Machine learning in agriculture: A review', *Sensors (Switzerland)*, 18(8), pp. 1–29.

Lin, H. *et al.* (2015) 'The Construction of a Precise Agricultural Information System Based on Internet of Things', *International Journal of Online and Biomedical Engineering (iJOE)*, 11(6), pp. 10–15.

Liu, M., Kojima, T. and Tanaka, M. (2006) 'Development of Soil−Cooling and Auto−Irrigating System with Negative Pressure', *American Society of Agricultural and Biological Engineers I*, 49(1), pp. 239–244.

Liu, Y. *et al.* (2018) 'Irrigation Canal System Delivery Scheduling Based on a Particle Swarm Optimization Algorithm', *MDPI-Water*, 10(9), pp. 1268–1281. doi: 10.3390/w10091281.

Ljung, L. (2008) *System Identification Toolbox ™ 7 Getting Started Guide*. Available at: www.mathworks.com.

Ljung, L., Ozdemir, A. A. and Singh, R. (2018) 'Online Features in the MATLAB® System Identification ToolboxTM', *ScienceDirect/IFAC-PapersOnLine*. Elsevier B.V., 51(15), pp. 700–705.\r Closed-Loop Irrigation', *IFAC Proceedings Volumes*. Elsevier, 47(3), pp. 4429–4434.

Lozoya, C., Mendoza, C., Mej, L., *et al.* (2014) 'Model Predictive Control for Closed-Loop Irrigation', in *Preprints of the 19th World Congress The International Federation of Automatic Control*. Cape Town, South Africa, pp. 4429–4434.

Lozoya, C. *et al.* (2015) 'A Scalable Design Approach for a Precision Irrigation Data Acquisition System', *American Society of Agricultural and Biological Engineers (ASABE)*, 152189487, pp. 1–10.

Lozoya, C. *et al.* (2016) 'Sensor-Based Model Driven Control Strategy for Precision Irrigation', *Journal of Sensors*, 2016(9784071), pp. 1–12.

Lozoya, C. *et al.* (2019) 'Spectral Vegetation Index Sensor Evaluation for Greenhouse Precision Agriculture', *2019 IEEE SENSORS*. IEEE, pp. 1–4.

Ma, Y. *et al.* (2019) 'Integration Agricultural Knowledge and Internet of Things for Multi-Agent Deficit Irrigation Control', in *21st International Conference on Advanced Communication Technology (ICACT)*. Global IT Research Institute (GIRI), pp. 299–304.

Mahmoud, M. S. (2018) *Advanced Control Design with Application to Electromechanical Systems*. 1st Editio. Edited by 1st Edition. Butterworth-Heinemann. Available at: 1st Edition.

Mantri, G. and Kulkarni, N. R. (2013) 'Design and Optimization of Pid Controller Using Genetic Algorithm', *International Journal of Research in Engineering and Technology (IJRET)*, 2(6), pp. 926–930.

Marinescu, T. *et al.* (2017) 'Advanced Control Strategies for Irrigation Systems', in *The 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications 21-23 September, 2017, Bucharest, Romania*, pp. 843–848.

Masde, R. M. M. and Mohd, N. R. N. (2016) 'Overview of Melon Industry in Malaysia', *Malaysian Agriculture Research and Development institute, MARDI*, pp. 1–6.

Masuda M, F. S. (2008) *Potential for Tomato Cultivation Using Capillary Wick-watering Method, Bull Fac Agric Okayama Univ.*

Mathur, Y. P., Sharma, G. and Pawde, A. W. (2009) 'Optimal Operation Scheduling of Irrigation Canals Using Genetic Algorithm', *International Journal of Recent Trends in Engineering*, 1(6), pp. 1–6.

Mathworks, T. (2015) *System Identification Toolbox ™ Getting Reference R 2015 a How to Contact MathWorks*.

Mccarthy, A. C., Hancock, N. H. and Raine, S. R. (2014) 'Simulation of irrigation control strategies for cotton using Model Predictive Control within the VARIwise simulation framework', *Computers and Electronics in Agriculture*. Elsevier B.V., 101, pp. 135–147.

Mehra, M. *et al.* (2018) 'IoT based hydroponics system using Deep Neural Networks', *Computers and Electronics in Agriculture*. Elsevier, 155(October), pp. 473–486.

Mishra, S., Deep, V. and Akankasha (2014) 'Expert Systems In Agriculture: An Overview', *International Journal of Science Technology & Engineering*, 1(5), pp. 45–49.

Mohamed, K., Mahdy, A. El and Refai, M. (2015) 'Model Predictive Control using FPGA', *International Journal of Control Theory and Computer Modeling (IJCTCM)*, 5(2), pp. 1–4.

