

**AN IOT BASED AUTOMATION SYSTEM FOR GREENHOUSE  
CULTIVATION**

*by*

**SIDDHARAM**

**(2020-28-006)**

**THESIS**

**Submitted in partial fulfilment of the requirements for the degree of**

**DOCTOR OF PHILOSOPHY**

**IN**

**AGRICULTURAL ENGINEERING**

**(Soil and Water Conservation Engineering)**

**Faculty of Agricultural Engineering and Technology**

**Kerala Agricultural University**



**DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING  
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD  
TECHNOLOGY, TAVANUR - 679 573**

**KERALA, INDIA**

**2026**

## **DECLARATION**

I, hereby declare that this thesis entitled “**AN IOT BASED AUTOMATION SYSTEM FOR GREENHOUSE CULTIVATION**” is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

Date:

**SIDHHARAM**

**(2020-28-006)**

## **CERTIFICATE**

Certified that this thesis entitled “**An IoT based automation system for greenhouse cultivation**” is a record of research work done independently by **Er. SIDDHARAM (2020-28-006)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Place: Tavanur

Date:

**Dr. Jinu A.**

(Major Advisor, Advisory Committee)

Assistant professor, FSRS,

Sadanandapuram, KAU

## CERTIFICATE

We, the undersigned members of the advisory committee of **Er. Siddharam (2020-28-006)**, a candidate for the degree of Doctor of Philosophy in Agricultural Engineering with major in Soil and Water Conservation Engineering, agree that the thesis entitled “**An IoT based automation system for greenhouse cultivation**” may be submitted by **Er. Siddharam (2020-28-006)** in partial fulfillment of the requirement for the degree.



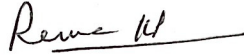
**Dr. Jinu A.**  
(Chairman, Advisory Committee)  
Assistant Professor  
FSRS, Sadanandapuram,  
KAU



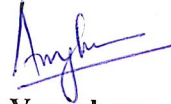
**Dr. Abdul Hakkim V.M.**  
(Member, Advisory Committee)  
Professor & Head  
Dept. of SWCE  
KCAEFT, Tavanur



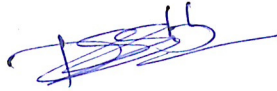
**Dr. Sathian K. K.**  
(Member, Advisory Committee)  
Professor  
Dept. of SWCE  
KCAEFT, Tavanur



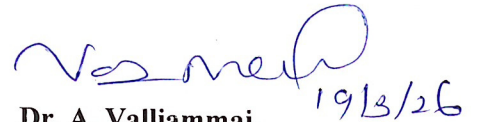
**Dr. Rema K. P.**  
(Member, Advisory Committee)  
Professor & Head,  
Dept. of IDE,  
KCAEFT, Tavanur



**Dr. Anu Varughese**  
(Member, Advisory Committee)  
Associate Professor  
Dept. of IDE,  
KCAEFT, Tavanur



**Dr. Prasanth K.**  
(Member, Advisory Committee)  
Asst. Professor  
Horticulture  
CoA Thrissur

  
19/13/26

**Dr. A. Valliammai,**  
Professor and Head  
Department of Irrigation and  
Drainage Engineering, AEC &  
RI, Kumulur, Trichy.  
**EXTERNAL EXAMINER**

## **DEDICATION**

*This thesis is dedicated to my  
parents Smt. Basamma M Patil and Sri.  
Mallikarjun N Patil who sacrificed much  
to bring me up to this level and Farming  
Community of India*

## ACKNOWLEDGEMENT

**With regardful memories.....**

*It is a matter of pleasure to glance back and recall the path one traverses during the days of hard work and pre-perseverance. It is still great at this juncture to recall all the faces and spirit in the form of teachers, friends, near and dear ones. I would consider this work nothing more than incomplete without attending to the task of acknowledging the overwhelming help I received during this endeavor of mine.*

*My diction would be inadequate to express my deepest sense of gratitude and heartfelt thanks to Chairman of my Advisory Committee, **Dr. Jinu A.**, Assistant Professor, FSRS, Sadanandapuram, KAU. His level of guidance, constructive criticism and generous assistance at every stage of my research work is beyond measure, in fact it was his ideas and smooth dealing with the thing which motivated me to work under his guidance. It is my proud privilege to express my heartfelt indebtedness and deepest sense of gratitude for laying out the guidelines of research work. I have real admiration and regards for his whole hearted support and untiring help.*

