

**IMPROVEMENT OF AN AUTOMATIC HAND WASHER WITH AN
ADJUSTABLE SINK BY IMPLEMENTING A DETECTION SYSTEM USING
ESP32-CAM AND AN AUTOMATED TISSUE-DISPENSING MECHANISM**

By

Benedeto Widyakso
12101011

BACHELOR'S DEGREE
in

MECHANICAL ENGINEERING – MECHATRONIC CONCENTRATION

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY



SWISS GERMAN UNIVERSITY
The Prominence Tower
Jalan Jalur Sutera Barat No. 15, Alam Sutera
Tangerang, Banten 15143 - Indonesia

Revision after the Thesis Defense on 1 July 2025

STATEMENT BY THE AUTHOR

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgement is made in the thesis.

Benedeto Widyakso

15 July 2025

Student

Date



Approved by:

Dr. Yunita Umniyati, S.Si., M.Sc.

15 July 2025

Thesis Advisor

Date

Dr. Rusman Rusyadi, B. Sc., M.Sc.

15 July 2025

Thesis Co-Advisor

Date

Dr. Maulahikmah Galinium, S.Kom., M.Sc.

Dean

Date

ABSTRACT

Improvement of An Automatic Hand Washer with an Adjustable Sink by Implementing a Detection System Using ESP32-CAM and An Automated Tissue- Dispensing Mechanism

By

Benedeto Widyakso

Dr. Yunita Umniyati, S.Si., M.Sc., Advisor

Dr. Rusman Rusyadi, B.Sc., M.Sc., Co-Advisor

SWISS GERMAN UNIVERSITY

This thesis presents the enhancement of an automated handwashing system to achieve a more reliable and fully touchless user experience, tailored for public hygiene settings such as schools and shared facilities. The improvements focus on integrating a vision-based user detection system using the ESP32-CAM and implementing a servo-driven tissue dispensing mechanism. The ESP32-CAM provides real-time presence detection and height estimation through grayscale motion analysis, replacing the conventional ultrasonic and infrared sensors that were limited by lighting and obstruction issues. The system is controlled by an Arduino MEGA, which coordinates water flow, soap dispensing, tissue delivery, and hand drying through a structured sequence of operations. Communication between the ESP32-CAM and Arduino is established via UART. The servo-driven tissue mechanism is designed for simplicity, energy efficiency, and ease of integration, contributing to a fully contactless cycle. The methodology includes electrical and mechanical system design, component testing, serial communication setup, and state-based control programming. This research supports the development of intelligent, low-maintenance hygiene systems and provides a foundation for future work involving unified ESP32-based control and enhanced software modularity.

Keywords: ESP32-CAM, Arduino MEGA, touchless hygiene system, tissue dispenser, motion detection, automated sink.



DEDICATION

I dedicated this work firstly to my family, friends, and partner. Secondly, advisor, Dr. Yunita, and my co-advisor, Dr. Rusman Rusyadi. Lastly, I also dedicated this work to the future of my country, Indonesia.



ACKNOWLEDGEMENTS

I wish to express my deepest gratitude and appreciation to Dr. Yunita Umniyati, S. Si., M. Sc., my thesis advisor and Dr. Rusman Rusyadi, my co-advisor, for their role in assisting my work and for giving me their full support in regards to time, energy, effort, and inspiration in completing my thesis.

I would also like to thank my family members, friends, and partner for supporting and encouraging me throughout the whole process. Without these figures, I would not be able to do my work smoothly. Their continuous support has been very helpful and highly appreciated.



TABLE OF CONTENTS

	Page
STATEMENT BY THE AUTHOR	2
ABSTRACT	3
DEDICATION	5
ACKNOWLEDGEMENTS	6
TABLE OF CONTENTS.....	7
LIST OF FIGURES.....	10
LIST OF TABLES.....	12
CHAPTER 1 - INTRODUCTION	13
1.1 Background	13
1.2 Problem Statement.....	14
1.3 Thesis Objectives.....	14
1.4 Significance of Study	14
1.5 Scope and Limitations.....	15
CHAPTER 2 - LITERATURE REVIEW.....	16
2.1 Overview of Relevant Studies	16
2.2 Research Gap in Literature.....	18
2.3 Theoretical Perspectives.....	19
2.3.1 IoT Architecture and Embedded Vision Systems	19
2.3.2 Lightweight Computer Vision Algorithms	20
2.3.3 Lighting Sensitivity in Embedded Vision Systems	21
CHAPTER 3 – RESEARCH METHODS	22
3.1 System Design Overview	22
3.2 System Breakdown Structures.....	24
3.3 Mechanical Design and Selection.....	26
3.4 Electrical Design and Selection.....	29
3.4.1 Arduino MEGA 2560	30
3.4.2 ESP32-CAM	31
3.4.3 Other Electrical Components	32
3.4.4 Tissue Dispensing Unit Motor Sizing	34
3.4.5 MG996R Servo Motor Justification	35

