AUTOMATED MANUAL ASSEMBLY STATION USING COMPUTER VISION

By

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ABSTRACT

This project aims to design an intelligent, data-driven workstation that efficiently measures operators' performance, assists operators in enhancing productivity and improving quality control, and addresses long-standing challenges within traditional manual assembly stations. This innovative technology is intended to replace outdated proprietary systems and paper-based processes, which provide little room for innovation and flexibility. This system includes sensors, open-source software, and computer vision to transform the assembly process. This project implements an integrated quality inspection model based on real-time picture data for immediate fault detection to streamline processes and remove roadblocks. This workstation's implementation of a unique QR code-based triggering event mechanism is a novel feature. This inventive method allows the system to decode QR code values to identify and initiate particular assembly tasks, bringing a new level of accuracy and efficiency to the assembly process. This innovative workstation's release has the potential to change the manufacturing industry completely. It's not only more affordable for startups, but it also positively impacts overall excellence by increasing quality standards, efficiency, and adaptability in a constantly changing industry. This project introduces a dynamic assembly process, advocates open-source architectures, and seamlessly integrates quality assurance throughout the assembly workflow to accomplish this goal.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

OSS	Open-Source Software
SME	Small Medium Enterprise
IoT	Internet of Things
KPI	Key Performance Indicator
QC	Quality Control
QI	Quality Inspection
CV	Computer Vision
IIoT	The Industrial Internet of Things
PCB	Printed Circuit Board
UI/UX	User Interface and User Experience
QR	Quick Response
SSIM	Similarity Structure Index Measure
ORB	Orientated FAST and Robust BRIEF
SIFT	Scale-Invariant Feature Transform

CHAPTER 1

Introduction

1.1 Problem Statement and Motivation

This project introduces an Automated Manual Station that aims to improve organisational flexibility and creativity while revolutionising traditional manual assembly methods. Through the project's mitigation of vendor lock-in and restrictive systems—which are especially detrimental to small and medium-sized enterprises (SMEs)—businesses will be better equipped to investigate new technologies and promptly adjust to changing production requirements. This programme is essential for small and medium-sized enterprises (SMEs) looking to leverage cutting-edge IT innovations and create a creative atmosphere to successfully navigate fast-paced markets.

To seek a more accessible and cost-effective alternative, QR codes emerge as a potential solution. Their quick response capability speeds up procedures and reduces the need for multiple cameras and sensors, simplifying the setup of the assembly station. In order to increase overall system effectiveness, the initiative emphasises the significance of a coordinated strategy that bridges the gap between inventory management and quality control within the manual assembly station. Intelligent restocking mechanisms are based on real-time insights, which guarantee optimal inventory levels and minimise stock imbalances. The incorporation of contemporary technologies ensures consistently high-quality products by not only detecting flaws but also anticipating potential issues beforehand. This will enable manual stations to be transformed into advanced, flexible systems that optimise operational processes, reduce downtime, and achieve previously unheard-of levels of assembly process efficiency.

The project aims to revolutionize human resource management by providing managers with a comprehensive tool that automatically monitors and assesses each employee's performance, eliminating the need for manual oversight. With the help of this creative strategy, managers can effectively distribute workload according to individual performance, improving productivity and organizational results. By directing users through the systematic assembly procedures, the system also seeks to reduce the likelihood of assembly errors significantly, improving assembly ease and guaranteeing product quality.

Through integrating these capacities, the project is motivated by a strong desire to revolutionize conventional assembly techniques, cultivate an innovative culture, and enable a smooth shift towards increased flexibility, creativity, and agility for small and medium-sized businesses (SMEs) in a competitive and dynamic business environment.

Problem statement:

1. The shortcomings of the existing traditional system in measuring and evaluating operators' performance have created significant challenges for management, serving as the driving force behind the Automated Manual Station project. The current conventional method of measuring and assessing operator performance frequently uses averages of results, making it challenging to spot outliers and individual performance problems. In addition to being time-consuming, this method is imprecise, which makes it difficult for management to recognize and support operators who might be having difficulties with the procedure. Furthermore, biases in the performance reports could make it more difficult to evaluate each operator's performance accurately. [1] has concurred that subjective filtration is complex with conventional human observation. The need for an innovative approach that can offer real-time insights into individual operator performance and enable targeted assistance to improve productivity and quality is highlighted by the fact that this issue has grown to be a primary source of headaches for high management levels.
2. The complex nature of assembly procedures frequently causes workers problems in recalling and correctly carrying out the necessary steps. Operators must also take on the additional task of learning, remembering, and practicing new assembly procedures in companies where product changes occur frequently. This learning and memorizing process can take time, increase errors, and decrease productivity. This problem makes it more difficult for operators to maintain consistency and accuracy in their work without an organized and efficient training and guidance system. Therefore, an inventive solution is desperately needed to give operators thorough and understandable guidance so they can quickly master new and unfamiliar assembly processes, perform better, and guarantee the quality of the finished product.

3. The current assembly process encounters a significant challenge due to the need for early detection mechanisms for defective products. Usually, quality control (QC) is managed by a separate system, which checks at the very end or after multiple assembly processes are finished. Because of the low communication between the assembly stages caused by this asynchronous approach, it is challenging to find and fix flaws quickly. Defective products might go unnoticed until the end, increasing the expense of scrap, rework, and customer returns. To prevent the production of faulty products and enhance overall product quality and reliability, there is an urgent need for an innovative solution that can incorporate early detection mechanisms into the assembly process and enable real-time monitoring and prompt corrective action.

1.2 Problem Scope

The project scope includes multiple important components that together with cutting-edge methods for step guidance and quality control and computer vision technology will transform the conventional assembly process. Creating a proof-of-concept model and base system will allow automated manual assembly stations to use a single web camera and computer vision to accomplish innovative automated quality control (QC) and step guidance. Quality control can be integrated into the assembly process by optimizing process instructions for increased efficiency and meeting customer standards to ensure consistent product quality, minimize waste, and reduce rework.

The main approach for resolving the issues raised is to strategically employ QR codes to initiate actions, which will raise the effectiveness of assembly. The system will cleverly use QR codes in place of buttons to provide a precise and easy-to-learn way to initiate actions within the system. With the use of QR codes as event triggers, this system offers a quick response in an easy-to-use and affordable structure. Using a single top-view camera to record the whole frame, different value QR codes are shown and then recorded. Depending on whether the QR code is successfully recognised or not, the system starts to trigger events. Based on the success or failure of the QR code recognition, the system will initiate the corresponding actions, guaranteeing immediate outcomes and improving the assembly process's general efficiency and dependability.

In addition to these features, the system will also have extensive performance reporting capabilities to assess and gauge the accuracy and efficiency of the operators during the assembly process. This will allow managers to evaluate operator performance quickly and effectively, allowing for the proactive identification of training needs and areas that require improvement.

In addition to proving that computer vision-based automated manual assembly stations are technically possible, this creative method seeks to reduce dependency on single-vendor devices. As the project moves forward, its goal is to provide a workable model that not only shows that an automated manual assembly station using computer vision is technically feasible but also tries to lessen reliance on devices made by a single vendor. This proof-of-concept, which prioritises a phased approach, acts as a fundamental building block for upcoming improvements and scalability. Initial phases concentrate on core functionality;

however, to guarantee a smooth integration of this automated quality control management solution into a variety of manufacturing environments, later phases may involve user interface and experience improvements.

1.3 Objectives

1.3.1 Measuring Operator Performance

The Automated Manual Station project aims to overcome the limitations of the current traditional system used to assess operators' performance during the assembly process. To achieve this, the project intends to implement a real-time performance measurement system that tracks the time taken for each assembly round and the number of incorrect steps. This will provide precise and timely insights into the accuracy and efficiency of the operators. The operators' performance data will be captured and stored for detailed analysis that prioritizes individual data analysis over batch analysis, enabling managers to identify and resolve issues with unsatisfactory employees.

The system will also help managers quickly and effectively evaluate operators' performance, allowing them to identify training needs and areas for improvement proactively. To ensure impartial and consistent performance evaluation, the project aims to create a standardized evaluation system that eliminates subjectivity and biases common in traditional human observation techniques.

1.3.2 Assisting Operator in Assembly Processes

The Automated Manual Station project's second objective is implementing a systematic and user-friendly guidance system that makes assembly easier for operators and guarantees a seamless, error-free workflow. The project intends to eliminate the need for operators to look for instructions from other sources and lower the risk of errors by offering step-by-step guidance and continuous checking to ensure that the assembly process stays on track. By giving clear, consistent instructions and feedback, this system will help new operators quickly adapt to the assembly procedures, lowering their learning curve and increasing productivity.

By assisting operators in following the proper assembly procedures, the project also seeks to reduce the likelihood of assembly errors and improve the end product's quality and dependability. By accomplishing these goals, the Automated Manual Station project hopes to transform the assembly line, promote an innovative culture, and help small and medium-sized businesses (SMEs) transition smoothly to increased adaptability, imagination, and agility in a fast-paced, highly competitive workplace.

1.3.3 Enhancing Manufacturing Quality and Efficiency by Integrating Quality Control

Integrating computer vision (CV) technology for early defect detection and seamless integration of the quality control (QC) and assembly processes is the third and final objective of the Automated Manual Station project. The project's goal is to reduce the Cost of Poor Quality (COPQ) and associated costs like scrap, rework, and customer returns while simultaneously increasing the overall quality of the manufactured product through systematic quality control techniques. By creating a system that successfully manages quality concurrently, the main objective is to improve overall manufacturing agility and efficiency, thereby addressing the shortcomings of the current fragmented approach.

Traditional assembly lines have significant expenses related to errors, such as expenses for human error correction and finished defective goods. By applying early flaw detection with CV, the project hopes to lower these expenses drastically, increasing the manufacturing process's overall profitability and efficiency. Traditional assembly stations have timing issues because error alerts are received too late, making it difficult to make necessary corrections or adjustments promptly. By preserving consistency throughout the assembly process and drastically lowering the need for human inspections, especially in the final stages of production, this system seeks to improve the quality of the final product.

1.4 Contributions

The development of an intelligent manual assembly station has the potential to revolutionize manufacturing and spur positive social change. The project lowers financial barriers, promotes innovation, and empowers small businesses by doing away with vendor lock-ins and adopting open-source technologies instead of proprietary ones. This move to an open platform encourages collaboration among developers worldwide, advances technological advancement, and creates a dynamic ecosystem that can quickly adjust to shifting customer needs. Small and medium-sized enterprises (SMEs) can affordably use cutting-edge technology to improve their manufacturing processes because the system only needs a laptop and one web camera.

By introducing the novel application of QR codes in computer vision, the system offers a dependable and easy-to-use interface that enhances the assembly process' overall efficiency and dependability. This new way of using QR codes allows for accurate and quick results, lowering operators' learning curve and guaranteeing consistent product quality.

The creation of an inexpensive, open-source system fosters affordability, openness, cooperation, and ongoing development in the manufacturing sector. The project integrates quality control into the assembly process to ensure consistent product quality, minimize waste and rework, and lower the overall cost of poor quality. It does this by optimizing process instructions for increased efficiency and customer standards.

By accomplishing these goals, the project significantly advances manufacturing excellence through more affordable automation and efficient production techniques, develops a robust local economy, and creates job opportunities. The system's capacity to boost productivity, lessen the workload, and maximize human and product resources leads to high productivity in producing faultless products, which lowers the expense of poor quality and improves overall product dependability and customer satisfaction.

1.5 Backgrounds

1.5.1 Manual Assembly Station

For decades, traditional manual assembly stations on production floors have been primarily reliant on human labour, simple tools, and paper-based operations. Using hand tools, workers conduct repeated assembly activities by following written job cards or checklists. These conventional stations are versatile but lack the instruments needed to drive significant changes, low efficiency and fail to record crucial production data.

In recent years, manufacturers have started adding various digital technologies and sensors to manual workstations to make them "intelligent". Multiple sensors are implanted throughout the work area to precisely track operations, gather quality data, and record operator motions and activities. Today's intelligent fixtures and tools combine sensors to guarantee accurate part placement, track cycle times, and provide digital assembly guidance. Workflows that used to be done on paper can be replaced with animated checklists and step-by-step directions on electronic screens.

By Utilizing advanced analytics software, data from all of these interconnected sensors is combined and evaluated in real-time. Without any direct human oversight, sophisticated software algorithms analyze trends, discover inefficiencies, and forecast maintenance requirements. Powerful new dashboards that provide management with unmatched visibility into operations and productivity are now available. Operators on the floor receive timely alerts and suggestions for problems via their screens.

Manufacturers are converting previously non-digital assembly stations into active, intelligence-driven work cells by utilizing these digital technologies. Processes become more effective, and production quantity and quality are under greater control. Additionally, improving workplace safety and ergonomics is built-in monitoring. The concept of an intelligent manual station applies data and automation principles to situations that have hitherto been too complex for robots. New degrees of optimization, consistency, and adaptability improve operations overall.

1.5.2 How automated/ smart/ intelligence manual station works.

A manual assembly station, sometimes referred to as a manual working or production station, is a designated space inside a manufacturing or production facility where employees carry out activities primarily by hand. Rather than being completed by automated devices or robots, these jobs often entail manually assembling products or components by operators.

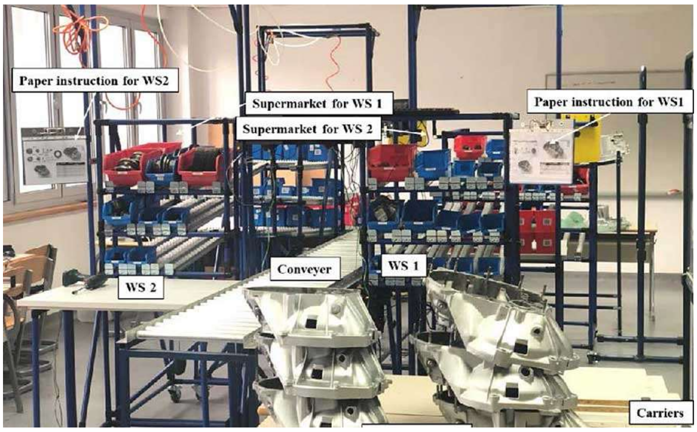


Figure 1.1 Traditional manual assembly station.

In recent years, industries have been implementing new technology to make these stations "intelligent". Traditional manual assembly stations are being digitally transformed to automated using a variety of industrial Internet of Things (IIoT) sensors, depth camera, edge computing devices, and analytics software. Common sensor payloads include RFID/barcode scanners, vision systems, weight scales, motion triggers and wearables that accurately trace human motions, part IDs, cycle times, and ergonomic data points. Low-latency protocols like IPv6, Modbus, or MQTT are used to network and communicate.

Figure 1.2 An example of smart manual assembly station

Figure 1.3 Demographic of Digital Work Instruction

This system represented an interactive instruction manual, the display monitors on the station will offer step-by-step instructions for tasks. Operators benefit from watching expert demonstrations of tasks in recordings. On-demand video playback is available for reference. In order to ensure accurate and error-free assembly, the system uses motion tracking to assist users through the assembly sequence, showing a green light on the appropriate component and turning on a red-light sensor when the incorrect component is picked. In place of paper-based methods, electronic checklists and signoffs are used. Before proceeding, operators digitally verify that they have understood.

Intelligent manual workstations frequently handle product assembly that requires integrating multiple parts. It is crucial to carefully trace which parts go into each product as operators are working on many assembly activities at once. The station uses a barcode scanner tool to read barcodes on both individual products and component parts in order to make this possible. Each component that an operator receives in bins that they need for their particular jobs is scanned and entered into the system database.

Due to the fact that human jobs are complicated, these intelligent manual stations seek to promote digitally enabled continuous improvement through contextualised timely delivery insights rather than full robotic automation.

1.5.3 What are QR codes?

The first Quick Response (QR) codes were created in 1994 by Denso Wave, a Toyota subsidiary based in Japan. Tracking automotive parts during the manufacturing process was the main goal. Two-dimensional barcodes known as QR codes are capable of storing a wide range of data types, including binary, alphanumeric, numeric, and even Kanji characters. A lot more data can be stored in QR codes than in traditional barcodes.

QR codes come in different models, each intended for a particular use. Micro QR Code, QR Code Model 1, and QR Code Model 2 are a few examples. Size and complexity are two factors that determine how much data these codes can store; Micro QR Codes are the smallest and best suited for storing a small amount of data. Models 1 and 2 are similar in structure, but they differ in terms of complexity and storage capacity. In comparison to Model 1, Model 2 has superior error correction capabilities and a larger storage capacity, which makes it appropriate for applications with more demanding specifications.

Figure 1.4 Example of QR codes.

When utilising smartphone or camera-equipped devices, QR codes provide a quick and easy way to access information. Their adaptability to a range of applications is facilitated by their ability to store a variety of data types, such as email addresses, text messages, contact details, and website URLs. Furthermore, QR codes have built-in error correction features that allow them to recover data from damaged or dirty codes; even codes with up to 30% damage may still be able to be successfully decoded. This strong feature improves QR codes' dependability and usability in a variety of situations.