*I avail this opportunity to express sincere thanks to my advisory committee members **Dr. Abdul Hakkim V.M.**, Professor & Head, Dept. of SWCE, KCAEFT, Tavanur; **Dr. Sathian K.K.**, Professor, Dept. of SWCE, KCAEFT, Tavanur; **Dr. Rema K. P.**, Professor and Head, Dept. of IDE, KCAEFT, Tavanur; **Dr. Anu Varughese** Associate Professor Dept. of IDE, KCAEFT, Tavanur; **Dr. Prashant K.** Assistant Professor Dept. of Horticulture, CoA Thrissur, for their valuable counsel, note-worthy guidance, and cordial co-operation during my research programme.*

*It is my pleasure to pay tribute to **Dr. Jayan P. R.**, Dean of Faculty (Agrl. Engg.), Professor and Head (Dept. of FMPE), KCAEFT, Tavanur, for his valuable advice and grateful suggestions rendered during this study.*

*I express my sincere gratitude to **Dr. Abdul Jabbar P K.**, Professor and Head, Instructional Farm, KCAET, Tavanur for his immense help, valuable suggestions,*

*advices and deemed support during the polyhouse experiment to complete the research successfully.*

*I place my special thanks to **Dr. Asha Joseph**, Professor, Dept. of IDE, KCAEFT, Tavanur; **Dr. Sajeena S.**, Associate Professor, Dept. of IDE, KCAEFT, Tavanur; **Dr. Prince M. V.**, professor and head, Dept. of PFE, KCAEFT, Tavanur; **Dr. Sarathjith S.**, Assistant Professor, Dept. of IDE, KCAEFT, Tavanur; **Dr. Sheeja P. S.**, Assistant Professor, Dept. of SWCE, KCAEFT, Tavanur; **Dr. Drisya J.** Assistant Professor, Dept. of SWCE, KCAEFT, **Er. Namitha M. R.**, Assistant Professor, Dept. of SWCE, KCAEFT, Tavanur and **Er. Praveena K. K.**, Assistant Professor, Dept. of IDE, KCAEFT, Tavanur; **Mr. Vaishak Venu**, Assistant professor and head, Dept. of BEAS, KCAEFT, Tavanur, for their grateful suggestions and research support. Also, I thank all my department lab Technicians, namely **Abhijit, Praveen, Surjith, Vimal and Danish.***

*I extend my deepest gratitude to the **Precision Farming Development Center, Tavanur**, for providing essential infrastructure, including the polyhouse facility and financial support, which was indispensable for the successful execution of this work.*

*I extend my sincere gratitude to the **Centre for Water Resources Development and Management, Kozhikode**, for providing essential support through the comprehensive analysis of the soil samples. Their technical assistance was instrumental to the commencement of the experimental phase.*

*I express my thanks to all the **faculty members** of KCAEFT, Tavanur; **Er. Ramdas, Dr. Ajeesh, Dr. Dipak Katawakar, Dr. Senthil, Mr. Harikrishna Sagar** for their ever-willing help and cooperation. I express my sincere thanks and gratitude to **Kelappaji College of Agricultural Engineering & Food Technology** for giving me an opportunity to undergo my PhD studies and **Kerala Agricultural University** for having offered me a chance to study in this institution.*

*Words are truly inadequate to express my thanks to my **parents, Mr. Mallikarjun Patil and Smt. Basamma Patil.** Their blessings, sacrifice, and belief in me provided the strength and motivation necessary to complete this work. I also extend*

*my deepest appreciation and respect to my dear brothers, **Sharanu, Shivayogiyappa,** and **Veerabhadra,** and my sisters, **Shailaja** and **Gangubai,** for their constant support and understanding throughout my academic journey. Finally, I wish to acknowledge the presence and joy brought by my young family members: my nephews, **Sourabh, Shivu,** and **Abhi,** and my niece, **Chinnu.** Their 'naughty' energy and affection served as a wonderful source of necessary distraction and happiness.*

*I have been highly fortunate in having many friends in whose company; I never felt the burden of my studies. To mention the names of only a few petals this together as a flower scented my life with an elegant fragrance. I must begin with my dearest friend, **Dr. Aiswarya L., Dr. Shohrat, Er. Rudramuni Swamy, Er. Pavankumar Katti, Dr. Amit Kumar, Dr. T. Mahesh Babu Er. Yesubabu, Er. Sharanbasava, Er. Rajesh, Er. Aravind, Er. A. Ajay, Er. P. Sambasiva Rao, Er. Mahantesh, Er. Naveen, Er. Vel Murugan, Er. Nagarjun, Er. Akansha, Er. Devika, Er. Monika B, Mr. Karthik, Mr. Venkatesh and Mr. Danish** for their invaluable help during study.*