Mohanraj, I. *et al.* (2017) 'Intelligent drip irrigation and fertigation using wireless sensor networks', in *IEEE Technological Innovations in ICT for Agriculture and Rural Development, TIAR*, pp. 36–41.

Mohanraj, I., Ashokumar, K. and Naren, J. (2016) 'Field Monitoring and Automation Using IOT in Agriculture Domain', *Procedia Computer Science*, *ScienceDirect*. The Author(s), 93(September), pp. 931–939.

Mohd, E. *et al.* (2007) *Practical System Identification*. Edited by R. A. Mohd Nasir Taib and M. H. F. Rahiman. Malaysia: Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Darul Ehsan, MALAYSIA.

Montesano, F. F., Van Iersel, M. W. and Parente, A. (2016) 'Timer versus moisture sensor-based irrigation control of soilless lettuce: Effects on yield, quality and water use efficiency', *Horticultural Science*, 43(2), pp. 67–75.

Moubarak, A., El-Saady, G. and Ibrahim, E. N. A. (2018) 'Optimal operation of renewable energy irrigation system using particle swarm optimization', *ARPN Journal of Engineering and Applied Sciences*, 13(24), pp. 9318–9327.

Munoth, P., Goyal, R. and Tiwari, K. (2016) 'Sensor based irrigation system: A review', *Int. J. Engg. Res. Tech.*, 4(23), pp. 86–90.

Nada, A., Nasr, M. and Hazman, M. (2014) 'Irrigation Expert System for Trees', *International Journal of Engineering and Innovative Technology (IJEIT)*, 3(8), pp. 170–175.

Nalliah, V. and Sri Ranjan, R. (2010) 'Evaluation of a capillary-irrigation system for better yield and quality of hot pepper (capsicum annuum)', *Applied Engineering in Agriculture*, 26(5), pp. 807–816.

Niu, Q., Fratta, D. and Wang, Y.-H. (2015) 'Precision agriculture * a worldwide overview', *Journal of Hydrology*, 522(20150806), pp. 475–487.

Norhaliza, A. W., Katebi, R. and Jonas, B. (2011) 'Multivariable PID control of an Activated Sludge Wastewater Treatment Process', in Mansour, T. (ed.) *PID Control Implementation and Tuning*.

Nutini, F. *et al.* (2017) 'A weekly indicator of surface moisture status from satellite data for operational monitoring of crop conditions', *Sensors (Switzerland)*, 17(6).

O'Grady, M. J. and O'Hare, G. M. P. (2017) 'Modelling the smart farm', *Information Processing in Agriculture*. China Agricultural University, 4(3), pp. 179–187. doi: 10.1016/j.inpa.2017.05.001.

Obiechefu, G. C. (2017) 'Evaluation of Evapotranspiration Models for Waterleaf crop using Data from Lysimeter', in *ASABE Annual International Meeting Sponsored by ASABE*, pp. 1–13.

Ocampo-Martinez, C. (2010) *Model predictive Control of Wastewater Systems*. London: Springer-Verlag London Limited.

Ohaba *et al.* (2015) 'Adaptive Control of Capillary Water Flow under Modified

Subsurface Irrigation Based on a SPAC Model', in *Proceedings of the 7th International Conference on Precision Agriculture (ICPA 2015)*.

Ooi, S. K. and Weyer, E. (2008) 'Control design for an irrigation channel from physical data', *Elsevier-Science Direct*, 16, pp. 1132–1150.

Koorevaar, G. M. and C. D. (2008) *Elements of Soil Physics, Elsevier Science B.V.*

Panawong, N. and Namahoot, C. S. (2017) 'Cultivation of plants harnessing an ontologybased expert system and a wireless sensor network', *Journal of Telecommunication, Electronic and Computer Engineering*, 9(2–3), pp. 109–113.

Patel, A., Sharda, R. and Siag, M. (2017) 'Development of Decision Support System for On-Farm Irrigation Water Management', *International Journal of Pure Applied Bioscience*, 5(3), pp. 749–763.

Patil, P. *et al.* (2012) 'Fuzzy Logic Based Irrigation Control System Using Wireless Sensor Network for Precision Agriculture', *Proceeding of the 3rd National Conference on Agro-Informatics and Precision Agriculture (AIPA 2012), 1-3 August 2012, Hyderabad, India.*, pp. 262–269.

Patil, P. and L. Desai, B. (2013) 'Intelligent Irrigation Control System by Employing Wireless Sensor Networks', *International Journal of Computer Applications*, 79(11), pp. 33–40.