1.6 Report Organisation

This report is organised into 6 chapters: Chapter 1 Introduction, Chapter 2 Literature Review, Chapter 3 System Design, Chapter 4 System Implementation and Testing, Chapter 5 System Outcome and Discussion, Chapter 6 Conclusion. The first chapter is the introduction of this project which includes problem statement, project background and motivation, project scope, project objectives, project contribution, highlights of project achievements, and report organisation. The second chapter is the literature review carried out on several existing IoT applications in the market to evaluate the strengths and weaknesses of each product. The third chapter is discussing the overall system design of this project. The fourth chapter is regarding the details on how to implement the design of the system. Furthermore, the fifth chapter reports the setup and how the system is implemented. The sixth chapter is focusing on system evaluation and discussion while the last chapter includes the conclusion and remarks.

CHAPTER 2

Literature Review

2.1 Existing Themes on Intelligent Manual Assembly Station

2.1.1 Proprietary System

A proprietary automated or intelligent manual assembly station is a specialized solution used in manufacturing and production floor operations to speed up manual assembly procedures. To increase the effectiveness of the assembly process, it integrates advanced sensors, software, and analytics. According to [1], IoT can significantly improve efficiencies and quality while reducing the source. Proprietary systems from prominent industry vendors predominate the intelligent manual assembly solutions market. This system is proprietary, meaning it was created and is owned by a particular business or organization, and neither its technology nor source code is made available to the public.

Proprietary system vendors prioritize customization in their commercial strategies. They pose as partners who can offer more than just generic products—tailored solutions. Sales involve on-site evaluations to comprehend the manufacturing requirements of each client. Customized proposals that include the assembly station in the customer's systems result from this. Vendors promise the optimization of essential KPIs and quality standards for the customer. Most system providers guarantee ongoing assistance through updates based on customer feedback. Vendors want to position their product as a collaborative relationship, not just a purchase, so they offer comprehensive implementation help and long-term support contracts. The objective is to persuade customers that they can modify systems to maximize value. The existing products in the market, such as Tulip Vision, Active Assist and Smart Klaus, are all proprietary systems.

Proprietary automated manual assembly systems are a popular choice for producers due to several of their advantages. First and foremost, they provide dependability and dependable support, frequently backed by respected businesses recognized for offering reliable solutions. These systems can be tailored to fit specific manufacturing processes and easily interface with other production software and machinery to create a productive and well-coordinated production ecosystem. They frequently include robust security features as well to protect sensitive data. These systems' suppliers' experience is a crucial advantage since it allows them to provide recommendations, best practices, and advice based on their market knowledge. Additionally, these proprietary systems are desirable for manufacturers looking for adaptable, secure, and well-supported solutions due to their thorough documentation and scaling possibilities.

2.1.2 Distinct Manual Quality Control in Production Floor

Traditional manufacturing quality control practices centred on the production floor have been critical for preserving product quality and adhering to established standards. Visual inspection, sampling, testing equipment, control charts, root cause analysis, and thorough record-keeping are among the approaches used. Existing systems are using distinct manual quality control in their production floor. It does not have a build in QC function inside their system. As an example, according to the ActiveAssist system done by Bosch Rexroth, they does not mention any QC support in their manual. As [2] states that quality inspection of produced products has always been a crucial step for every production line. This indicates that the company who using the assist system must have a separate QC station. They requited skilled QC specialists are to perform QC in this process. Qualified QC employees, such as inspectors and engineers, must discover faults and guarantee standard compliance.

Different manual quality control procedures have several benefits in production environments. First of all, they offer a practical and easy method for finding flaws and guaranteeing product quality. A skilled inspector can frequently spot minute problems that an automatic system might overlook. Manual quality control is flexible enough to handle various product types and variances. During the inspection process, it provides immediate input, enabling quick judgements and corrections. Additionally, it can be affordable because it doesn't necessitate substantial expenditures in automated inspection machinery, which is vital for smaller manufacturing businesses with tighter budgets. Overall, manual quality control improves product quality and reliability by bringing a human touch, expertise, and adaptability to the process, complementing automated solutions.

However, [3] states that manual defect detection that trained people perform is tedious, time-consuming, and expensive. [2] also note that the use of human operators and manual inspection is a time-consuming and labour-intensive task. As a result, modern technologies are being integrated into intelligent manufacturing to supplement existing practices, bringing in new dimensions of quality assurance.

2.2 Limitation of Previous Studies

2.2.1 Missing interoperability

However, proprietary intelligent manual assembly stations have some disadvantages. One notable disadvantage is the possibility of high beginning expenses, which might be prohibitively expensive for smaller production businesses. These systems frequently necessitate substantial upfront investments in licensing fees, hardware, and continuing support contracts. Delay response or low vendor support availability can also be a significant issue. A lack of rapid vendor support can result in considerable production delays and financial losses in cases where timely assistance is critical for resolving difficulties or installing necessary changes. Furthermore, while customization possibilities are available, the proprietary nature of the software may limit manufacturers' ability to adapt the system to specific or growing demands. Again, the closed nature of these systems might restrict transparency, making understanding and modifying the underlying code difficult and potentially limiting innovation and introducing new features. [6] states that prominent vendors with different product interfaces and protocols have rapidly increased in the IoT market. According to the analysis [7], these commercial products need a vital component: interoperability. The author also stated that 40% of the benefits can be obtained from interoperability.

2.2.2 Vendor Lock In

Vendor lock-in is a significant concern in proprietary intelligent manual assembly stations, particularly for Small and Medium-sized Enterprises (SMEs). These systems frequently bind SMEs to a single provider for maintenance, updates, and support, initially offering stability but posing long-term issues. Switching to a different design or vendor might be too expensive for SMEs with limited funds and resources. Potential migrations are further complicated by the need for interoperability with other software and the closed nature of proprietary solutions, making them complex and costly. From the view of IoT providers, a lack of interoperability means that the service's client must stick to the provider. It will bring the potential risk of higher operation costs and low product flexibility [6]. As a result, although larger enterprises may be able to tolerate the costs associated with vendor lock-in, SMEs may find themselves locked in an inflexible and costly technical ecosystem that limits their agility and scalability.

2.2.3 Lack of Real time Quality Control

Traditional quality control methods, while valuable, have limitations that might have an impact on production processes. One notable constraint is that the strict quality assurance stage is often performed at the end of the assembly process. While this guarantees that the finished products satisfy quality standards, it can be challenging to implement in large manufacturing lines with several phases. When flaws or issues are discovered at the end of the production line, it can result in significant rework, resource waste, and production schedule delays. Furthermore, identifying the core causes of faults at this level might be more difficult, as it may necessitate retracing numerous stages to determine the source of the problem. Delays in discovering and resolving quality concerns can have far-reaching repercussions, compromising product schedules and overall efficiency. To address this constraint, several manufacturers are increasingly implementing real-time quality control methods that incorporate quality checks at multiple stages throughout the manufacturing process, assisting in the early identification and resolution of errors and reducing the risk of costly rework.

2.3 Comparison of Previous Works

Table 2.1 Comparison table of previous works

Method	Strength	Limitations
1) Proprietary System	- Offer tailored solutions. - Robust security purpose. - Well supported solutions.	- Missing interoperability. - Vendor lock in.
2) Distinct Quality Checking	- Practical and easy method for QC - Fast process during the inspection stage - Flexible to handle various type.	- No real time control. - Waste of resources when discover faulty product at the end of assembly work. - Affect efficiency.

CHAPTER 3

System Methodology

Proposed Method

The processes of the project were categorized into different phases in the development, which were project pre-development, data generation, computer vision development, implementation, and evaluation. Figure 4.1 shows the overall development of the project.

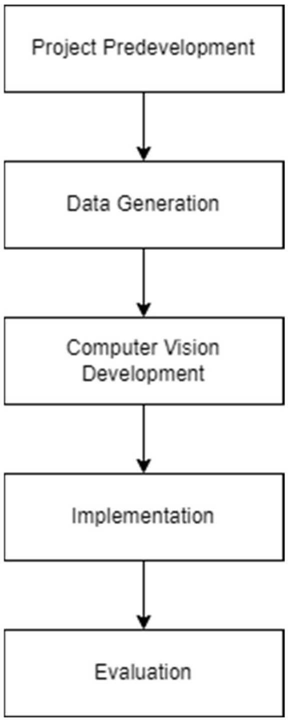


Figure 3.1 Overall development phase of the project.

Project Predevelopment

The predevelopment stage of a project acts as a crucial foundation for the following stages. In order to fully comprehend the project's scope and requirements, it starts with a thorough research and assessment procedure. A thorough examination and study into pertinent technologies, such as computer vision and real-time guiding systems, is also required during this phase. Creating a foundational automated manual assembly station prototype is also a critical turning point in this phase. This prototype includes crucial features like inventory control, on-the-fly instruction, and sequence verification. A prototype process during this stage ensures the project's adaptability, allowing for incremental improvements and adjustments based on preliminary testing and priceless feedback. This system will implement is prototype methodology.

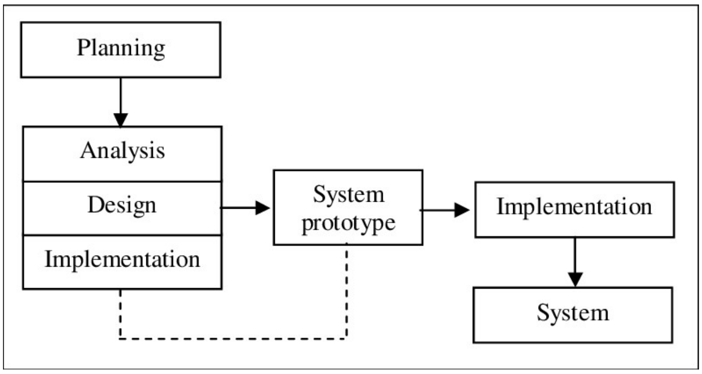


Figure 3.2 The prototyping model use in this project.

Computer Vision Development

The development stage entails the establishment of distinct CV models with specialised functionality for QC and Inventory Control. Besides, QR codes is used as the main technology in this project. Notably, at this time, the automated manual assembly station does not include these models. The main idea driving this phase is the effective use of CV to recognise and assess items in specified situations. To optimise performance, CV algorithms are first put through a rigorous testing process utilising self-generated datasets. The CV models are then evaluated and validated using unique QC and Inventory Control datasets to determine their correctness and dependability, guaranteeing that they are prepared for integration and practical deployment in the future.

Implementation and Evaluation

The automated manual assembly system is now fully integrated with the QC and Inventory Control modules that were previously created, ensuring flawless coordination and communication. Rigorous testing is done to ensure that this integrated system is operating correctly inside the assembly sequence. The workflow is assessed using LEGO bricks in a realistic setting to simulate real-world conditions. Speed, defect rate, and computational effectiveness are all taken into account. The point of a system is determined by its ability to improve the assembly process and lower faults. This evaluation's valuable feedback is used to guide additional improvements and refinements in later project phases.

3.1 System Design Diagram

3.1.1 Use Case Diagram

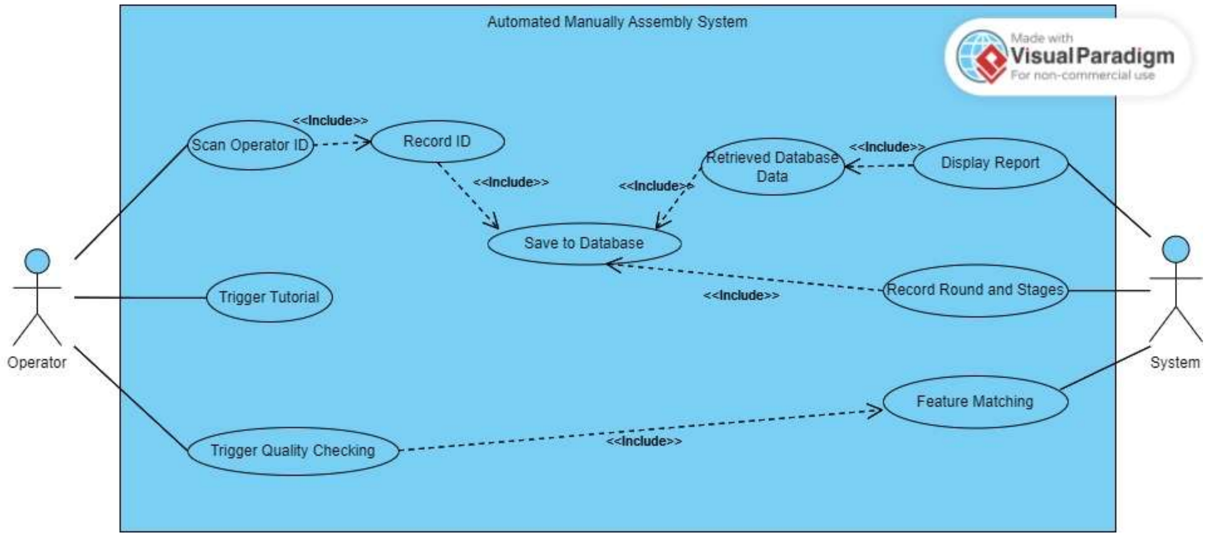


Figure 3.3 Use Case Diagram

3.1.2 Use Case Description

Table 3.1 Use Case Description

Use case ID	UC01
Use Case Description	Utilize the System
Actor	Operator
Precondition	The QR code is placed on the table and set into the system. The system is running, waiting operator to start the sessions.
Main Flow	1. Sessions Start: 1.1. Operator starts the system by covering power QR code. 1.2. The system initialises system variables. 1.3. The system loads steps images, instruction images and tutorial videos. 2. Identification process 2.1. The system prompts the operator to present their identification badge. 2.2. The operator complies by displaying their identification badge. 2.3. The system verifies the identification and displays a personalized greeting message featuring the operator's name. 3. Instruction phased: 3.1. The system presents the first step of instructions to be performed. 4. Task Execution and Monitoring: 4.1. The operator executes the instructed tasks. 4.2. After completing the step, operator need to cover 'LeftHand' and 'RightHand' QR codes to trigger quality checking event. 4.3. Operator needs to cover 'Tutorial' QR code to trigger display tutorial video event. 4.4. The system displays tutorial video according to the current step. 4.5. The system evaluates the accuracy of the performed tasks and records any incorrect attempts. 4.6. The system measures and records the duration of the round. 4.7. The system progresses to the subsequent round or concludes the session based on the operator's performance.
Alternative Flow – Performance Metrics Recording	4.6.1 The system logs the commencement time of the session. 4.6.2 For each round: a) The system logs the initiation time of the round. b) The system presents the step-by-step instructions.

	c) The operator completes the assigned tasks. d) The system evaluates the correctness of the tasks and records any errors. e) The system calculates and logs the round duration. f) The system advances to the next round or terminates the session based on the operator's progression.
Alternative Flow – Operator decides not to watch tutorials	Skips step 4.3 – 4.4 and proceed to step 4.5.
Postconditions	- The system generates and displays a performance report. - The system persists the recorded results to a designated text file. - The session concludes, and the system becomes available for subsequent operator use.
Exception	- If the system fails to detect any QR code within a predefined interval, it displays a "No QR code detected" alert. - In the event the operator does not present their identification badge, the system displays a "Please display your badge" alert. - If the operator fails to adhere to the start code or hand-covering instructions, the system issues appropriate error notifications. - Should the operator opt to shut down the system, the session terminates, and the system powers off.
Author	Ch'ng Shin Joe