*I also feel happy to express my heartfelt thanks to my nearest and dearest seniors **Dr. Chandrashekar R. C., Dr. Chethan B. J., Dr. Kari Venkata sai, Dr. Venkat Reddy, Dr. N. L. Kalyan Chakravarthy, Dr. J. Srinivas, Dr. Shaheemath Suhara K. K.,** for their boundless help and care in every step of my studies and research work. I would like to place my special thanks to my friends,*

*I would like to acknowledge my own perseverance and dedication that enabled me to complete this research successfully despite various challenges and setbacks. This journey has strengthened my confidence and commitment to continuous learning.*

*No words can describe the unending love, moral support and help by my friends, senior and juniors who shared these beautiful days with me in class, mess, sports ground, hostel and every moment in KCAEFT, Tavanur. Finally, I thank God for bestowing me with divine spirit, essential strength and necessary succor to find my way towards a glorious career amidst several hurdles and struggles.*

*Since it is practically impossible to list every contribution to this work, I wish to offer a **blanket of sincere thanks** to all those who helped me directly or indirectly*

*during the course of my study. The omission of any name does not signify a lack of gratitude, but merely the constraints of space. With all good things, an ending is inevitable, and with this, I conclude my acknowledgment.*

***Er. Siddharam***

## CONTENTS

Chapter No.	Title	Page No.
	LIST OF TABLES	i-ii
	LIST OF FIGURES	iii-vii
	LIST OF PLATES	viii
	SYMBOLS AND ABBREVIATIONS	ix-xii
I	INTRODUCTION	1-6
II	REVIEW OF LITERATURE	7-37
III	MATERIALS AND METHODS	38-88
IV	RESULTS AND DISCUSSION	89-155
V	SUMMARY AND CONCLUSION	156-159
	REFERENCES	160-178
	APPENDICES	179-184
	ABSTRACT	

## LIST OF TABLES

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
3.1	Standard analytical methods for soil physical and chemical characteristics	40
3.2	Specifications, description and function of the hardware placed inside the data acquisition system	47
3.3	Threshold values for irrigation scheduling based on field capacity	57
3.4	Lower threshold values (50% PAW) for pump activation	57
3.5	Threshold values for NPK sensor-based fertigation control	57
3.6	Structural and material specifications of the experimental greenhouse	73
3.7	Crop and experimental layout details for salad cucumber cultivation	81
4.1	Soil characteristics of experimental site	88
4.2	Soil chemical characteristics of experimental site during season1 (13-09-2023 to 28-12-2023)	88
4.3	Soil chemical characteristics of experimental site during season two (13-04-2024 to 13-06-2024)	89
4.4	Performance metrics and statistical validation of low-cost IoT sensors integrated into the automated control system.	89
4.5	Water use efficiency for first season	111
4.6	Water use efficiency for second season	111
4.7	Fertilizer use efficiency of two seasons	111
4.8	Time-lagged correlation analysis of temperature on cucumber yield for first season	113
4.9	Time-lagged correlation analysis of RH on cucumber yield for first season	113

---

4.10	Time-lagged correlation analysis of light intensity on cucumber yield for first season	114
4.11	Time-lagged correlation analysis of temperature on cucumber yield for second season	114
4.12	Time-lagged correlation analysis of RH on cucumber yield for second season	117
4.13	Time-lagged correlation analysis of light intensity on cucumber yield for second season	117
4.14	Statistical validation of IoT microclimate control	120
4.15	Performance Evaluation of IoT vs. Non-IoT Control Systems: Correlation and Mean Absolute Error (MAE) for Environmental Parameters	120
4.16	Morphologic parameter analysis for first season	125
4.17	Yield parameter analysis for first season	125
4.18	Morphologic parameter analysis for second season	131
4.19	Yield parameter analysis for second season	131
4.20	Benefit cost ratio with IoT automation	154
4.21	Benefit cost ratio without IoT automation	155