Patil, S. J. and Patil, A. (2017) 'Precision Agriculture for Water Management Using IOT', *International Journal on Recent and Innovation Trends in Computing and Communication*, 5(12), pp. 142–144.

Pawlowski, A. *et al.* (2017) 'Evaluation of event-based irrigation system control scheme for tomato crops in greenhouses', *Agricultural Water Management*. Elsevier B.V., 183, pp. 16–25.

Payero, J. O. *et al.* (2017) 'Evaluating the Effect of Soil Texture on the Response of Three Types of Sensors Used to Monitor Soil Water Status', *Journal of Water Resource and Protection*, 09(06), pp. 566–577.

Perea, R. G. *et al.* (2018) 'Optimisation of water demand forecasting by artificial intelligence with short data sets', *ScienceDirect-Biosystems Engineering*, 7, pp. 3–10.

Pereira, R. M. S. *et al.* (2018) 'Optimized Planning of Different Crops in a Field Using Optimal Control in Portugal', *sustainability Article, MDPI*, pp. 1–16.

Peters, R. T. (2014) *Low Energy Precision Application (LEPA) Low Energy Spray Application (LESA) on Center Pivots in the PNW*. WSU Irrigated Agriculture Research and Extension Center, Prosser, WA Howard.

Pham, X. and Stack, M. (2018) 'How data analytics is transforming agriculture', *Business Horizons, ScienceDirect www.elsevier.com*, 61(1).

Picard, D., Sourbron, M. and Jorissen, F. (2016) 'Comparison of Model Predictive Control Performance Using Grey-Box and White-Box Controller Models of a Multi-zone Office Building', *International High Performance Buildings Conference*, p. 4.

Pierce, F. J. (2010) 'Precision Irrigation', *Landbauforschung Völkenrode, Special Issue*, (340), pp. 45–56.

Pierpaoli, E. *et al.* (2013) 'Drivers of Precision Agriculture Technologies Adoption : A Literature Review', *6th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2013)*. Elsevier B.V., 8(Haicta), pp. 61–69.

Pongnumkul, S., Chaovalit, P. and Surasvadi, N. (2015) 'Applications of Smartphone-Based Sensors in Agriculture : A Systematic Review of Research', *Hindawi Publishing Corporation, Journal of Sensors*, 2015.

Pramanik *et al.* (2016) 'Effect of Drip Fertigation on Yield, Water Use Efficiency, and Nutrients Availability in Banana in West Bengal, India.', *Commun Soil Sci Plant Anal.*, 47, pp. 13–14.

Prasad, A. N. *et al.* (2016) 'Smart water quality monitoring system', in *2nd Asia-Pacific World Congress on Computer Science and Engineering, APWC on CSE 2015*. IEEE, pp. 1–6.

Puig, V. *et al.* (2012) 'Model predictive control of combined irrigation and water supply systems: Application to the Guadiana river', in *Proceedings of 2012 9th IEEE International Conference on Networking, Sensing and Control*. IEEE, pp. 85–90.

Qin, S. J. and Badgwell, T. A. (2003) 'An overview of industrial model predictive control technology', *Control Engineering Practice*, 11(7), pp. 733–764.

Rad, C., Hancu, O. and Takacs, I. (2015) 'Smart Monitoring of Potato Crop : A Cyber-Physical System Architecture Model in the Field of Precision Agriculture', *ST26733", International Conference 'Agriculture for Life, Life for Agriculture'*. Elsevier Srl, 6, pp. 73–79.

Raes, D. and Munoz, G. (2009) *The ETo Calculator, Fao Reference Manual Version*. Available at: http://www.fao.org/NR/WATER/docs/ReferenceManualV32.pdf.

Ragab, S. *et al.* (2018) 'An Expert System for Selecting the Technical Specifications of Drip Irrigation Control Unit', *Arab Universities Journal of Agricultural Sciences*, 26(2), pp. 601–609.

Rahman, M. K. I. A. *et al.* (2018) 'Enhanced fertigation control system towards higher water saving irrigation', *Indonesian Journal of Electrical Engineering and Computer Science*, 10(3), pp. 859–866.

Rahman, M. K. I. A., Abidin, Mohamad Shukri Zainal, *et al.* (2019) 'Advancement of a smart fibrous capillary irrigation management system with an internet of things integration', *Bulletin of Electrical Engineering and Informatics*, 8(4), pp. 1402–1410.

Raspberry Pi (2019) *Raspberry Pi 4 Computer*. Available at: https://static.raspberrypi.org/files/product-briefs/Raspberry-Pi-4-Product.