3.1.3 Sequence Diagram

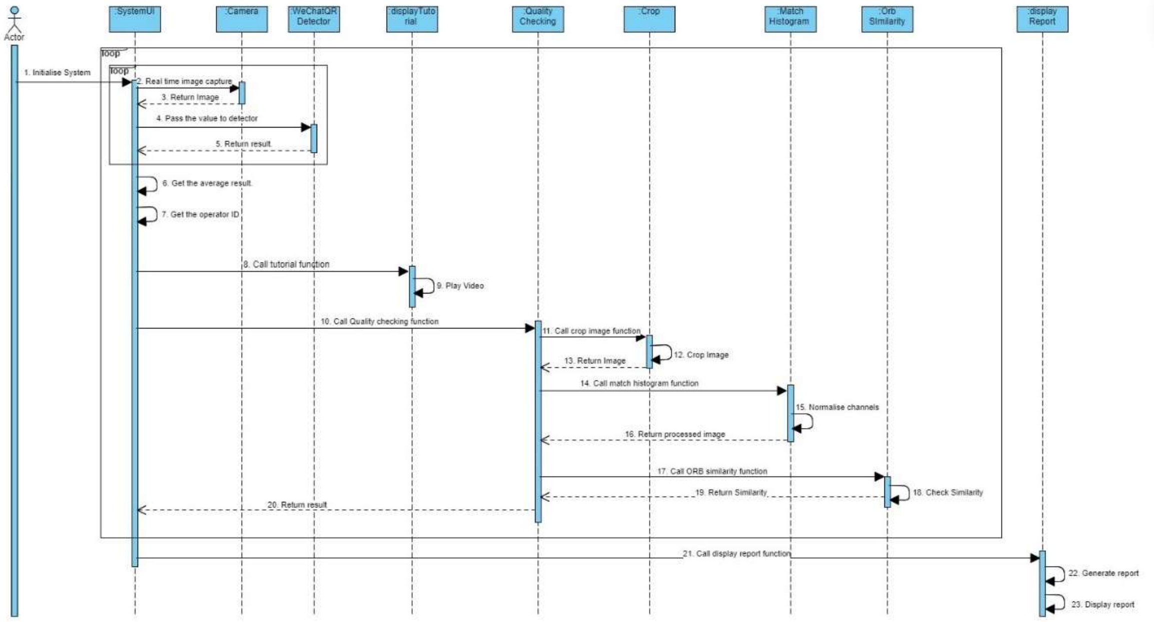


Figure 3.4 Sequence Diagram

3.1.4 ER Diagram

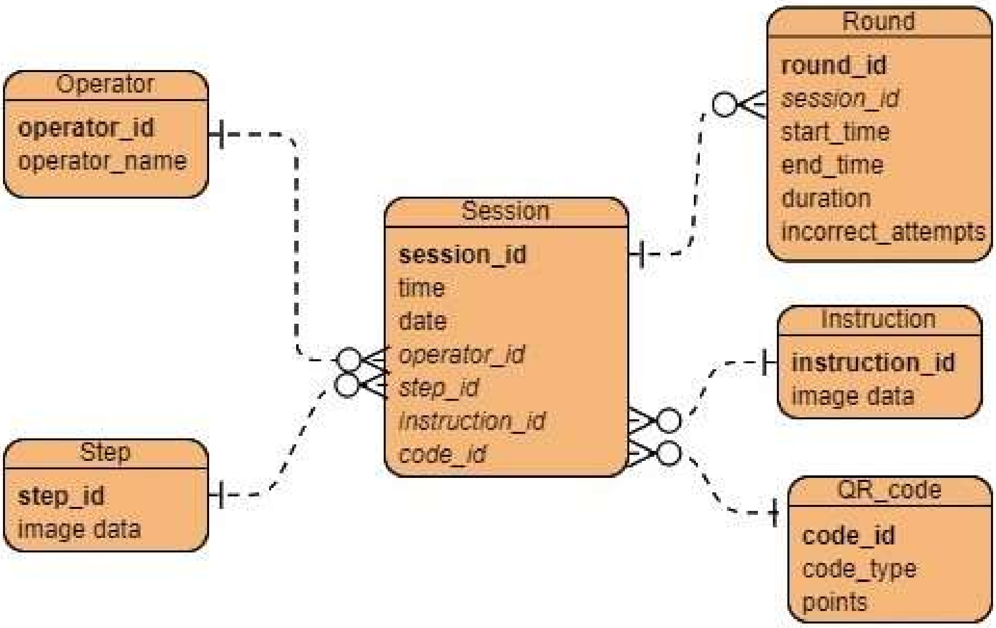


Figure 3.5 ER Diagram

3.2 Timeline

IIPSPW

Project Start Date: 19-Jun-23

Project Name: AUTOMATED MANUAL ASSEMBLY STATION USING COMPUTER VISION

#	Activity	Start	End	Days	Status	Jun 19-Jun	26-Jun	Jul 3-Jul	10-Jul	17-Jul	24-Jul	31-Jul	Aug 7-Aug	14-Aug	21-Aug	28-Aug	Sep 4-Sep	11-Sep	18-Sep	25-Sep
1	***IIPSPW***	19-Jun-23	25-Sep-23	98	Completed															◆
2	**Chapter 1: Project Background & Chapter 3: Project Scope and Objectives**	19-Jun-23	10-Jul-23	21	Completed				◆											
3	Introduction	19-Jun-23	10-Jul-23	21	Completed				◆											
4	Motivation & Problem Statement	03-Jul-23	17-Jul-23	14	Completed					◆										
5	Project Objectives & Contributions	10-Jul-23	17-Jul-23	7	Completed					◆										
6	Project Scope	10-Jul-23	24-Jul-23	14	Completed						◆									
7	**Chapter 2: Literature Review**	17-Jul-23	28-Aug-23	42	Completed											◆				
8	Find & study relevant papers	17-Jul-23	31-Jul-23	14	Completed							◆								
9	Identify pros & cons of relevant papers	31-Jul-23	14-Aug-23	14	Completed									◆						
10	Propose Solution	07-Aug-23	28-Aug-23	21	Completed											◆				
11	**Chapter 4: Methods/Technologies Involved**	14-Aug-23	04-Sep-23	21	Completed												◆			
12	System Requirement - Hardware	21-Aug-23	04-Sep-23	14	Completed												◆			
13	System Requirement - Software	28-Aug-23	04-Sep-23	7	Completed												◆			
14	**Report Checking**	11-Sep-23	18-Sep-23	7	Completed														◆	
15	**Presentation**	18-Sep-23	25-Sep-23	7	Completed															◆

Figure 3.6 IIPSPW Timeline

FYP1

Project Start Date: 30-Oct-23

Project Name: AUTOMATED MANUAL ASSEMBLY STATION USING COMPUTER VISION

#	Activity	Start	End	Days	Status	Oct 30-Oct	Nov 6-Nov	13-Nov	20-Nov	27-Nov	Dec 4-Dec	11-Dec	18-Dec
1	***FYP1***	30-Oct-23	18-Dec-23	49	Completed								◆
2	**Project Analysis**	30-Oct-23	27-Nov-23	28	Completed					◆			
3	Refine project scope & objective	30-Oct-23	20-Nov-23	21	Completed				◆				
4	Research on QR Decoder	13-Nov-23	27-Nov-23	14	Completed					◆			
5	**Project Implementation**	30-Oct-23	04-Dec-23	35	Completed						◆		
6	Experiment on Different QR code Decode Library	30-Oct-23	06-Nov-23	7	Completed		◆						
7	Experiment on Characteristic of QR codes	06-Nov-23	20-Nov-23	14	Completed				◆				
8	Setting Up	06-Nov-23	20-Nov-23	14	Completed				◆				
9	Develop QR code based Inventory System	20-Nov-23	04-Dec-23	14	Completed						◆		
10	Develop Event Triggered based on QR coeds	27-Nov-23	04-Dec-23	7	Completed						◆		
11	**Report Writing**	20-Nov-23	04-Dec-23	14	Completed						◆		
12	**Report Checking**	27-Nov-23	04-Dec-23	7	Completed						◆		
13	**Presentation**	11-Dec-23	18-Dec-23	7	In progress								◆

Figure 3.7 FYP1 Timeline

FYP2

	Project Start Date:	29-Jan-24				Jan	Feb				Mar				Apr					May
	Project Name:	AUTOMATED MANUAL ASSEMBLY STATION USING COMPUTER VISION			Date	29-Jan	5-Feb	12-Feb	19-Feb	26-Feb	4-Mar	11-Mar	18-Mar	25-Mar	1-Apr	8-Apr	15-Apr	22-Apr	29-Apr	6-May
#	Activity	Start	End	Days	Status															
1	*FYP2*	29-Jan-24	6-May-24	98	Not started															◆
2	Project Analysis	29-Jan-24	05-Feb-24	7	Not started		◆													
3	Research on Reactive Programming Module	29-Jan-24	05-Feb-24	7	Not started		◆													
4	Project Implementation	29-Jan-24	18-Mar-24	49	Not started								◆							
5	Develop the quality checking system.	05-Feb-24	19-Feb-24	14	Not started				◆											
6	Develop reactive programming model	19-Feb-24	04-Mar-24	14	Not started						◆									
7	Develop repositioning module.	26-Feb-24	11-Mar-24	14	Not started							◆								
8	Enhance the inventory checking system.	04-Mar-24	11-Mar-24	7	Not started							◆								
9	Enhance the inventory checking system.	04-Mar-24	18-Mar-24	14	Not started								◆							
10	System Testing	25-Mar-24	01-Apr-24	7	Not started										◆					
11	Report Writing	01-Apr-24	15-Apr-24	14	Not started												◆			
12	Report Checking	15-Apr-24	22-Apr-24	7	Not started													◆		
13	Presentation	29-Apr-24	06-May-24	7	Not started															◆

Figure 3.8 FYP2 Timeline

CHAPTER 4

System Design

4.1 System Flow Design

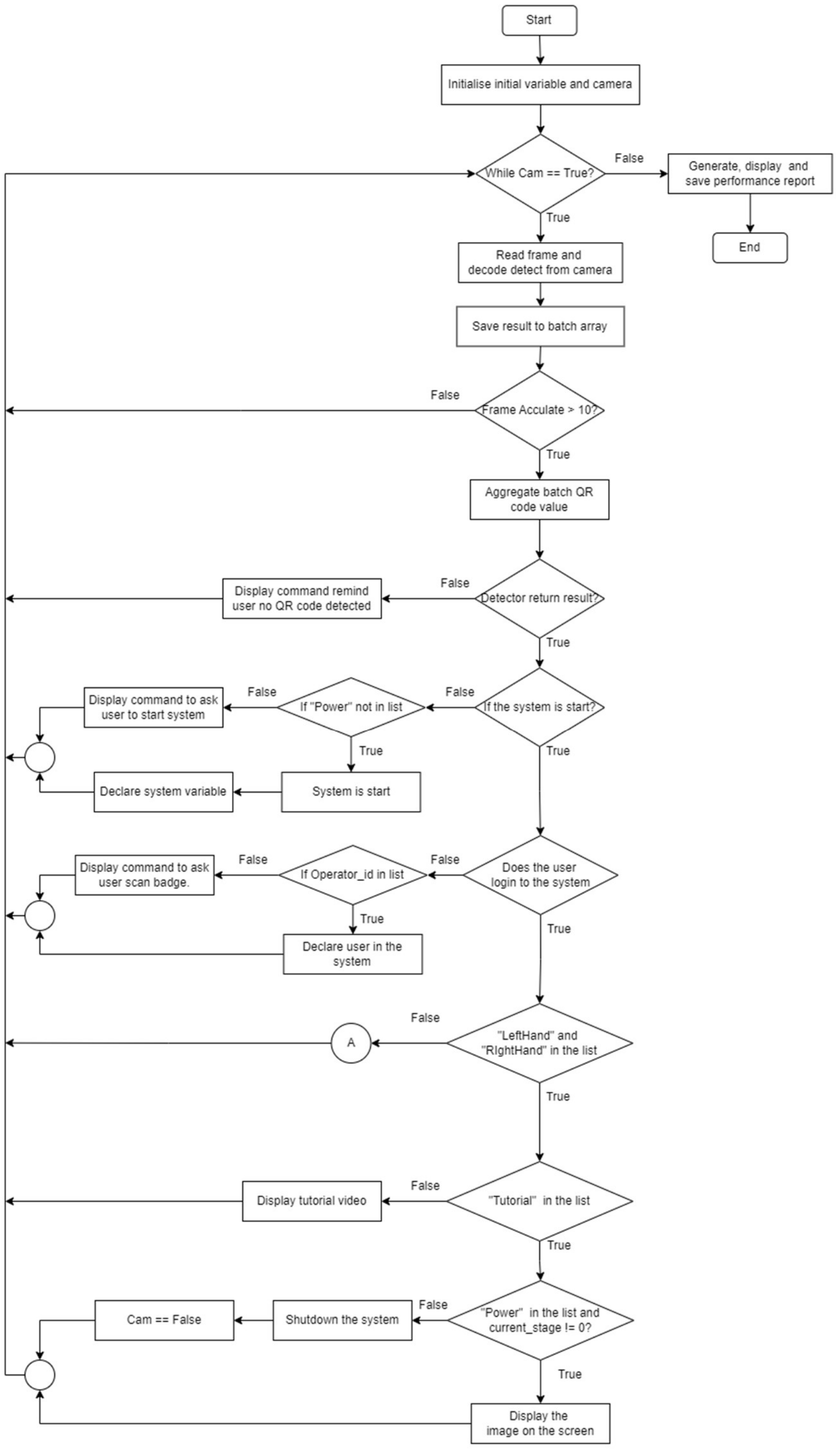


Figure 4.1 Flowchart

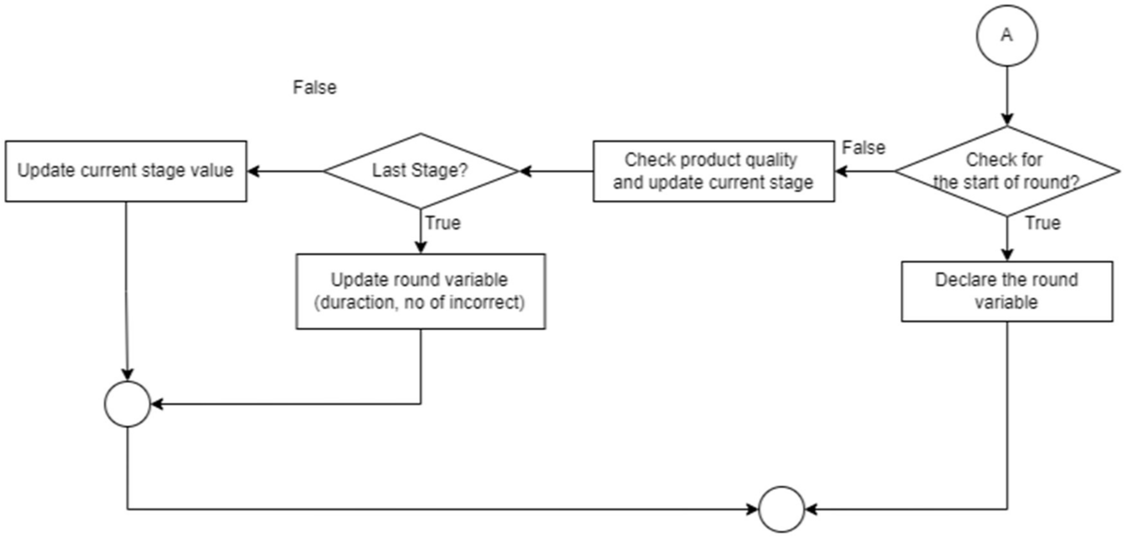


Figure 4.2 Flowchart (Continued)

4.2 System Components Specification

This program is designed to facilitate a user in performing an assembly task, focusing on image processing and verification. The program is built using Python and utilizes the OpenCV library for the implementation of image processing and computer vision tasks. The primary goal is to guide the user (operator) through the assembly of components step by step, providing checking on the completeness of the assembled product through image processing and analysis. The program consists of six main components:

4.2.1 Initialization and Importing Libraries

i. OpenCV library for image processing. OpenCV is a real-time computer vision open-source library. In this program, multiple functions are utilized for image reading and display, image preprocessing, feature extraction, histogram matching, drawing and verification.

ii. NumPy library for scientific calculation in Python. NumPy is used with OpenCV, manipulating arrays and matrices essential for image processing.

iii. OS library. The os library is used to interact with the operating system for file and directory handling, such as reading image files from directories.

iv. Sys library. The sys library is used to provide access to some variables used or maintained by the Python interpreter and to functions that interact with the interpreter. In this program, this library is required to get the user monitor window size.

v. Datetime and time library. These libraries are used for utilizing time-related functions and classes for manipulating dates and times. The time library is used to record the duration of the assembly process, while Datetime is used for display purposes.

vi. Ctypes and Textwrap: These libraries work together for the command displayed.

vii. Seaborn and Matplotlib: These are used in generating reports to beautify the visualization of the program.

4.2.2 Constants and Initializations.

This section mainly defines the constant initializations and the QR detector initializations. This section is important for making the program structure consistent by defining constant variables and reusing them.

4.2.3 Utility Functions

These utility functions perform specific tasks required for image preprocessing, feature extraction, and similarity checking:

i. LoadSteps: This function is used to load a list of images corresponding to different steps in the task.
ii. LoadInstructions: This function is used to load a list of images corresponding to different instructions in the task.
iii. orbSimilarity: Calculate image similarity using ORB feature extraction.
iv. crop: Crop the image to focus on the target area.
v. match_histograms: Perform histogram matching between images.
vi. pointToArray: Convert WeChat QR detector points to a NumPy array.
vii. Checking: Main function for image checking, which includes cropping, histogram matching, and similarity checking.

4.2.4 WeChat QR Detection Function

This function detects and decodes WeChat QR codes in the input image. This is the most important part of this innovative system. By frequently checking on the values of the QR code on the table, the system will know what function is triggered by the user.

4.2.5 Display Functions

These functions use ctypes and textwrap libraries for displaying text, images, and tutorial videos to guide the user through the task:

i. displayText: Display text on the screen.
ii. displayImage: Display the instruction image for the current step.
iii. displayTutorialVideo: Display the tutorial video for the current step.