---

## LIST OF FIGURES

<b>Fig. No.</b>	<b>Title</b>	<b>Page No.</b>
3.1	Overall workflow of the study	39
3.2	Calibration graph for soil moisture sensor vs gravimetric method	49
3.3	Calibration graph for temperature and humidity sensor	50
3.4	Calibration graph for LDR sensor	51
3.5	Calibration graph for NPK sensor a) Phosphorus b) Potassium c) Nitrogen	52
3.6	Circuit diagram of irrigation automation system	64
3.7	Circuit diagram of microclimate automation system	66
3.8	Circuit diagram of fertigation automation system	69
3.9	Circuit diagram of overall automation system	72
3.10	Structure of the experimental naturally ventilated greenhouse	74
3.11	Layout of automation plot	75
3.12	Layout of Treatments	75
4.1	Monthly microclimatic variation in polyhouse during September–2023	93
4.2	Monthly microclimatic variation in polyhouse during October–2023	94
4.3	Monthly microclimatic variation in polyhouse during November–2023	95
4.4	Monthly microclimatic variation in polyhouse during December–2023	96

---

4.5	Monthly microclimatic variation in polyhouse during April–2024	98
4.6	Monthly microclimatic variation in polyhouse during May–2024	99
4.7	Monthly microclimatic variation in polyhouse during June–2024	100
4.8	Time-series plot of soil moisture dynamics under I <sub>1</sub> treatments (September 2023)	102
4.9	Time-series plot of soil moisture dynamics under I <sub>2</sub> treatments (September 2023)	102
4.10	Time-series plot of soil moisture dynamics under I <sub>3</sub> treatments (September 2023)	103
4.11	Time-series plot of soil moisture dynamics under I <sub>4</sub> treatments (September 2023)	103
4.12	Time-series plot of soil moisture dynamics under I <sub>1</sub> treatments (October 2023)	105
4.13	Time-series plot of soil moisture dynamics under I <sub>2</sub> treatments (October 2023)	105
4.14	Time-series plot of soil moisture dynamics under I <sub>3</sub> treatments (October 2023)	106
4.15	Time-series plot of soil moisture dynamics under I <sub>4</sub> treatments (October 2023)	106
4.16	Time-Series plot of soil moisture dynamics under I <sub>1</sub> treatments (November 2023)	108
4.17	Time-Series plot of soil moisture dynamics under I <sub>2</sub> treatments (November 2023)	108
4.18	Time-Series plot of soil moisture dynamics under I <sub>3</sub> treatments (November 2023)	109
4.19	Time-Series plot of soil moisture dynamics under I <sub>4</sub> treatments (November 2023)	109
4.20	Time-Series plot of soil moisture dynamics under I <sub>1</sub> treatments (December 2023)	110

---

---

4.21	Time-Series plot of soil moisture dynamics under I <sub>2</sub> treatments (December 2023)	110
4.22	Time-Series plot of soil moisture dynamics under I <sub>3</sub> treatments (December 2023)	111
4.23	Time-Series plot of soil moisture dynamics under I <sub>4</sub> treatments (December 2023)	111
4.24	Time-series analysis of soil moisture dynamics under I <sub>1</sub> treatments (April 2024)	114
4.25	Time-series plot of soil moisture dynamics under I <sub>2</sub> treatments (April 2024)	114
4.26	Time-series plot of soil moisture dynamics under I <sub>3</sub> treatments (April 2024)	115
4.27	Time-series plot of soil moisture dynamics under I <sub>4</sub> treatments (April 2024)	115
4.28	Time-series plot of soil moisture dynamics under I <sub>1</sub> treatments (May 2024)	116
4.29	Time-series plot of soil moisture dynamics under I <sub>2</sub> treatments (May 2024)	116
4.30	Time-series plot of soil moisture dynamics under I <sub>3</sub> treatments (May 2024)	117
4.31	Time-series plot of soil moisture dynamics under I <sub>4</sub> treatments (May 2024)	117
4.32	Time-series plot of soil moisture dynamics under I <sub>1</sub> treatments (June 2024)	118
4.33	Time-series plot of soil moisture dynamics under I <sub>2</sub> treatments (June 2024)	118
4.34	Time-series plot of soil moisture dynamics under I <sub>3</sub> treatments (June 2024)	119
4.35	Time-series plot of soil moisture dynamics under I <sub>4</sub> treatments (June 2024)	119
4.36	Time-series analysis of NPK nutrient dynamics throughout	123