Rahmat, M. F. *et al.* (2011) 'Control Strategies of Wastewater Treatment Plants Control Strategies of Wastewater Treatment Plants', *Aust. J. Basic & Appl. Sci*, 5(8)(May 2014), p. 2011.

Raine, S. R. and Mccarthy, A. C. (2014) 'Advances in intelligent and autonomous systems to improve irrigation and fertiliser efficiency', in *27th Annual FLRC Workshop held at Massey University, Palmerston North, New Zealand*. New Zealand, pp. 1–11.

Rajalakshmi, P. and Devi, M. (2016) 'IOT based crop-field monitoring and irrigation automation', in *Proceedings of the 10th International Conference on Intelligent Systems and Control, ISCO 2016*, pp. 1–6.

Rajkumar, M. N., Abinaya, S. and Kumar, V. V. (2017) 'Intelligent irrigation system - An IOT based approach', in *IEEE International Conference on Innovations in Green Energy and Healthcare Technologies - IGEHT*, pp. 1–5. doi: 10.1109/IGEHT.2017.8094057.

Rajeswari, S., Suthendran, K. and Rajakumar, K. (2017) 'A Smart Agricultural Model by Integrating IoT , Mobile and Cloud-based Big Data Analytics', in *International Conference on Intelligent Computing and Control (I2C2)*.

Ramesh, M. V and Rangan, V. P. (2017) 'High Yield Groundnut Agronomy : An IoT

Based Precision Farming Framework', in *IEEE Global Humanitarian Technology Conference (GHTC)*.

Ramli, L. *et al.* (2017) 'Control strategies for crane systems : A comprehensive review', *Mechanical Systems and Signal Processing*. Elsevier Ltd, 95, pp. 1–23.

Ravina, I. *et al.* (1992) 'Control of emitter clogging in drip irrigation with reclaimed wastewater', *Irrigation Science*. Springer-Verlag, 13(3), pp. 129–139.

Rekha *et al.* (2015) 'Impact of Drip Fertigation on Water Use Efficiency and Economics of Aerobic Rice', *Irrigation Drain System Engineering.*, 04(S1), pp. 1–3.

Richey, A. S. *et al.* (2015) 'Quantifying renewable groundwater stress with GRACE', *Water Resources Research*. Blackwell Publishing Ltd, 51(7), pp. 5217–5237.

Richter, S., Jones, C. N. and Morari, M. (2012) 'Computational complexity certification for real-time MPC with input constraints based on the fast gradient method', *IEEE Transactions on Automatic Control*. IEEE, 57(6), pp. 1391–1403.

Rodríguez, D. *et al.* (2015) 'Development of a new control algorithm for automatic irrigation scheduling in soilless culture', *Applied Mathematics and Information Sciences*, 9(1), pp. 47–56.

Rossiter, J. A. (2017) *Model based Predictive Control - A Practical Approach*. Taylor & Francis e-Library.

Rossiter, J. A. (2018) *A First Course in Predictive Control*. Second Edi. CRC Press.

Sadati, S. K. *et al.* (2014) 'Optimal Irrigation Water Allocation Using a Genetic Algorithm under Various Weather Conditions', *MDPI-water*, 6, pp. 3068–3084.

Sadler, E. J. *et al.* (2005) 'Opportunities for conservation with precision irrigation', *Journal of Soil and Water Conservation*, 60(6), pp. 371–379.

Sahbani, F. and Ferjani, E. (2018) 'Identification and Modelling of Drop-By-Drop Irrigation System for Tomato Plants Under Greenhouse Conditions', *Irrigation and Drainage*, 67(4), pp. 550–558.

Saleem S K *et al.* (2013) 'Model Predictive Control for Real-Time Irrigation Scheduling', in *Proceedings of the 4th IFAC Conference on Modelling and Control in Agriculture, Horticulture and Post Harvest Industry*.

Salvi, S. *et al.* (2017) 'Cloud Based Data Analysis and Monitoring of Smart Multi-level Irrigation System Using IoT', in *International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2017)*, pp. 752–757.

Saraf, S. B. and Gawali, D. H. (2017) 'IoT Based Smart Irrigation Monitoring And Controlling System', in *2nd IEEE International Conference On Recent Trends* *in Electronics Information & Communication Technology (RTEICT).*, pp. 1–5.

Say, S. M. *et al.* (2018) 'Adoption of Precision Agriculture Technologies in Developed and Developing Countries', in *International Science and Technology Conference (ISTEC*. Berlin,Germany, pp. 7–15.

Scherer, T. F., Franzen, D. and Cihacek, L. (2017) *Soil, Water and Plant Characteristics Important to Irrigation, K-State Research and Extension*. Available at: www.ksre.ksu.edu/irrigate.