4.2.6 Performance Report Generation

This section uses seaborn and matplotlib libraries to generate an informative report and save the results of the assembly process to a text file. The report will be displayed and saved as a JPEG file.

4.3 System Operation Logic: Approach to track current stage

In each session, there are multiple rounds, with each round consisting of the same assembly steps. At the start of each new round, the system initializes a variable called current_stage to track the current step of the assembly process. This variable is reset to 0 at the beginning of each new round. As the operator successfully completes each step (QC success), the current_stage is incremented by 1. For instance, if current_stage is 1, it signifies that the operator has successfully completed the first step. However, if the operator makes a mistake during a step (QC fails), the current_stage remains unchanged. This indicates that the operator has not passed the QC and needs to redo that particular step to ensure quality before proceeding further.

CHAPTER 5

SYSTEM IMPLEMENTATION

5.1 Hardware Setup

The hardware involve in this project is a computer, a depth camera and display monitor. A computer is used to develop and run the automated manual assembly system and the supervised CV system.

Table 5.1 Specifications of Laptop

Description	Specifications
Model	HP Pavilion Laptop 14-ce3xxx
Processor	Intel(R) Core(TM) i7-1065G7 CPU @ 1.30GHz
Operating System	Windows 11 Home Single Language
Graphic	Nvidia geforce mx250
Memory	8192MB RAM
Storage	477 GB SSD

Figure 5.1 Logitech C922 Pro Stream 1080p Webcam

Table 5.2 Specifications of Webcam

Description	Specifications
Model	Logitech C922 Pro Stream 1080p Webcam
Max Resolution	1080p/30 fps - 720p/ 60 fps
Camera mega pixel	3
Focus type	Autofocus
Lens type	Glass
Built-in mic	Stereo
Mic range	Up to 1 m
Diagonal field of view (dFoV)	78°
Digital zoom	1.2x

Figure 5.2 LED Lamp

Table 5.3 Specifications of LED Lamp

Description	Specifications
Model	LED Lamp
Lumen	180lm
Color	Daylight 600k
Lamp Size	7.5 x 2.3cm
Power	2W
LED Quantity	30pcs
Plug	EU Plug 230V

Hardware Setup:

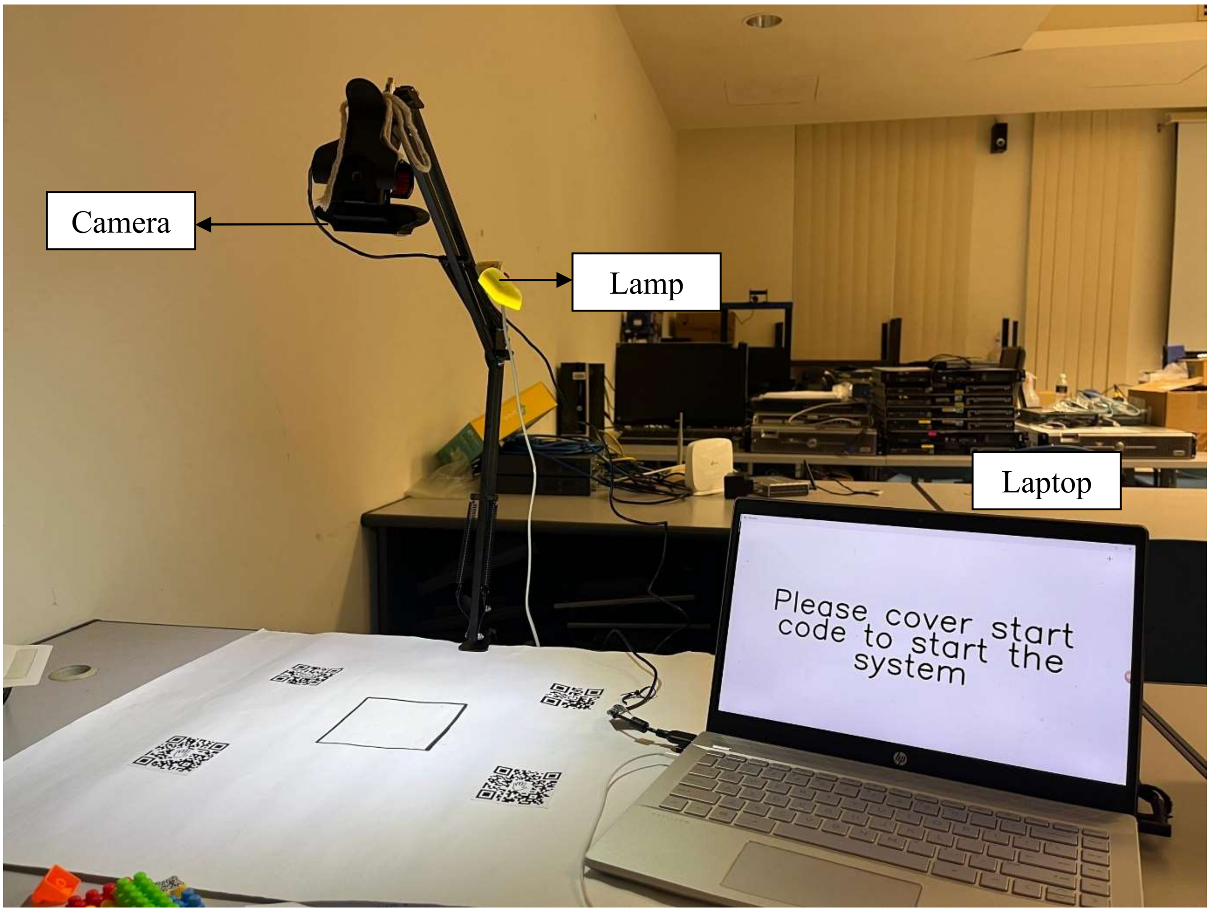


Figure 5.3 Example of Setup

The fundamental concept of this innovative system is using QR code detection to start certain actions. Dynamic interaction is provided by a deliberately positioned overhead camera that records user movements in real-time and decodes QR codes. The system has a repositioning module that allows for camera angle readjustment even when it is not perpendicular to the table, ensuring optimal performance. The strategy is broken down into two main parts: what to do when the QR code can be read and what to do otherwise.

A piece of paper with several QR codes on it acts as a dynamic user interface in this system. QR codes are essential for video control and quality checks within the operational space that the paper defines. By scanning pertinent QR codes, users interact with the system in an easy-to-use manner that provides a user-friendly interface.

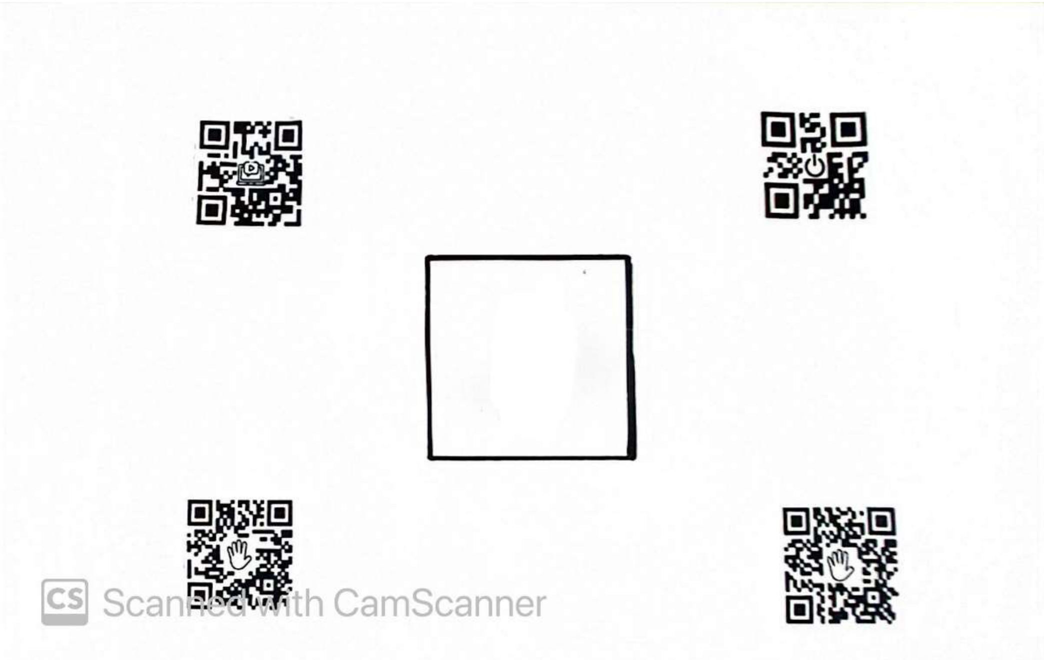


Figure 5.4 Placement of QR codes on the table

In this system, four QR codes are employed to activate different functions. The 'Tutorial' and 'Power' codes are positioned on the top left and top right, respectively. These buttons are placed at the top as they are not frequently accessed compared to the bottom area due to the lower frequency of their use. The 'Power' button is activated only twice during each session: once to start the session and once to shut it down. Similarly, the 'Tutorial' code is used only when users need to watch the instructional video, which is a more time-consuming alternative to following the on-screen instructions.

On the other hand, the 'LeftHandChecking' and 'RightHandChecking' codes are positioned on the bottom left and bottom right, respectively. These functions are activated more frequently as they need to be triggered for every assembly step. The ergonomic design allows users to perform quality checking effortlessly once they have completed the assembly. There's almost no need for them to extend their hand to reach the button; they can simply place their hand gracefully on the side of the desk. Both hands are positioned to ensure that the user has fully completed the assembly, preventing accidental activation while still in the process. Additionally, the placement of these hand-trigger codes allows users to activate the top layer functions without accidentally covering and triggering the bottom layer functions.

The placement of the QR codes is dynamic. Users can design their own interface by setting the locations of the QR codes. However, it should be noted that the placement of the QR codes must be within the frame of the camera's capture area and should not accidentally cover other QR codes when trying to trigger a specific one.

5.2 Software Setup

I. Integrated development environment – Visual Studio Code

Microsoft created Visual Studio Code (VS Code), a free cross-platform source code editor for Linux, macOS, and Windows. OpenCV has been used to implement the QR code detection module, which makes use of two CNN models from the Caffe Deep Learning module. These elements are smoothly integrated into the Visual Studio Code environment, offering a strong foundation for cooperation and development.

II. Programming language – Python

The Intelligent Manual Assembly System is a cutting-edge software programme that was painstakingly created in Python with the intention of revolutionising and improving manual assembly procedures. Through the use of Python's powerful features, this system detects and decodes QR codes with unmatched intelligence and efficiency, offering a novel solution to manual assembly tasks.

III. Software library – OpenCV

The OpenCV library is a crucial component of the system and must be downloaded onto the running laptop. Known for its cross-platform adaptability and real-time performance, OpenCV is an open-source computer vision library renowned for its powerful image and video processing capabilities. This versatile tool empowers developers to create a broad spectrum of applications. In this system, OpenCV facilitates video streaming, QR code decoding, and image processing, thereby enhancing the overall functionality and efficiency of the project.

IV. Software library – Seaborn, Matplotlib

To generate and display the reports on the laptop, two specific libraries need to be downloaded. Once the system is operational, it will automatically generate reports based on the operator's ID, assembly durations, and incorrect attempts. The clean and aesthetic design of the graphs provides clear and informative insights into the operator's performance, making it easy for high-level management to understand.

5.3 Setting and Configuration

In this system, an external webcam is used to capture real-time frames. The camera is connected to the laptop, continuously capturing frames with commendable stability and achieving a resolution of up to 1920x1280. However, using the OpenCV video capture function with this camera presented a significant challenge. In the initial setup, it took approximately 350 seconds to start the system each time the Python file was run, which severely impacted the system's efficiency.

Fortunately, this issue was successfully resolved by switching the API used to connect the webcam to the system. By utilizing cv.cap_dshow to configure the video capture object, the startup time was significantly reduced. Interestingly, this API is not widely known within the community; online tutorials rarely mention it, and only a small portion of developers are familiar with it. Despite its obscurity, switching to this more efficient API reduced the camera startup time to just 10 seconds, greatly enhancing the overall performance and efficiency of the system.

5.4 System Operation

5.4.1 QR Code Detector

The QR code is a central component of the system, as users place QR codes on the table to trigger events. This feature demands high-response real-time capabilities and a fast decoder to quickly and accurately decode the QR code values. WeChatQR Decoder, an open-source decoder, offers relatively high performance compared to other open-source QR code decoders. When the camera is activated, it captures the frame and passes it to the decoder. The decoder analyzes the results and returns a list of values and points. This QR detector is capable of detecting and decoding QR codes, returning the decoded values in less than one second. The diagram below illustrates the interaction between the camera, system, and the decoder.

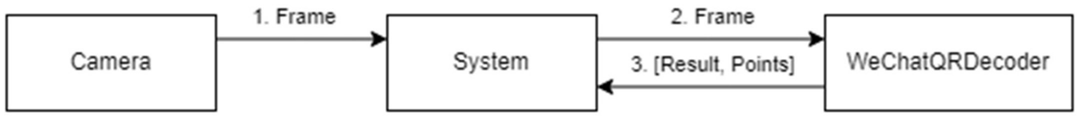


Figure 5.5 Interaction between Camera, System and QR Decoder

In this project, the system utilizes four QR codes for various functionalities: 'LeftHandChecking' and 'RightHandChecking' are used for round initialization and checking, 'Tutorial' is employed for displaying tutorial content, and 'Power' serves to turn the system on and off.

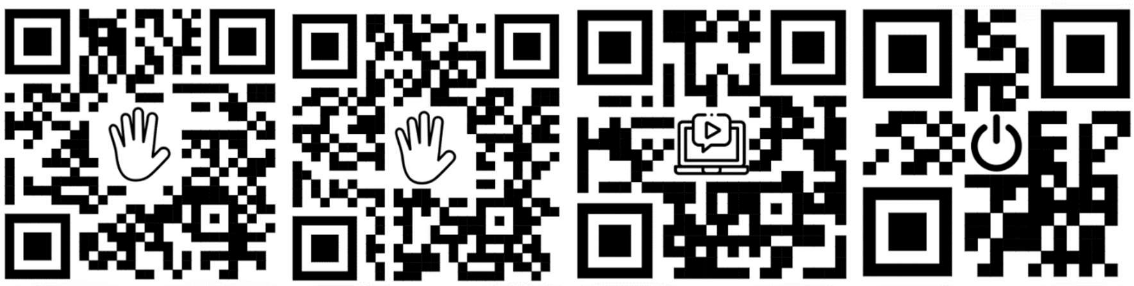


Figure 5.6 Examples of QR codes been used in the system.

LeftHandChecking, RightHandChecking, Tutorial, Power

(From left to right)

5.4.2 Event Activation: Functions Triggered by QR Code Coverage

Actions Triggered by Covering the 'Power' QR Code

The "Power" QR code is aptly named as it serves to both activate and shut down the system, essentially controlling the system's operational state.

When the program file is running, the window displays the message, “Please cover the 'Power' code to start the session.” This serves as a prompt to the user that while the program is active, the assembly session has not yet commenced. During this phase, no functions are activated or executed. Instead, the system remains in a waiting state, anticipating the user to cover the "Power" QR code to initiate the session.

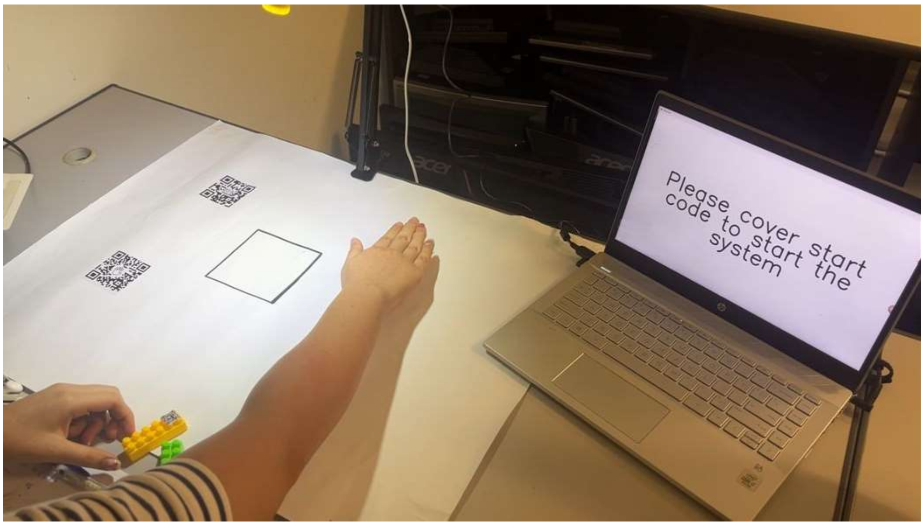


Figure 5.7 An example of covered the power to start the session.

Once the session starts, the system initializes the necessary variables specific to that session. This initialization establishes the foundational parameters and configurations essential for the smooth execution of the Automated Manual Station's operations and functionalities.