3.5 Program and Control Design.....	36
3.5.1 System Logic Flowchart	36
3.5.2 Arduino MEGA 2560 Logic	38
3.5.3 ESP32-CAM Logic	39
3.5.4 Communication and Reliability Handling	41
3.6 Testing and Validation Protocols	41
3.6.1 Component-Level Testing	41
3.6.2 System Integration and Sequence Testing	42
3.6.3 Key Performance Indicators (KPIs)	42
3.6.4 Accepted Criteria	43
CHAPTER 4 – RESULTS AND DISCUSSIONS	44
4.1 Initial Evaluation Strategy.....	44
4.2 Component Level Testing Approach.....	44
4.2.1 VL53L0X Distance Sensor Evaluation	45
4.2.2 ESP32-CAM Motion-Based Height Estimation	45
4.2.3 Ambient Light Influence	45
4.2.4 MG996R Servo Motor Dispensing Functionality	45
4.3 User Presence Detection Testing via Motion Analysis.....	46
4.4 First Motion-Based Height Estimation Testing – One Test Subject	49
4.4.1 Results Summary	49
4.4.2 Conclusion	51
4.5 Second Motion-Based Height Estimation with Multiple Test Subjects	51
4.5.1 Summary of Results	52
4.5.2 Graphical Interpretation	52
4.5.3 Observations and Discussion	53
4.5.4 Conclusion	54
4.6 Final Height Estimation Test with Calibrated Formula with Multiple People.....	54
4.7.1 Summary of Results	55
4.7.2 Analysis and Discussion	56
4.7.3 Conclusion	56
4.8 Servo-Based Tissue Dispensing Performance Test	57
4.8.1 Hardware Context and Setup	57

4.8.2 Test Data Summary	57
4.8.3 Result Analysis	58
4.8.4 Engineering Implications	58
4.8.5 Conclusion	59
4.9 Light Intensity Testing and Its Effect on ESP32-CAM Height Estimation	
Accuracy	59
4.9.1 Testing Methodology	60
4.9.2 Summary of Results	60
4.9.3 Discussion	61
4.9.4 Conclusion	62
4.10 Full Cycle Testing.....	62
CHAPTER 5 – CONCLUSIONS AND RECCOMENDATIONS	64
5.1 Conclusions	64
5.2 Recommendations.....	65
REFERENCES.....	67
GLOSSARY	71
CURRICULUM VITAE.....	75
APPENDICES A – SERVO MG996R 360° CONTINUOUS SERVO DATASHEET	76
APPENDICES B – LOGIC LEVEL SHIFTER 4-CHANNEL BI-DIRECTIONAL DATASHEET	77
APPENDICES C – ESP32-CAM DATASHEET	78
APPENDICES D – BILL OF MATERIAL	79
APPENDICES E – FINAL IMPROVED MACHINE ASSEMBLY	80
APPENDICES F – FINAL ELECTRICAL WIRING.....	81
APPENDICES G – FULL SYSTEM TESTINGS	82
APPENDICES H – ESP32-CAM’S FINAL SOURCE CODE	84
APPENDICES I – ARDUINO MEGA 2560’S FINAL SOURCE CODE.....	92
APPENDICES J – DATA TAKING TABLES.....	103

LIST OF FIGURES

Figures	Page
Figure 2.1 Visual sequence of motion-based blob detection using frame differencing in embedded vision systems.....	17
Figure 2.2 System architecture of an ESP32-CAM-based embedded vision setup for IoT applications.....	20
Figure 3.1 System Framework Flowchart.....	22
Figure 3.2 Overall System Block Diagram.....	23
Figure 3.3 System Breakdown Structure	25
Figure 3.4 Aluminium Profile 30x30	26
Figure 3.5 Gusset Corner Profile.....	26
Figure 3.6 Final assembly tissue dispensing unit.....	27
Figure 3.7 Custom-made servo bracket.....	27
Figure 3.8 Servo horn kit	28
Figure 3.9 ESP32-CAM Housing.....	28
Figure 3.10 Electrical Wiring Diagram	29
Figure 3.11 Arduino MEGA 2560.....	30
Figure 3.12 ESP32-CAM.....	31
Figure 3.13 Logic Level Shifter	32
Figure 3.14 IBT-2 H-Bridge Motor Driver (BTS7960).....	32
Figure 3.15 TowerPro MG996R 360° Continuous Servo	33
Figure 3.16 VL53L0X ToF Sensor	33
Figure 3.17 E18-D80NK Proximity IR Sensor	34
Figure 3.18 Breadboard	34
Figure 3.19 System Logic Flowchart	37
Figure 3.20 Pseudocode for Arduino MEGA 2560's logic	39
Figure 3.21 Pseudocode for ESP32-CAM's logic.....	40
Figure 3.22 Calibrated linear regression formula.....	40
Figure 4.1 visual summary of the average Motion%, Center%, and Intensity% recorded across the 10 subjects.....	47
Figure 4.2 Average Motion% by Subject	48
Figure 4.3 Average Center% by Subject	48

Figure 4.4 Average Intensity% by Subject	48
Figure 4.5 Accuracy rate compare to error percentage.....	50
Figure 4.6 Estimated heights in regard to avgY	50
Figure 4.7 Comparison between Estimated and Actual Heights.....	53
Figure 4.8 Error percentage compare to accuracy rate	53
Figure 4.9 Comparison table between estimated and real height of final test	56
Figure 4.10 Height Estimation Accuracy vs Lighting Conditions	61



LIST OF TABLES

Table 2.1 Summary of Selected Studies on Automated Hand Hygiene and Vision Systems	18
Table 4.1 ESP32-CAM first testing.....	47
Table 4.2 Key metrics for each test subjects.....	52
Table 4.3 Final testing metric performance	55
Table 4.4 Servo test performance result	58
Table 4.5 Light intensity test results.....	60
Table 4.6 Full cycle time for each phase	62
Table 4.7 Initial Motion Based Height Estimating testing	108
Table 4.8 Second Motion-Based Height Estimation with Multiple Test Subjects....	110
Table 4.9 Final Height Estimation Test with Calibrated Formula with Multiple People	111
Table 4.10 Full Cycle Testing Data Table	111