Schulker, B. A. *et al.* (2020) 'Comparison of water capture efficiency through two irrigation techniques of three common greenhouse soilless substrate components', *Agronomy*, 10(9).

Searle, G. E. *et al.* (2002) 'System identification of electronic nose data from cyanobacteria experiments', *IEEE Sensors Journal*, 2(3), pp. 218–228.

Semananda, N., Ward, J. and Myers, B. (2018) 'A Semi-Systematic Review of Capillary Irrigation: The Benefits, Limitations, and Opportunities', *Horticulturae*, 4(3), p. 23.

Seyfi, K. and Rashidi, A. M. (2007) 'Effect of Drip Irrigation and Plastic Mulch on Crop Yield and Yield Components of Cantaloupe', *International Journal of Agriculture & Biology*, 9(2), pp. 9–2.

Shahzadi, R. *et al.* (2016) 'Internet of Things based Expert System for Smart Agriculture', *International Journal of Advanced Computer Science and Applications*, 7(9).

Shang, Y., Rogers, P. and Wang, G. (2012) 'Design and evaluation of control systems for a real canal', *Science China Technological Sciences*, 55(1), pp. 142–154.

Sharma, S. and Regulwar, D. G. (2016) 'Prediction of Evapotranspiration by Artificial Neural Network and Conventional Prediction of Evapotranspiration by Artificial Neural Network and Conventional Methods', (May), pp. 1–5.

Shashi, S. *et al.* (2017) *Intelligent Infrastructure for Smart Agriculture : An Integrated Food , Energy and Water System, Computing Community Consortium Catalyst*. USA.

Shekhar, Y. *et al.* (2017) 'Intelligent IoT Based Automated Irrigation System', *International Journal of Applied Engineering Research*, 12(18), pp. 7306–7320.

Shibusawa, S. (2001) 'Precision Farming Approaches to Small-Farm Agriculture', *Elsevier-2nd IFAC-CIGR Workshop on Intelligent Control and Agricultural*

Applications [preprints], Bali, Indonesia., 34(11), pp. 1–10.

Shigeta, R. *et al.* (2018) 'Capacitive-Touch-Based Soil Monitoring Device with Exchangeable Sensor Probe', in *2018 IEEE SENSORS*. IEEE, pp. 1–4.

Shukri Bin Zainal Abidin *et al.* (2012) 'Transient Water Flow Model in a Soil-Plant System for Subsurface Precision Irrigation', in *Proceedings of the 13th International Conference on Precision Agriculture (ICPA 2012)*, pp. 1–8.

Shukri Bin Zainal Abidin *et al.* (2014) 'Capillary flow responses in a soil – plant system for modified subsurface precision irrigation', *Precision Agric open access at Springerlink.com*, 15, pp. 17–30.

Shukri Bin Zainal Abidin, M. *et al.* (2014) 'Water Uptake Response of Plant in Subsurface Precision Irrigation System', *Science Direct-Engineering in Agriculture, Environment and Food*. Asian Agricultural and Biological Engineering Association (AABEA), 6(3), pp. 128–134.

Singh, S. N. and Jha, R. (2012) 'Optimal Design of Solar Powered Fuzzy Control Irrigation System for Cultivation of Green Vegetable plants in Rural India', in *1st Int'l Conf. on Recent Advances in Information Technology | RAIT-2012 |*.

Smith and Baillie (2009) 'Defining precision irrigation : A new approach to irrigation management', in *irrigation and Drainage Conference 2009, Irrigation Australia Ltd,*. Swan Hill, Vic, Australia., pp. 18–21.

Smith, R. J. *et al.* (2009) 'Managing Spatial and Temporal Variability in Irrigated Agriculture Through Adaptive Control', *Australian Journal of Multi-Disciplinary Engineering*, 7(1), pp. 79–90.

Smith, R. J. *et al.* (2010) *Review of Precision Irrigation Technologies and their Application*. National Centre for Engineering in Agriculture University of Southern Queensland Toowoomba.

Su, C. and Ma, J. (2012) 'Nonlinear Predictive Control Using Fuzzy Hammerstein Model and Its Application to CSTR Process', *AASRI Procedia*, 3, pp. 8–13.

Sudarmaji, A. *et al.* (2019) 'Time based automatic system of drip and sprinkler irrigation for horticulture cultivation on coastal area', *IOP Conference Series: Earth and Environmental Science*, 250(1).

Sulaiman, S. F. *et al.* (2016) 'Linear and Nonlinear ARX Model for Intelligent Pneumatic Actuator Systems', *Jurnal Teknologi*, 6(78), pp. 21–28. Available at: www.jurnalteknologi.utm.my.