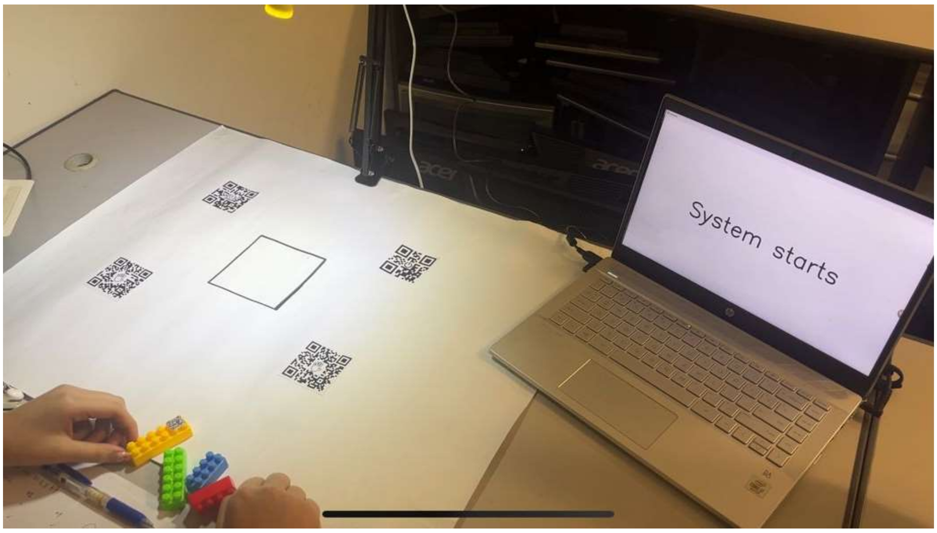


Figure 5.8 An example of a started session.

The "Power" code also serves as a trigger for a shutdown event. This occurs when the session has commenced, and the user has completed the current round, with no ongoing steps at that stage. A current_stage of 0 and a start_time of 0 indicate that the user is not in the midst of any rounds. To shut down the session, the user must complete the ongoing round before the system can be turned off.

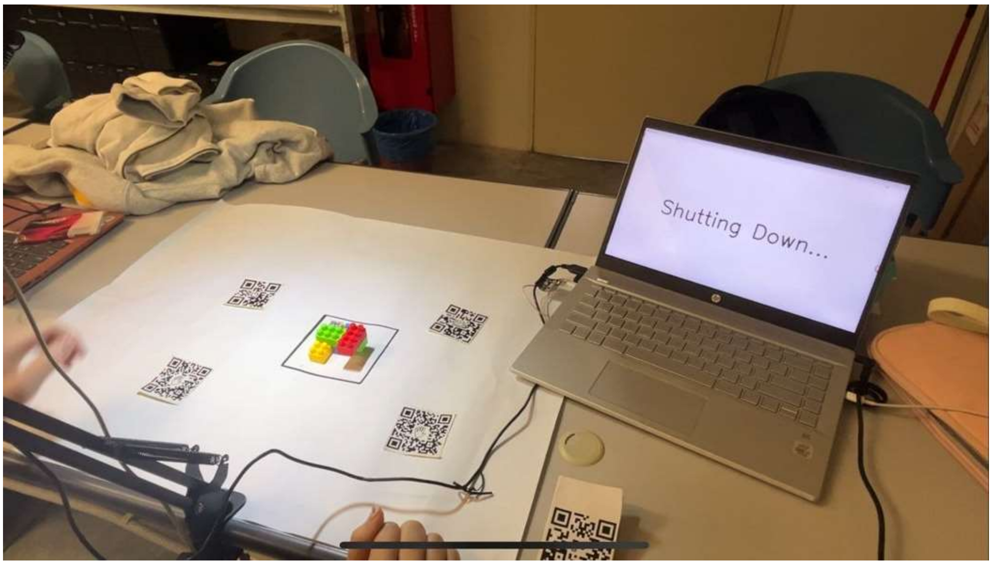


Figure 5.9 An example of cover the power button to shut down the session.

Actions Triggered by Covering the 'Tutorial' QR Code

Upon successful activation of the session, a tutorial video demonstrating the assembly process for the current stage is automatically played. A series of tutorial videos are pre-loaded into the system at the start of each session. Users have the flexibility to watch the demo repeatedly by simply covering the respective QR code multiple times. This feature provides users with a personalized learning experience, akin to having a personal assistant or receiving private lessons. By providing users with on-demand access to instructional content, it reduces the dependency on external assistance and minimizes the time spent on referencing manuals or seeking help. This streamlined approach ensures a smoother and more autonomous workflow, ultimately leading to a more efficient and productive assembly process.

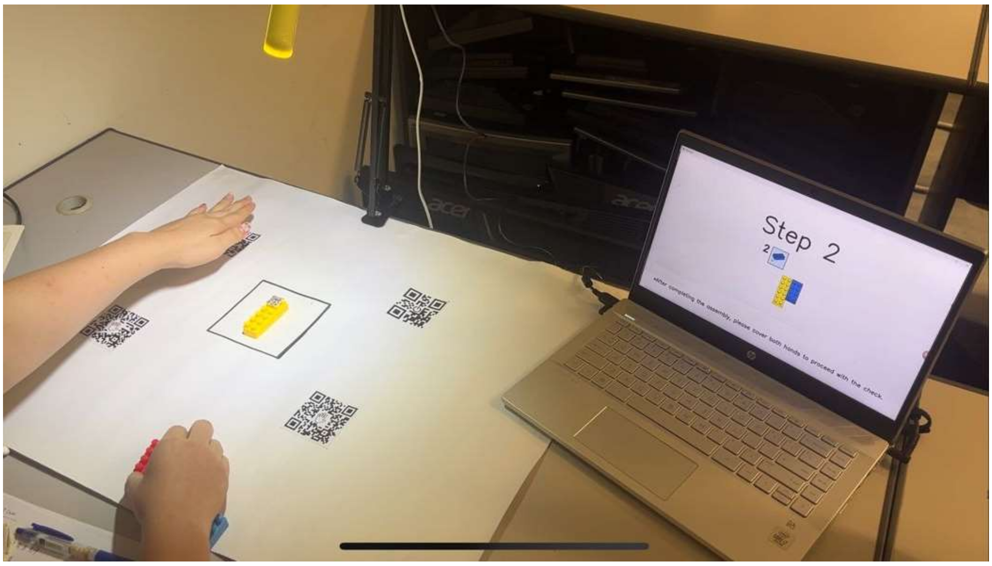


Figure 5.10 An example of the tutorial code is covered for playing the tutorial video.

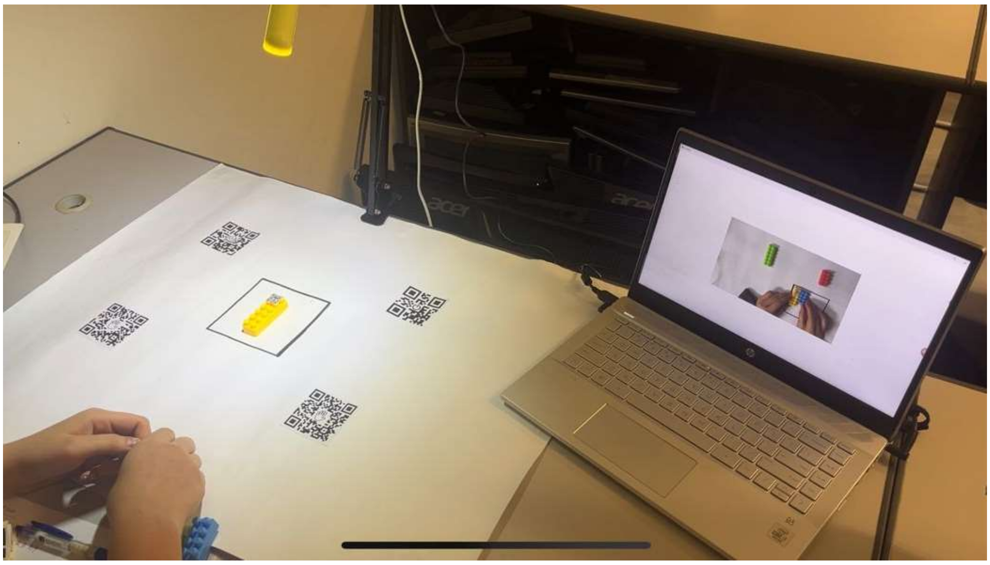


Figure 5.11 An example of tutorial is played.

Actions Triggered by Covering the 'LeftHandChecking' QR Code and 'RightHandChecking' QR Code at the same time.

Two distinct actions are activated based on conditions when both the 'LeftHandChecking' and 'RightHandChecking' QR Codes are simultaneously covered. Positioned at the bottom left and bottom right corners of the table, these placements are ergonomically designed to allow users comfortable and efficient movement.

The decision to require both hands to cover the codes, as opposed to just one, serves as a safety precaution to ensure that the operator is fully prepared and intentional in their actions. This two-handed approach minimizes the risk of unintentional system activation or shutdown. Given the potential for inadvertent covering of the code due to large hand movements, this safety feature is essential in maintaining the integrity and reliability of the assembly process.

Starting a New Round

The first action is triggered when the user intends to start a new assembly round. Placing both hands on the QR codes signifies this intention. Upon activation, the system reinitializes the round variables, resetting the current stage variable to 0. This indicates that the user has initiated a new round and is currently at the starting point of the assembly steps.

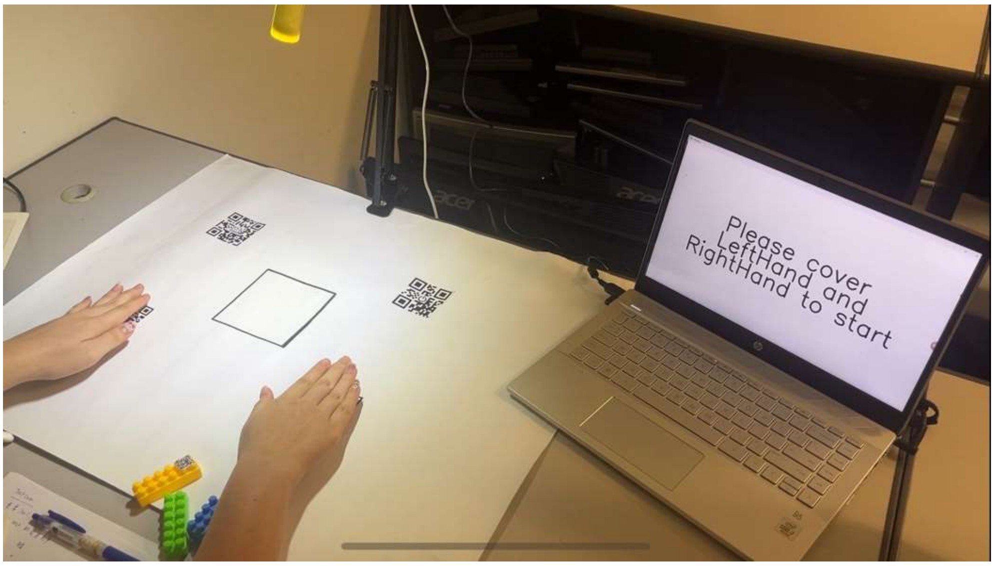


Figure 5.12 An example of start a new round by covering the LeftHandChecking and RightHandChecking QR codes.

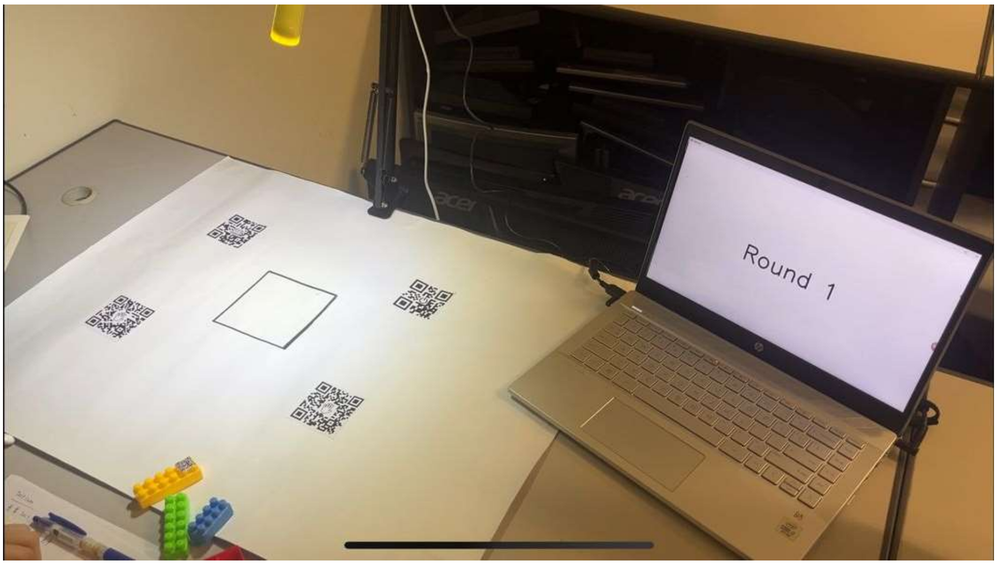


Figure 5.13 An example of a new round has started.

Quality Checking Process

The second action is activated when the user is ready to perform a quality check after completing a step. Upon triggering the quality checking function, the system captures a screenshot of the current frame. This screenshot is then passed to a similarity comparison function to assess the accuracy and quality of the assembly step performed.

By incorporating these two actions, the system enhances the efficiency and reliability of the assembly process, providing clear instructions and safeguards to ensure accurate and consistent results. This approach not only streamlines the assembly operations but also reduces the potential for errors and inconsistencies, thereby maintaining the overall integrity of the assembly process.

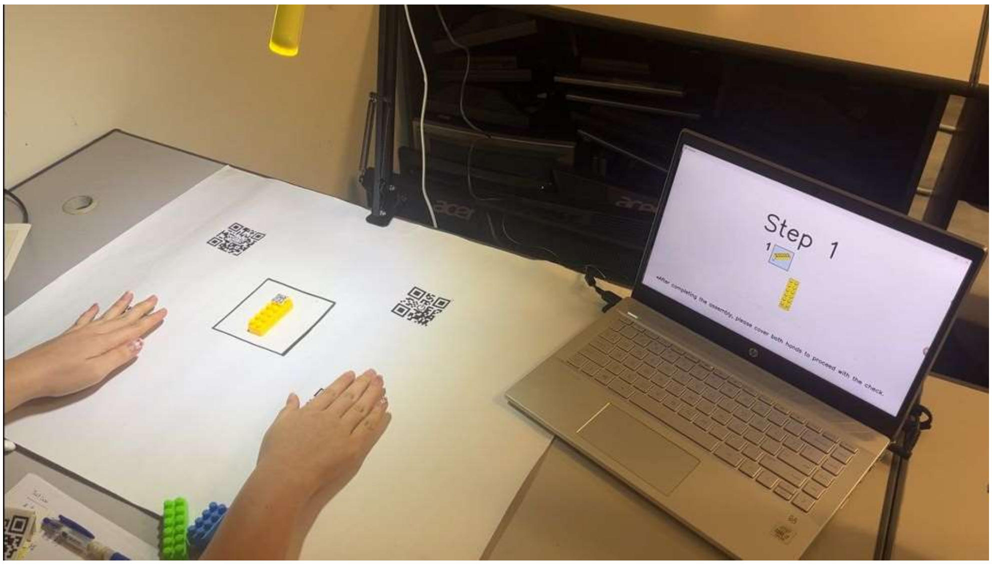


Figure 5.14 An example of covered the code to triggered QR code.

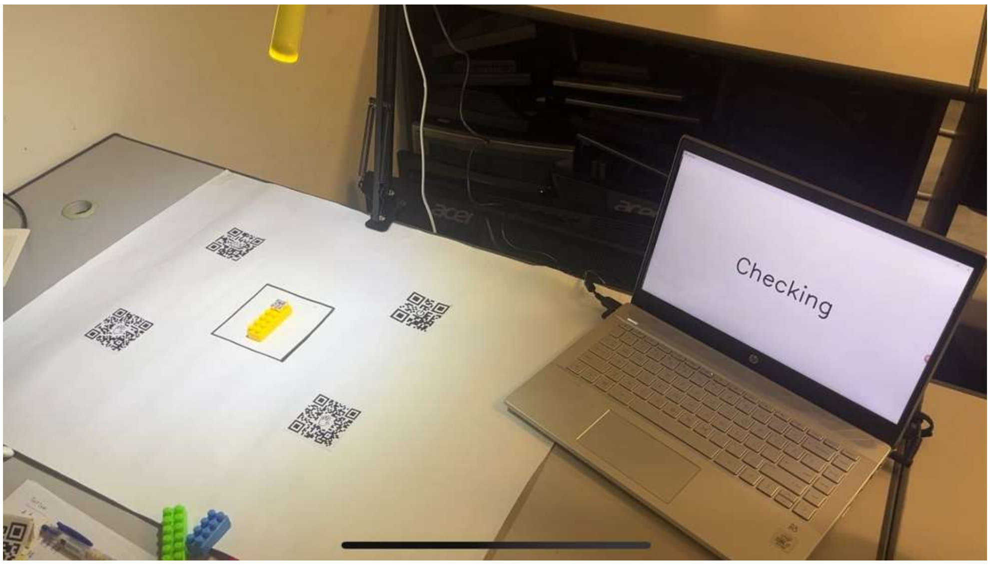


Figure 5.15 An example of the system is in the checking process.