---

---

	the complete cultivation period	
4.37	Weekly stability and trends of NPK concentrations under IoT-automated fertigation	123
4.38	Daily NPK concentration fluctuations and automated replenishment events (April)	124
4.39	Daily NPK concentration fluctuations in (May)	124
4.40	Daily NPK concentration fluctuations and automated replenishment events (June)	125
4.41	Comparative WUE of cucumber across smart IoT and non-automated drip irrigation treatments in two cultivation seasons.	125
4.42	Correlation analysis temperature time-lagged correlation of preceding temperature intervals on subsequent cucumber yield	133
4.43	Correlation analysis relative humidity temporal analysis of relative humidity impact on future cucumber yield across varying day intervals	133
4.44	Correlation analysis: light intensity correlation between integrated light intensity and subsequent yield output: a multi-day interval analysis	133
4.45	Correlation analysis temperature time-lagged correlation of preceding temperature intervals on subsequent cucumber yield for second season	136
4.46	Correlation analysis of relative humidity impact on future cucumber yield across varying day intervals for second season	136
4.47	Correlation analysis: light intensity correlation between integrated light intensity and subsequent yield output: a multi-day interval analysis	136
4.48	Distribution and variability of key microclimate parameters a) temperature b) humidity c) light intensity across IoT, non-	139

---

---

	automated, and open field environments	
4.49	Correlation Analysis of Microclimate Decoupling: IoT and Non-Automated Systems vs. Open Field	139
4.50	Monthly variation of temperature, humidity, and light intensity distribution (September–November)	140
4.51	MAE comparison of environmental tracking between control systems	140
4.52	Impact of automation levels on average number of flowers per cucumber plant	144
4.53	Average number of fruits per plant across IoT and non-automated treatments.	144
4.54	Effect of low-cost IoT automation on final yield per plant	145
4.55	Yield productivity (t/ha) under IoT-automated and non-automated environmental control	145
4.56	Season 2: effect of IoT-based automation on average flower production per plant.	150
4.57	Season 2: average fruit set percentage across automated and non-automated treatments	150
4.58	Season 2 comparative performance of IoT systems on average number of harvestable fruits	151
4.59	Season 2: validation of IoT system on average yield per plant (g)	151
4.60	Season 2: total yield productivity (t/ha) under IoT-controlled and conventional regimes.	152

---

## LIST OF PLATES

<b>Plate No.</b>	<b>Plate Title</b>	<b>Page No.</b>
3.1	Soil sample collection	41
3.2	Design and Installation of automation set up	62
3.3	Installation of fertigation setup in experimental plot	62
3.4	IoT based automation control system in experimental plot	62
3.5	Field preparation inside the greenhouse using power tiller and manual levelling	74
3.6	Seed selection, nursery tray preparation, sowing, and seedling of salad cucumber	81
4.1	Biometric and yield parameters observation	128-129

## **SYMBOLS AND ABBREVIATIONS**

%	: Percentage
&	: And
'	: Minute
"	: Second
<	: Less than
=	: Equal to
>	: Greater than
°	: Degree
°C	: Degree Celsius
A	: Ampere
ADC	: Analogue to Digital Converter
API	: Application Programming Interface
CO <sub>2</sub>	: Carbon dioxide
DAS	: Days After Sowing
DC	: Direct Current
Dept.	: Department
EC	: Electrical Conductivity

GB	:	Gigabyte
GHz	:	Gigahertz
GPRS	:	General Packet Radio Service
GSM	:	Global System for Mobile Communication
Hz	:	Hertz
IDE	:	Integrated Development Environment
±	:	Plus or Minus
IoT	:	Internet of Things
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	Kilogram
kg/cm <sup>2</sup>	:	Kilogram per square centimeter
l	:	Litre
l/m <sup>2</sup>	:	Litre per square meter
LCD	:	Liquid Crystal Display
LDR	:	Light Dependent Resistor

LED	:	Light-Emitting Diode
lh <sup>-1</sup>	:	Litre per hour
lx	:	Lux
m <sup>2</sup>	:	Square metre
mA	:	Milliampere
CSMS	:	Capacitive Soil Moisture Sensor
PAR	:	Photosynthetically Active Radiation
NPK	:	Nitrogen Phosphorus Potassium
PCB	:	Printed Circuit Board
pH	:	Potential of Hydrogen
POP	:	Package of Practices
ppm	:	Parts per million
PVC	:	Poly Vinyl Chloride
RH	:	Relative Humidity
SD	:	Secure Digital
WUE	:	Water Use Efficiency
FUE	:	Fertilizer Use Efficiency
BCR	:	Benefit Cost Ratio

t/ha-mm	:	Tons per hectare millimeter
UART	:	Universal Asynchronous Receiver-Transmitter
UIDs	:	Unique Identifiers
V	:	Volt
VPD	:	Vapour Pressure Deficit
Wi-Fi	:	Wireless Fidelity
WSN	:	Wireless Sensor Network