Sun, F. *et al.* (2018) 'Research on Water-Fertilizer Integrated Technology Based on

Neural Network Prediction and Fuzzy Control', in *IOP Conference Series: Earth and Environmental Science*.

Sun, L. *et al.* (2018) 'Reinforcement learning control for water-efficient agricultural irrigation', *Proceedings - 15th IEEE International Symposium on Parallel and Distributed Processing with Applications and 16th IEEE International Conference on Ubiquitous Computing and Communications, ISPA/IUCC 2017*, pp. 1334–1341.

Susilo Adi Widyanto, Achmad Widodo, Achmad Hidayatno, S. (2014) 'Error Analysis of ON-OFF and ANN Controllers Based on Evapotranspiration', *TELKOMNIKA Indonesian Journal of Electrical Engineering*, 12(9), pp. 6771–6779.

Tamilselvan, G. M. and Aarthy, P. (2017) 'Online tuning of fuzzy logic controller using Kalman algorithm for conical tank system', *Journal of Applied Research and Technology*. Universidad Nacional Autónoma de México, Centro de Ciencias Aplicadas y Desarrollo Tecnológico.

Tanaka, R., Koga, T. (2019) 'An approach to linear active disturbance rejection controller design with a linear quadratic regulator for a non-minimum phase system', in *Chinese Control Conference (CCC)*, pp. 250–255.

Touati, F. *et al.* (2013) 'A fuzzy logic based irrigation system enhanced with wireless data logging applied to the state of Qatar', *Computers and Electronics in Agriculture*. Elsevier B.V., 98, pp. 233–241.

Tropea, F. (2014) 'Precision Agriculture: an Opportunity for Eu Farmers- Potential Support With the Cap 2014 - 2020', *Europian Union*, p. 56.

Tsang, S. W. and Jim, C. Y. (2016) 'Applying artificial intelligence modeling to optimize green roof irrigation', *Scence Direct, Energy and Buildings*. Elsevier B.V., 127, pp. 360–369.

Tseng, D. *et al.* (2018) 'Towards Automating Precision Irrigation : Deep Learning to Infer Local Soil Moisture Conditions from Synthetic Aerial Agricultural Images', *2018 IEEE 14th International Conference on Automation Science and Engineering (CASE)*. IEEE, pp. 284–291.

Tzounis, A. *et al.* (2017) 'Internet of Things in agriculture, recent advances and future challenges', *Elsevier -Biosystems Engineering*. Elsevier Ltd, 164, pp. 31–48.

Uddin, M. A. *et al.* (2017) 'Agriculture internet of things: AG-IoT', in *2017 27th International Telecommunication Networks and Applications Conference,* *ITNAC 2017*, pp. 1–6.

Umair, S Muhammad, R. U. (2015) 'Automation of Irrigation System Using ANN based Controller', *International Journal of Electrical & Computer Sciences IJECS-IJENS*, Vol:10 No:(January 2010).

UN (2020) *Water Scarcity | UN-Water*. Available at: https://www.unwater.org/water-facts/scarcity/ (Accessed: 21 February 2020).

Vegetronix (2016) *VH400 Soil Moisture Sensor Probes*. Available at: https://vegetronix.com/Products/VH400/ (Accessed: 14 August 2019).

Viani, F. *et al.* (2017) 'Low-Cost Wireless Monitoring and Decision Support for Water Saving in Agriculture', *IEEE Sensors Journal*, 17(13), pp. 4299–4309.

Villarrubia, G. *et al.* (2017) 'Combining multi-agent systems and wireless sensor networks for monitoring crop irrigation', *Sensors (Switzerland)*, 17(8).

Wahab, N. A., Balderud, J. and Katebi, R. (2008) 'Data Driven Adaptive Model Predictive Control With Constraints', in *Emss 2008 20Th European Modeling and Simulation Symposium*, pp. 231–236.

Waher, P. *et al.* (2017) *IoT: Building Arduino-Based Projects*. First Edit. Birmingham UK: Packt Publishing.

Wakitani, S. *et al.* (2018) 'Study on a Kalman Filter based PID Controller', in *IFAC-PapersOnLine*. Elsevier B.V., pp. 422–425.

Waller, P. and Muluneh, Y. (2016) *Irrigation and Drainage Engineering*, *Springer International Publishing AG Switzerland*.

Wang, D., Tan, D. and Liu, L. (2018) 'Particle swarm optimization algorithm: an overview', *Soft Computing*. Springer Berlin Heidelberg, 22(2), pp. 387–408.