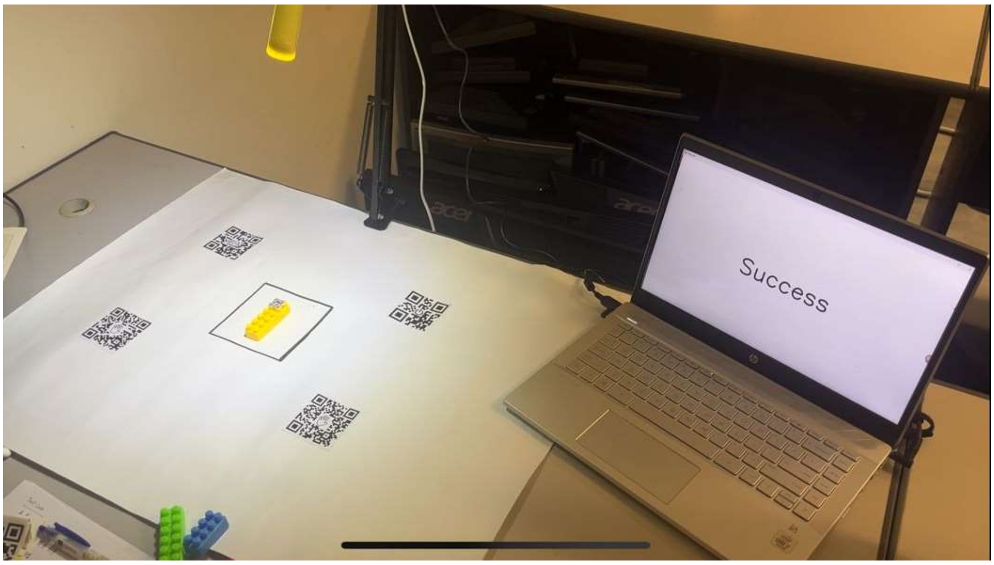


Figure 5.16 An example of the system checked that the component is assembly correctly.

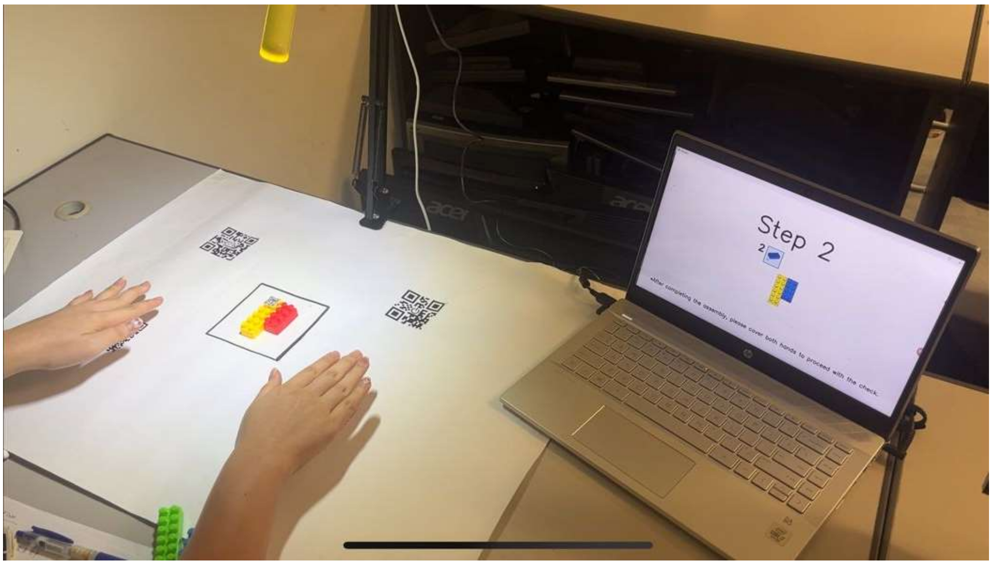


Figure 5.17 An example of the user tried to check a wrong-assemble product.

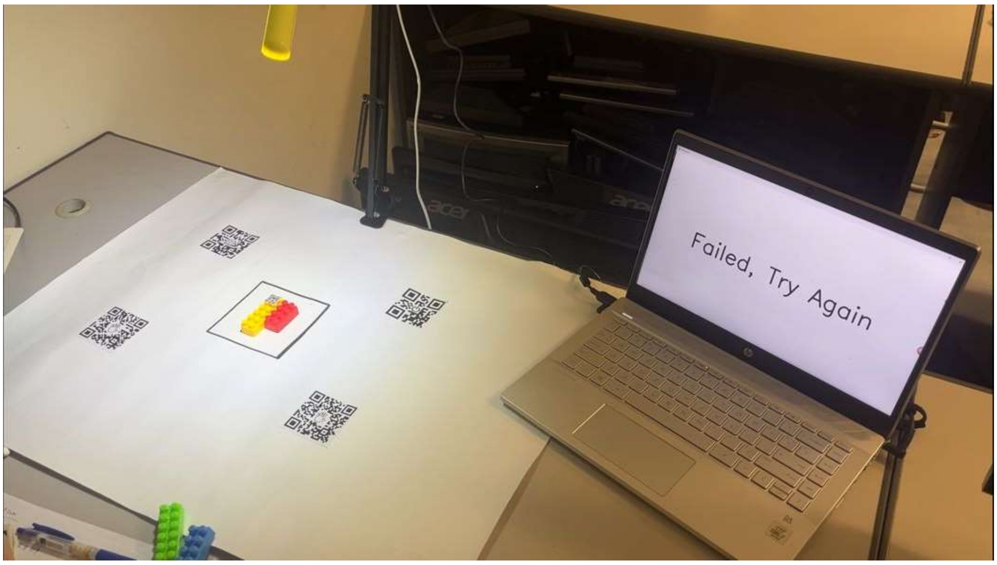


Figure 5.18 An example of the system correctly checked a wrongly assemble product.

Actions Triggered by Showing the Operator Identity QR Code

The system mandates that users display their unique Operator ID to record their identity during system usage. This Operator ID is pivotal for monitoring and evaluating the performance of the operator throughout the assembly process. Operators are required to scan their ID after they start the session.

By incorporating this feature, the system offers a comprehensive tracking mechanism that not only guides the user through the assembly steps but also ensures accountability and traceability of the operator's performance. This enables better management and assessment of the assembly operations, thereby facilitating improvements in efficiency and quality control.

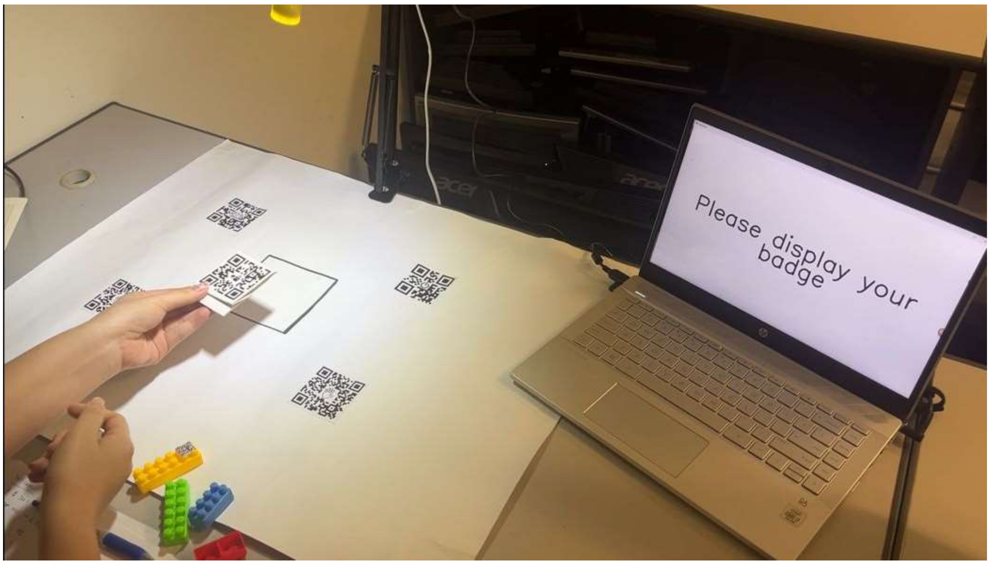


Figure 5.19 An example of the user login the system by displaying his/her badge.

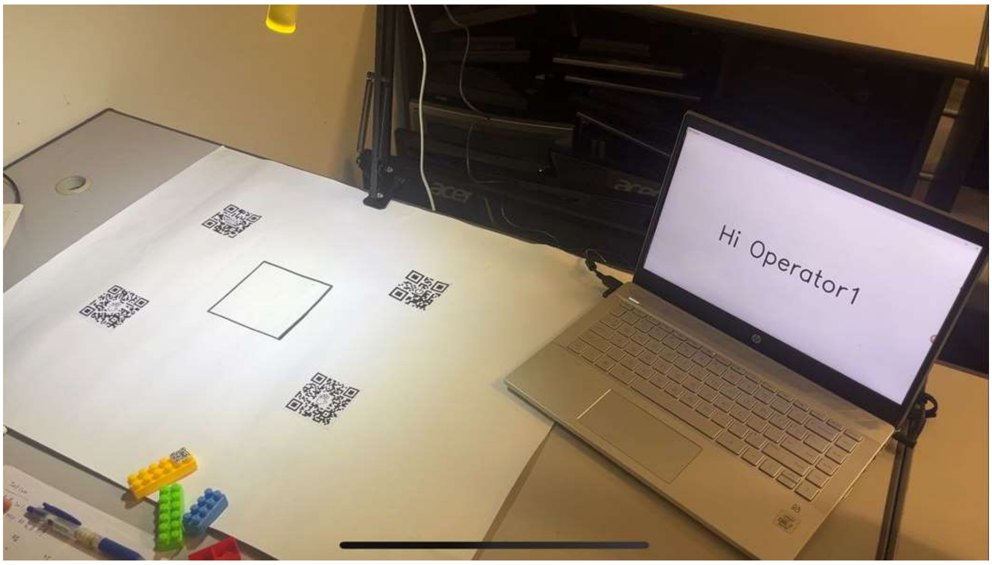


Figure 5.20 An example of the user successfully login to the system.

5.4.3 Perform Quality Checking

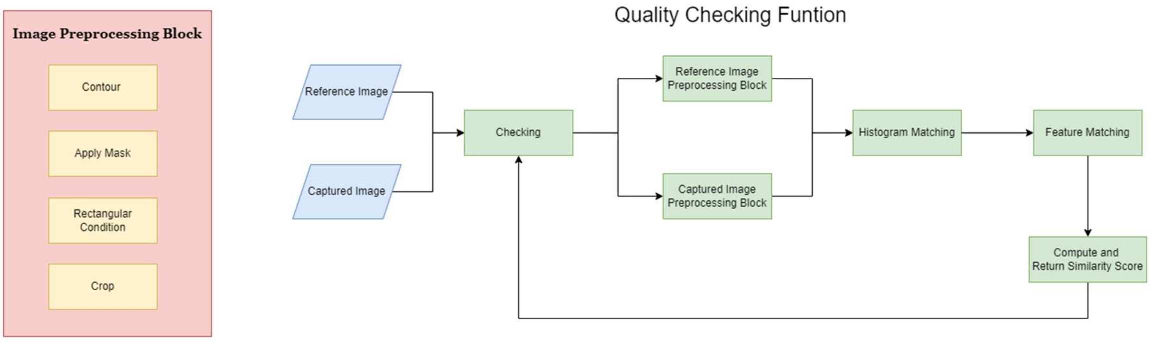


Figure 5.21 A Sub flow Chart of the quality checking module.

The quality checking process employs a series of image processing techniques to crop the Region of Interest (ROI) and utilizes various computer vision modules like histogram matching and feature matching to determine the similarity score.

Image Processing of ROI.

Figure 5.22 An example of real time captured image.

The primary goal of this block is to identify the Region of Interest (ROI) within a bounding box, as indicated by the square rectangular black border in the frame setup. Due to the presence of noise in the frame, including similarly shaped QR codes, there's a high probability of erroneously cropping the QR code as the ROI, which would disrupt the system's functionality. To address this issue, the decoder returns the value of the QR code along with its corresponding points. We can use these points to mark the locations of the QR codes and create a mask to indicate the areas to be ignored when determining the ROI. This masking process enables the image processing block to accurately crop the desired ROI.

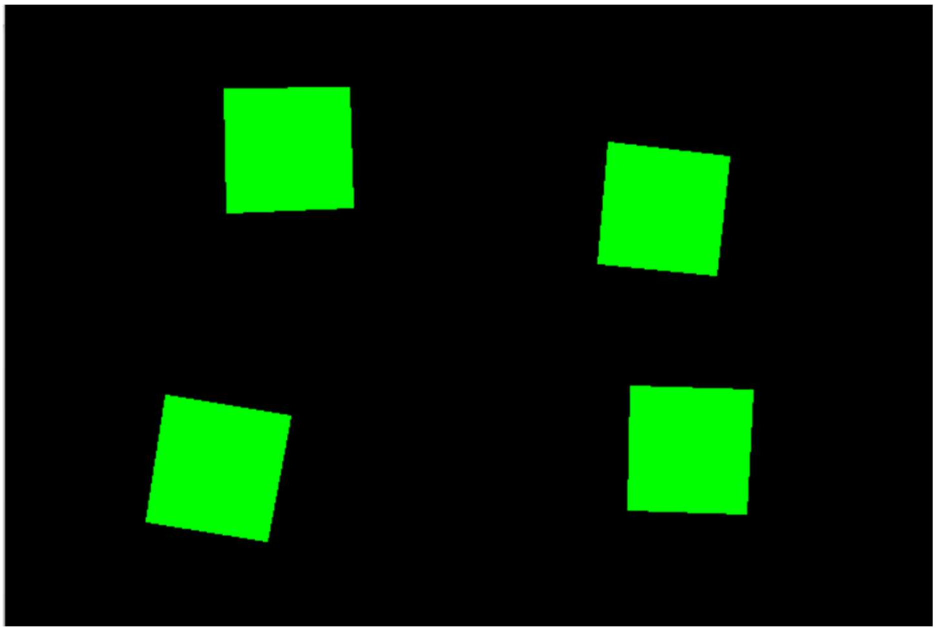


Figure 5.23 An example of QR code locations and transform it to a mask.

By using this mask, the crop function identifies the green areas as the location of the QR codes and ignores these areas when determining the Region of Interest (ROI).

Figure 5.24 An example of correct ROI contour detection.

Histogram Matching

After processing both the reference and captured images, they are passed through a histogram matching function to normalize them for subsequent image processing, such as feature matching. Given that the reference and captured images may come from different sources under varying lighting conditions, histogram matching helps "calibrate" the color intensity of the captured image to align with the reference image quickly and effectively. Based on our experiments, histogram matching before feature matching using Oriented FAST and Rotated BRIEF (ORB) is crucial.

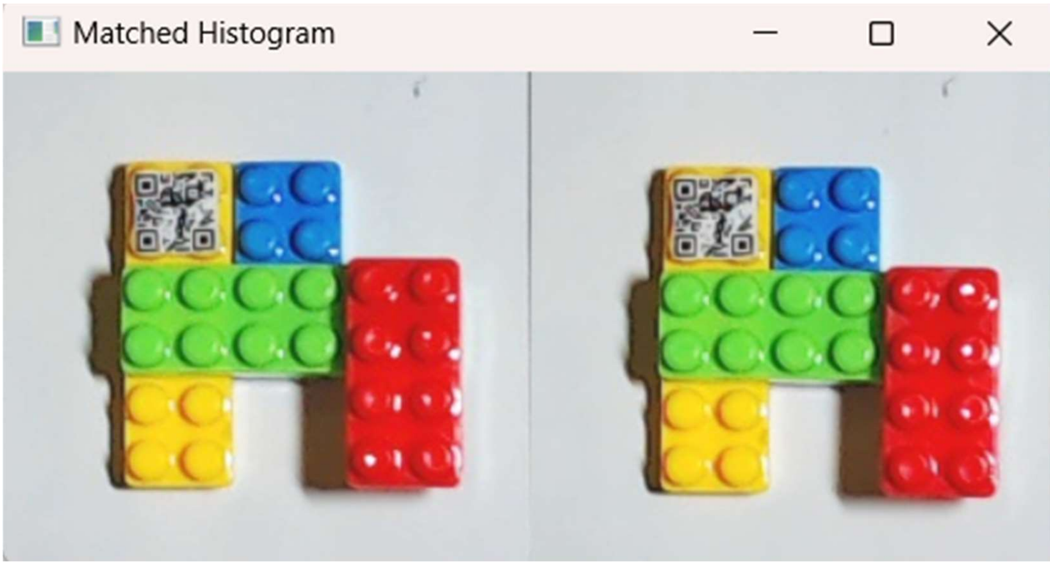


Figure 5.25 An example of histogram matching.

Feature Matching with ORB (Oriented FAST and Rotated BRIEF)

The similarity score is computed using the Oriented FAST and Rotated BRIEF (ORB), a feature detection and description method in computer vision. ORB combines the keypoint detection capabilities of FAST (Features from Accelerated Segment Test) with the descriptor calculation of BRIEF (Binary Robust Independent Elementary Features). FAST is utilized to detect features from the provided images and employs a pyramid to produce multiscale features. BRIEF is applied to smooth the image using a Gaussian Kernel to prevent the descriptor from being sensitive to noise. ORB is partially scale-invariant, meaning it is capable of matching features between two images that have different scales. This is particularly useful in this project as the cropping process might result in images of slightly different sizes.

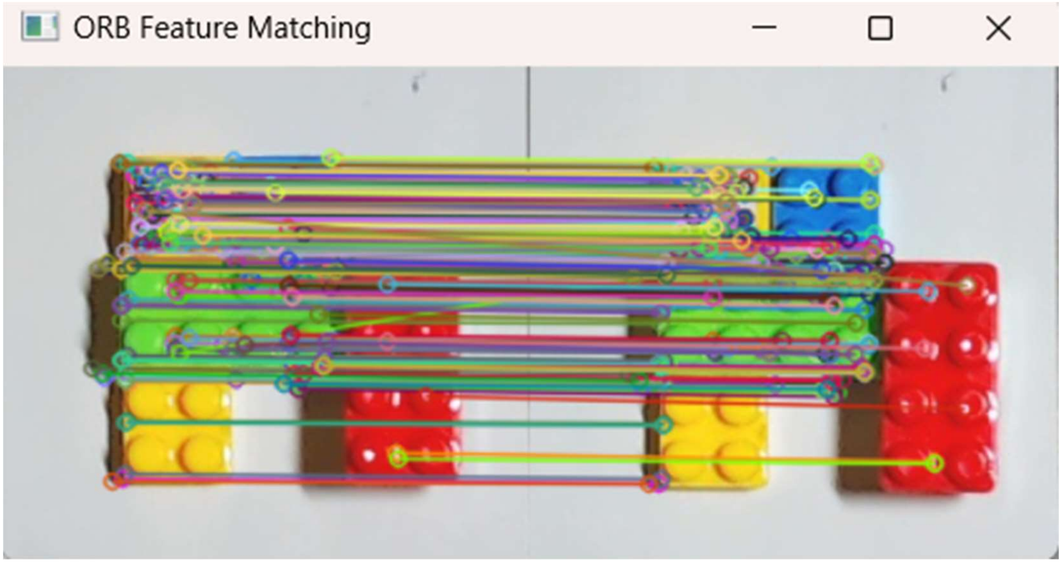


Figure 5.26 An example of ORB matching.

Moreover, ORB is efficient and strikes a good balance between speed and accuracy, making it suitable for real-time applications. During the implementation, ORB demonstrated observable accuracy in the computation. The computation results were relatively stable and correct compared to other descriptors and methods. The false-negative values decreased after applying ORB. This feature matching algorithm can be easily called from the OpenCV library by initializing the ORB object.

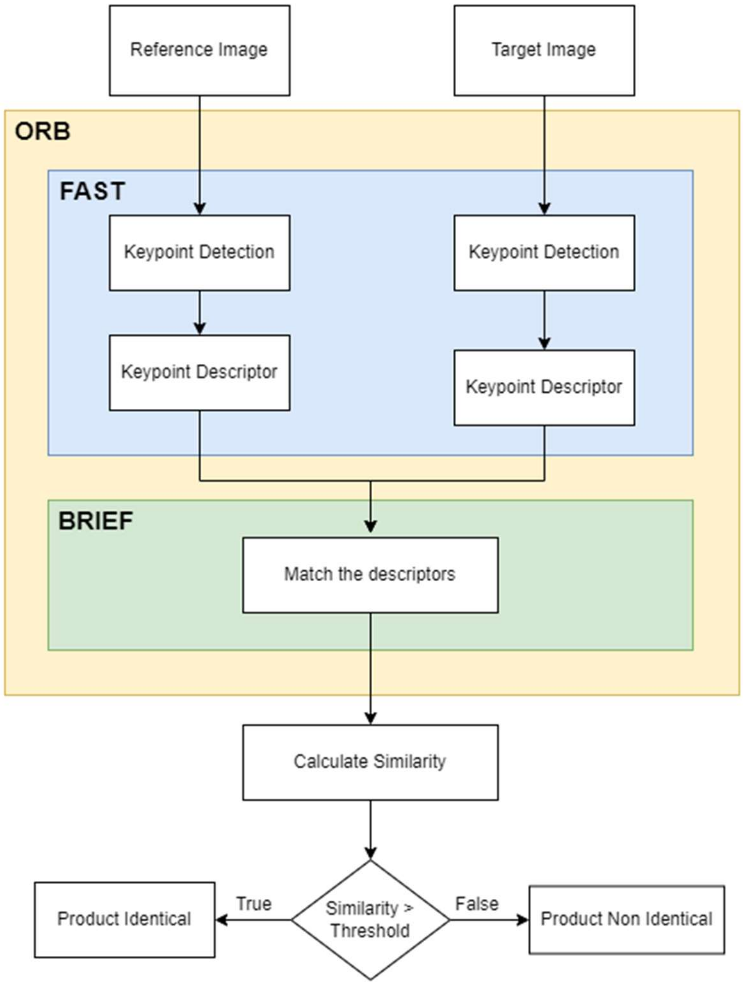


Figure 5.27 An example of ORB feature matching flow.

Based on the figure above, this is an example of how ORB is used in the quality checking system. The reference image serves as the standard or template for the assembly step, while the target image is captured in real-time during the assembly process. Both images are preprocessed (cropped and histogram matched) and sent into the ORB object to first perform detection and description using FAST. Then BRIEF is used to match the keypoints, resulting in both total matches and good matches. To compute the similarity score, the following formula is used:Formula to compute the similarity score:

$$Similarity\ score\ =\ len(good\ Matches) \div len(matches)$$

The system has set a threshold value of 0.85; a score greater than 0.85 is considered a match or identical, while a score below this threshold indicates that the images are not identical.

5.4.4 Report Generation

The system has the capability to record and store the performance metrics of the users, including the operator's name, date and time of the session, the number of incorrect attempts for each round, and the duration of each round. All this performance data is stored in a Word file.

The system can retrieve this data from the text file and generate insightful graphs. These graphs offer a comprehensive overview of the operator's performance, providing valuable insights for management to assess and understand the efficiency and proficiency of the operators in the assembly process. This enables the management to make informed decisions and take necessary actions to enhance the overall performance and quality control of the assembly operations. The graph will be saved as a png file for record keeping.

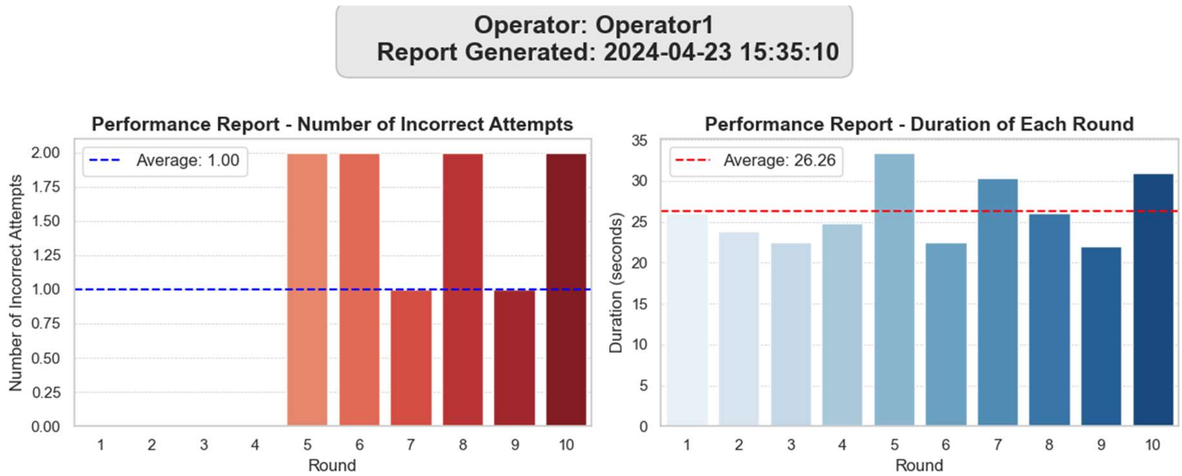
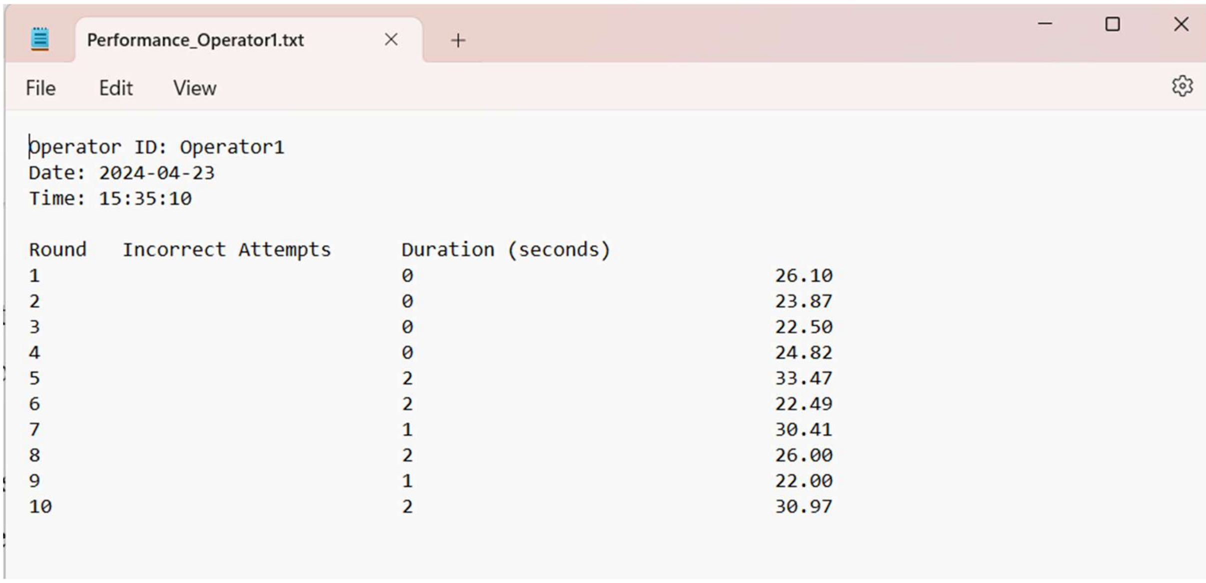


Figure 5.28 An example of report generation.



```
Operator ID: Operator1
Date: 2024-04-23
Time: 15:35:10

Round   Incorrect Attempts      Duration (seconds)
1                               0                               26.10
2                               0                               23.87
3                               0                               22.50
4                               0                               24.82
5                               2                               33.47
6                               2                               22.49
7                               1                               30.41
8                               2                               26.00
9                               1                               22.00
10                              2                               30.97
```

Figure 5.29 An example of performance text file.

5.5 Implementation Issues and Challenges

5.5.1 The Negative Effect of Environmental Issues.

Environmental issues, particularly poor lighting, posed significant challenges in detecting QR codes and comparing image similarity. Computer vision heavily relies on consistent illumination, and fluctuations in brightness can adversely affect the decoding and detection processes. The presence of noise in the captured image, due to inconsistent brightness in the frame, also troubled the quality checking process. The system's operability is limited to a specific range of lighting conditions, and variations such as light flickering, shadows, reflections, or uneven illumination can impact the visibility of QR codes. The flickering light issues observed in the lab did not occur in my working environment, causing a considerable impact on my project as image processing was integral to the entire project. Fortunately, this challenge was overcome by providing a more constant light source, ensuring consistent and reliable image processing.

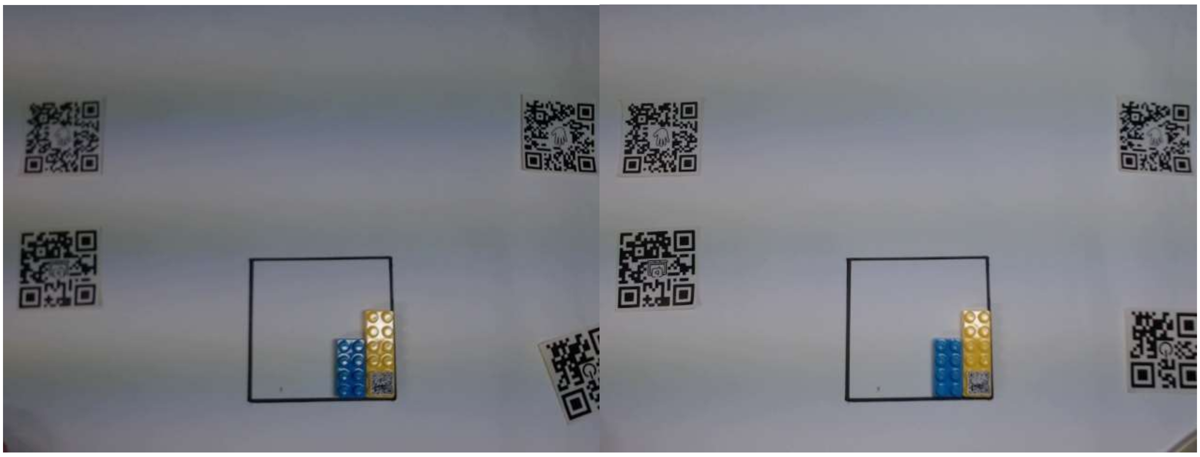


Figure 5.30 An example of light flickering issue.

5.5.2 Challenges in Cropping Function

During the implementation of the cropping function, several challenges were encountered when detecting the rectangle borders. The basic crop function often confused with the QR codes or detected unknown areas, causing significant obstacles in continuing my project as the cropping function is the preliminary work for the quality checking function. After generating endless ideas and testing various methods, the correct method to crop was finally identified, achieving almost 98% accuracy in cropping the correct product.

5.5.3 Challenges in Similarity Checking Function

Attempts were made to use the Structural Similarity Index Measure (SSIM) to measure the similarity score for the images. SSIM computes and compares the similarity of each pixel value; however, the results were extremely unstable and easily affected by the color, brightness, and location compared. Subsequently, feature keypoint descriptors were discovered and tested. SIFT was initially tested, showing improvement in stability and accuracy in the structure; however, it was unable to detect color differences even using histogram matching beforehand. Lastly, ORB was tried, which was able to produce satisfactory results, able to differentiate color and structure. This is crucial as the similarity algorithm must be precise and fit this system, ensuring the accuracy of the quality checking function and the reliability of this system.

CHAPTER 6

SYSTEM EVALUATION AND TESTING

6.1 Performance of Different QR Code Decoder

The QR code decoder is a key component of this system, acting as a foundational mechanism for event triggers that rely on QR code detection. In order to evaluate this decoder's precision and accuracy, three widely used, open-source barcode libraries that can be accessed with Python will be used and examined. The first library is the built-in OpenCV QR code decoder, then comes the C-based, free and open-source zbar library, along with its Python binding, pyzbar. The WeChat QR Code Scanner in OpenCV, which stands out for incorporating deep learning modules from the Caffe deep learning framework, is the third decoder that is examined. WeChat QR code detector is based on two Convolutional Neural Network (CNN) modules: the detector model that uses machine learning to find QR codes and the super-resolution model that uses machine learning to improve, sharpen, and upscale QR codes while maintaining their distinctive features. This super-resolution method works especially well for deciphering tiny QR codes. For a thorough assessment, performance metrics such as the rate of successful decodes and the decoding time will be used.