Wang, L. (2009) *Model Predictive Control System Design and Implementation Using MATLAB®, Advances in Industrial Control*. Springer-Verlag London Limited.

Wang, L. and Zhang, H. (2018) 'An adaptive fuzzy hierarchical control for maintaining solar greenhouse temperature', *Computers and Electronics in Agriculture*. Elsevier, 155(October), pp. 251–256.

Wasson, T. *et al.* (2017) 'Integration of Rfid And Sensor In Agriculture Using Iot', in *International Conference On Smart Technology for Smart Nation*, pp. 217–222.

Wen, Y. and Shang, S. (2019) 'Pre-Constrained Machine Learning Method for Multi-Year Mapping of Three Major Crops in a Large Irrigation District', *remote sensing Article, MDPI*.

Wesonga, J. M. *et al.* (2014) 'Wick Material and Media for Capillary Wick Based', *Irrigation System in Kenya. Int Journal Sci Res*, 3(4), pp. 613–617.

White, S. C. and Raine, S. R. (2008) *A Grower Guide to Plant Based Sensing for Irrigation Scheduling, NCEA Publication 1001574/6 National*. Available at: http://eprints.usq.edu.au/23521.

Wilson, E. D. *et al.* (2018) 'Dealing with observational data in control', *Elsevier-Annual Reviews in Control*. Elsevier, 46(May), pp. 94–106.

Winkler, D. A. *et al.* (2016) 'MAGIC: Model-Based Actuation for Ground Irrigation Control', in *2016 15th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*. IEEE, pp. 1–12.

Wong, W. C. *et al.* (2018) 'Recurrent Neural Network-Based Model Predictive Control for Continuous Pharmaceutical Manufacturing'.

Yahya, A., Safie, H. and Kahar, S. (1997) 'Properties of cocopeat-based growing media and their effects on two annual ornamentals', *Journal of Tropical Agriculture and Food Science*, 25(2), pp. 151–157.

Yakub, F. and Mori, Y. (2013) 'Model Predictive Control for Car Vehicle Dynamics System – Comparative Study', in *Third International Conference on Information Science and Technology Yangzhou, Jiangsu, China.*

Yashaswini, L. S. *et al.* (2017) 'Smart Automated Irrigation System with Disease Prediction', *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*. IEEE, pp. 422–427.

Yesil, E., Guzelkaya, M. and Eksin, I. (2014) 'Fuzzy PID controllers : An overview', in *The Third Triennial ETAI International Conference on Applied Automatic Systems, Skopje, Macedonia*, pp. 1–8.

Yonts, C. D. (1994) 'Surface Irrigation.', *Encycl Agric Food Biol Eng.*

Yubin, Z. *et al.* (2017) 'Control strategy for precision water-fertilizer irrigation system and its verification', *Journal of Drainage and Irrigation Machinery Engineering*, 35(12).

Yubin, Z. (2018) 'The control strategy and verification for precise water-fertilizer irrigation system', *2018 Chinese Automation Congress (CAC)*. IEEE, pp. 4288–4292.

Zacepins, A., Stalidzans, E. and Meitalovs, J. (2012) 'Application of Information Technologies in Precision Agriculture', in *Proceedings of the 13th International Conference on Precision Agriculture (ICPA 2012)*.

Zamora-izquierdo, M. A., Martı, J. A. and Skarmeta, A. F. (2018) ‘Smart farming IoT platform based on edge and cloud computing’, *ScienceDirect -Biosystems Engineering*, 7, pp. 4–17.

Zazueta, F. S., Smajstrla, A. G. and Clark, G. A. (2008) ‘Irrigation System Controllers’, *Agricultural and Biological Engineering Department, Institute of Food and Agriculture Science, University of Florida*, SSAGE22, pp. 1–11.

Zhang, X. *et al.* (2017) ‘Monitoring citrus soil moisture and nutrients using an IoT based system’, *Sensors (Switzerland)*, 17(3), pp. 1–10.

Zhang, X., Gu, Q. and Bin, S. (2004) ‘Water saving technology for paddy rice irrigation and its popularization in China’, *Irrigation Drain System*, 18(4), pp. 347–356.

Zhang, Y. *et al.* (2018) ‘MBD of grey prediction fuzzy-PID irrigation control technology’, *Desalination and Water Treatment*, 110, pp. 328–336.

Zhao *et al.* (2009) ‘Study on precision water-saving irrigation automatic control system by plant physiology’, in *4th IEEE Conference on Industrial Electronics and Applications*, pp. 1296–1300.

Zhong, K. *et al.* (2018) ‘Linear Quadratic Optimal Controller Design for Constant Downstream Water-Level PI Feedback Control of Open-Canal Systems’, in *MATEC Web of Conferences*.

Zhu, H. *et al.* (2018) ‘Modified Richards’ equation to improve estimates of soil moisture in two-layered soils after infiltration’, *Water (Switzerland)*, 10(9).

Zhu, X. *et al.* (2018) ‘Review of intelligent sprinkler irrigation technologies for remote autonomous system’, *International journal of agricultural and biological engineering.* Association of Overseas Chinese Agricultural, Biological and Food Engineers & CSAE, 11(1), pp. 23–30.

Appendix C List of publications

List of Published Journals

1. **Abioye, Abiodun Emmanuel,** Mohammad Shukri Zainal Abidin, Muhammad Naveed Aman, Mohd Saiful Azimi Mahmud, Salinda Buyamin**,** (2020) **'A Model Predictive Controller for Precision Irrigation using Discrete Laguerre Networks**' Elsevier B.V., 181, p. 105953. Computer and Electronics in Agriculture). **(Published – IF: 3.858, Q1, ISI)**

2. **Abioye, Abiodun Emmanuel,** Mohammad Shukri Zainal Abidin, Mohd Saiful Azimi Mahmud, Muhammad Khairie Idham Abd R., Salinda Buyamin, Mohamad Hafis Izran Ishak, Abdulrahaman O., Onotu Patrick. (2020) '**A Review on Monitoring and Advanced Control Strategies for Precision Irrigation**' Computer and Electronics in Agriculture, Elsevier, 173, p. 105441 **(Published – IF: 3.858, Q1, ISI)**

3. **Abioye, Abiodun Emmanuel,** Mohammad Shukri Zainal Abidin, Mohd Saiful Azimi Mahmud, Muhammad Khairie Idham Abd R Abdulrahaman O. Ona Denis Ijike. (2020) '**IoT Monitoring and Data-Driven Modelling of Drip Irrigation System for Mustard Leaf Cultivation Experiment'** Information Processing in Agriculture, Elsevier. **(Indexed by Scopus)**

4. **Abioye Abiodun Emmanuel**, Mohammad Shukri Zainal Abidin, Mohd Saiful Azimi Mahmud, Salinda Buyamin, Mohamad Hafis Izran Ishak, Muhammad Khairie Idham Abd Rahman, Umar Zangina. (2020) '**Performance Comparison of Experimental IoT Based Drip and Fibrous Capillary Irrigation Systems in the Cultivation of Cantaloupe Plant'** Advances in Agricultural & Food Research, vol. 1, no. 2. **(Non-Indexed Journal)**

Presented Conference Papers:

- **Abioye Abiodun Emmanuel**, Mohammad Shukri Zainal Abidin, Mohd Saiful Azimi Mahmud, Salinda Buyamin, Mohamad Hafis Izran Ishak, Muhammad Khairie Idham Abd Rahman, Umar Zangina. Performance Comparism of Experimental IoT Based Drip and Fibrous Capillary Irrigation Systems in the Cultivation of Cantaloupe Plant. **Malaysia Society of Agricultural and Engineers Conference 2020. Kualar Lumpur, June 2020.**

- **Abioye Abiodun Emmanuel**, Mohammad Shukri Zainal Abidin, Oborkhale L.I., Mohd Saiful Azimi Mahmud, Muhammad Khairie Idham Abd Rahman, Amadi Amadi O. Advance Monitoring and Control Strategy for Fibrous Capillary Irrigation System towards Water-Saving Agriculture- Second International Engineering Conference (IECON 2019) College of Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike. Nigeria. pp. 240-253.

Collaborative Research Papers

- Muhammad Khairie Idham Abd Rahman, Mohammad Shukri Zainal Abidin, Mohd Saiful Azimi Mahmud, Salinda Buyamin, Mohamad Hafis Izran Ishak, **Abioye Abiodun Emmanuel.** Advancement of a smart fibrous capillary irrigation management system with an Internet of Things integration-International Conference on Electrical, Electronic, Communication and Control Engineering (ICEECC2018)
- Mohd Saiful Azimi Mahmud*, Mohamad Shukri Zainal Abidin, **Abioye Abiodun Emmanuel** and Hameedah Sahib Hasan Robotics and Automation in Agriculture: Present and Future Applications, Applications of Modelling and Simulation pp130-140
- Mohd Saiful Azimi Mahmud, Mohamad Shukri Zainal Abidin, Salinda Buyamin, **Abioye Abiodun Emmanuel** & Hameedah Sahib Hasan ; Multi-objective Route Planning for Underwater Cleaning Robot in Water Reservoir Tank, Journal of Intelligent & Robotic Systems.