Table 6.1 Comparison between decode libraries

Decode Library	Successful Decode		
	OpenCV Default QR Code Scanner	Open CV WeChat QR Scanner	Pyzbar
Support Multiple QR Code	No	Yes	Yes
Distance 60 cm	No	Yes	No
Distance 45 cm	No	Yes	No
Distance 30 cm	Yes	Yes	Yes
Distance 15 cm	Yes	Yes	Yes
Uneven Lighting	No	Yes	Yes
Bright Environment	Yes	Yes	Yes
Dark Environment	Yes	Yes	Yes

Several important findings are revealed following an experiment of three QR code decoding libraries: Pyzbar, OpenCV WeChat QR Scanner, and OpenCV Default QR Code Scanner. The OpenCV Default QR Code Scanner is inferior to Pyzbar and the OpenCV WeChat QR Scanner in terms of supporting multiple QR codes. In terms of decoding performance analysis at various distances, the WeChat QR Scanner is consistently successful, even at longer ranges, whereas Pyzbar and the OpenCV Default QR Code Scanner both have limits at longer ranges. Furthermore, the WeChat QR Scanner demonstrates its resilience in a variety of lighting scenarios, such as uneven lighting, bright environments, and dark environments. Considering these aspects, the WeChat QR Scanner from OpenCV stands out as the recommended library due to its extensive support for numerous QR codes, reliable decode performance at various distances, and flexibility to adjust to different lighting conditions, making it the best option for project specifications.

6.2 Characteristics or Restriction of The QR Code Decoder.

6.2.1 Distance Between QR Codes.

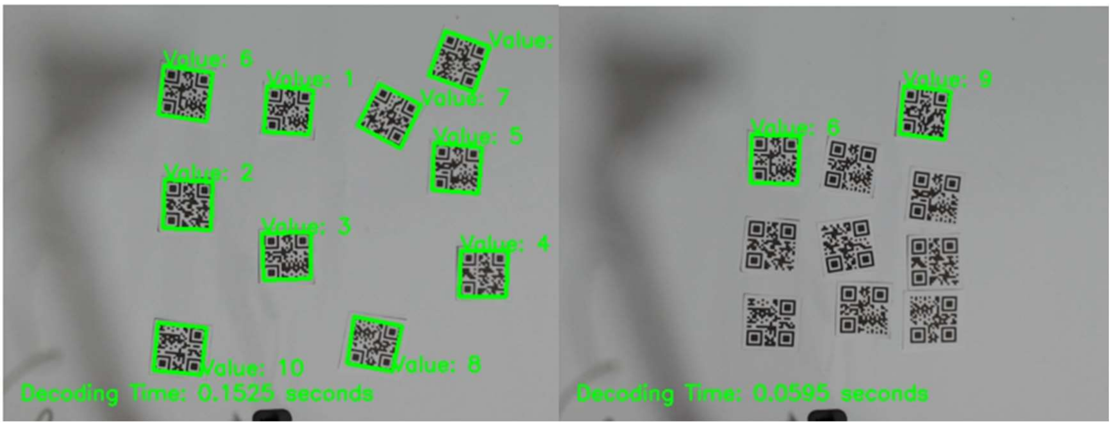


Figure 6.1 Comparison of distance between QR codes

The placement of QR codes is very important, and analysis and experimentation have shown that the decoding performance is greatly affected by the distance between QR codes. In practical trials, only two out of ten QR codes could be successfully decoded when they were arranged densely with little space between them. On the other hand, all QR codes were successfully scanned when the arrangement was looser and more expansive. This emphasises the idea that placing QR codes too close to one another will negatively impact the decoding process. To maximise decoding accuracy, QR codes are purposefully placed with plenty of space between them in the implemented system.

6.2.2 The Relationship Between the Number Of QR Codes and Their Corresponding Decode Times.

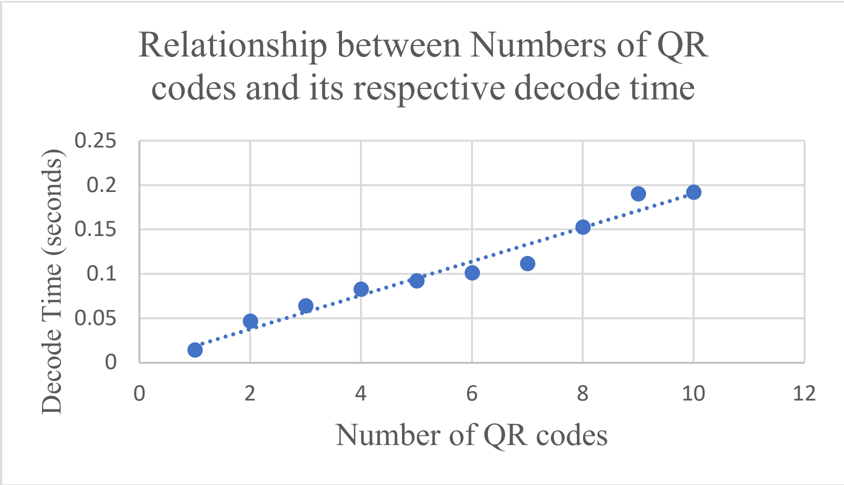


Figure 6.2 Relationship between numbers of QR codes and its respective decode time.

This experiment looks into the connection between a barcode's number and its corresponding decoding time. A proportional trendline that shows a decrease in decoding time as the number of QR codes increases is visible on the plotted graph. It will perform worse and become less responsive if there are too many QR codes in the captured frame. Before being passed to the decode function, the frame is cropped into four parts. In order to improve the decoder's performance, the number of QR codes in a frame must be reduced through cropping.

Figure 6.3 Examples of cropped decode image.

Additionally, the decoding rate of QR codes on the edges of the frame is typically lower. The performance could be greatly improved by using this cropped frame technique. In a full frame, only one QR code can be detected; in cropped frames, three codes can be decoded altogether.

6.2.3 the relationship between distance of Camera and its respective decode time.

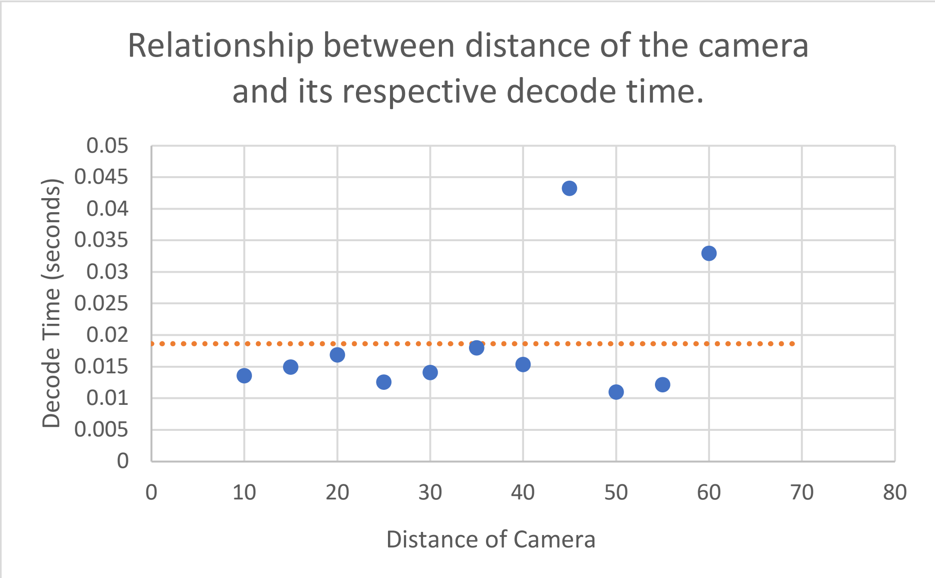


Figure 6.4 Relationship between distance of the camera and its respective decode time.

Table 6.2 Distance of the camera and its respective decode time

Distance of the Camera	Decoded Time (seconds)
10	0.0136
15	0.0150
20	0.0169
25	0.0126
30	0.0141
35	0.0180
40	0.0154
45	0.0433
50	0.0110
55	0.0122
60	0.0330

Using three different libraries, the previous experiment examined how camera distance affected the process of decoding QR codes. The results show that the size of the QR code within the captured frame is directly correlated with the camera distance. A smaller QR code in the frame corresponds to a higher barrier to successful decoding for the libraries. This experiment uses the OpenCV WeChat QR Code scanner, which is selected as the main library, to measure the camera's distance. The decoding time was stable and mostly fell between 10 and 20 milliseconds, even though the experimental distance ranged from 10 to 60 cm. The average decoding time stabilised at about 20 milliseconds, although outliers were seen at 30 and 40 milliseconds.

The task of decoding small QR codes was made less difficult by the WeChat QR Scanner, which used a super resolution CNN model. This model showed how small QR codes could be made larger without sacrificing their features or content. As a result, the experiment offered a resolution to the problems with QR code scanning that are related to distance. The WeChat QR Scanner's performance surpasses that of other QR code decoders, even though there is still a maximum distance restriction. This gives users more confidence that it can be used for the intended purpose.

6.3 Performance of Histogram Matching

Table 6.3 Performance of Histogram

Image	Does not go through histogram matching	Go through histogram matching
Reference Image compared with Wrong Image (Same block but in different color)	0.87	0.70
Reference Image compared with Correct Image (Same block but in different color)	0.86	0.93

* *Assumed a threshold value*: 0.85

The similarity scores are relatively high, indicating a good match between the reference image and the target images even when the target image is not the correct one. This suggests that the ORB algorithm without histogram matching is fairly tolerant to slight color variations. The similarity score decreases when histogram matching is applied, especially when comparing the reference image with the wrong image. This is likely because histogram matching adjusts the color distribution of the images to make them more consistent, making it harder for the algorithm to find a good match between images that have significant color differences.

Interestingly, when the correct image is used, the similarity score increases from 0.86 to 0.93 with histogram matching. This suggests that histogram matching has made the system more sensitive to the color consistency between the reference and target images. By aligning the color distributions, histogram matching ensures that the algorithm focuses more on the structural similarities rather than being misled by color variations, thus improving the accuracy of the similarity score.

Histogram matching plays a crucial role in enhancing the accuracy of the similarity scores in the quality checking system. By improving the consistency and uniformity of the color distributions in the images, it increases the system's discrimination between correct and incorrect matches. This results in a more reliable and accurate quality checking system, ensuring that the assembly process is more precise and less prone to errors.

6.4 Time Comparison Traditional Assembly Method and Automated Manual Assembly Station

Table 6.4 Time Comparison

Time taken for finishing assembly a product	
Without assistance	13s
With assistance	26s

. The data shows that while using the assistance system increases the assembly time from 13 seconds to 26 seconds, it significantly improves the accuracy of the assembly process to 96%. This high accuracy rate means that the system effectively reduces the number of defective products, which is crucial for maintaining product quality and reducing the costs associated with defects.

Even though the assembly process takes longer with the assistance system, the trade-off in time is justified by the substantial increase in accuracy. The assistance system not only enhances the quality of the assembly but also provides consistent and reliable results, making it a valuable tool for improving the overall efficiency and quality control of the assembly process.

In summary, the assistance system offers a beneficial solution for improving the accuracy and quality of the assembly process, outweighing the slight increase in assembly time.

6.5 Comparison Between Methods Compute Similarity.

6.5.1 Comparing Accuracy

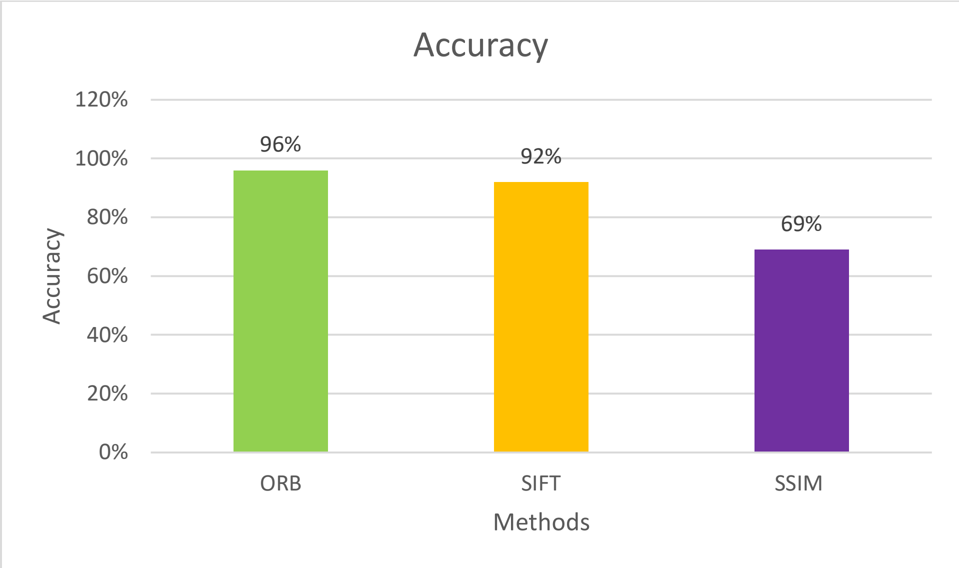


Figure 6.5 Comparing accuracy between methods.

The accuracy of the quality checking system is pivotal for ensuring the reliability and effectiveness of the assembly process. The similarity checking function serves as a crucial metric for evaluating the accuracy of the system, where the reference image (the example image from the database) is compared with the target image (the captured image from the frame). This performance was tested through 50 rounds of checking both correct and wrong images for every method. In this system, three different algorithms are employed for feature matching: ORB (Oriented FAST and Rotated BRIEF), SIFT (Scale-Invariant Feature Transform), and SSIM (Structural Similarity Index Measure).

ORB

The ORB method achieved the highest accuracy rate of 96%. ORB is renowned for its efficiency and offers a commendable balance between speed and accuracy, making it particularly suitable for real-time applications. The ORB detector has demonstrated outstanding results with the ability to correctly detect the component parts and colors, showcasing its effectiveness in detecting and matching features in the images. This high accuracy rate of 96% emphasizes the reliability and robust performance of the system when using the ORB algorithm for feature matching in the quality checking process.

SIFT

The SIFT method achieved an accuracy rate of 92%. SIFT is a robust method for feature detection and description in computer vision, renowned for its ability to detect and match key features across different scales and orientations. However, its sensitivity to color changes poses a limitation. If a component with a different color but the same structure and size is placed, SIFT may detect and determine it as correct. This is attributed to SIFT's feature matching on grayscale images. Despite its high accuracy rate, the potential for false positives due to color variations could significantly impact the quality control process, making it less suitable for applications where color accuracy is crucial.

SSIM

In contrast, the SSIM algorithm exhibited the lowest accuracy rate of 69% among the three methods. SSIM is a method specifically designed to measure the structural similarity between two images. Due to its sensitivity to brightness and location, SSIM often struggles to produce accurate results in dynamic assembly environments. The lower accuracy rate of SSIM, as compared to ORB and SIFT, suggests that SSIM may not be as effective in capturing the detailed structural information essential for accurate feature matching in the quality checking process.

6.5.2 Comparing Time

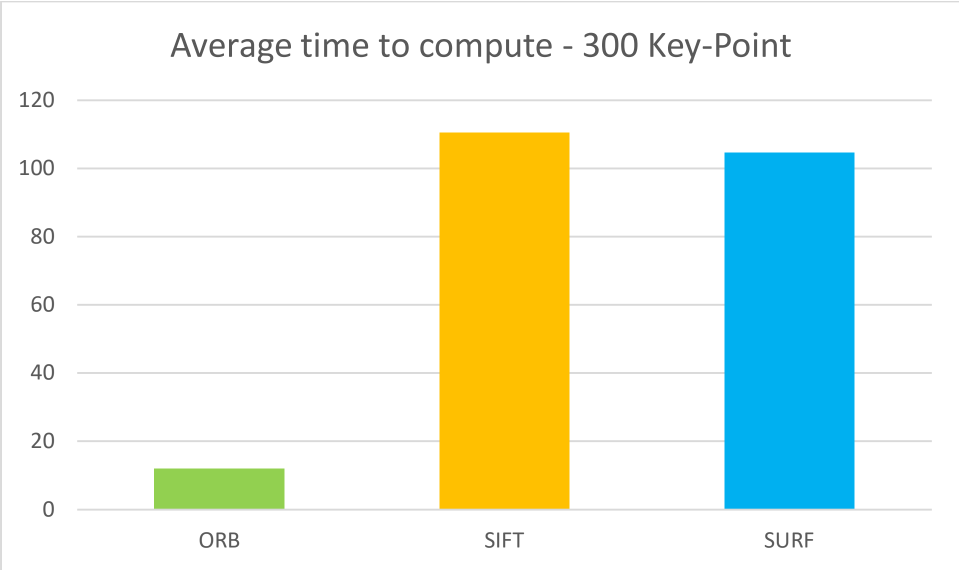


Figure 6.6 Comparing Time

ORB (Oriented FAST and Rotated BRIEF): The ORB feature extractor demonstrated the fastest processing time of 12.1 ms. ORB is known for its efficiency and computational speed, making it particularly suitable for real-time applications. The low processing time of 12.1 ms indicates that ORB can efficiently extract features from the images with minimal computational overhead.

SIFT (Scale-Invariant Feature Transform): The SIFT feature extractor had a processing time of 110.5 ms, which is considerably longer compared to ORB. SIFT is a robust method for feature detection and description but is generally more computationally intensive due to its complex algorithm and the need for extensive computations for feature detection and description. The longer processing time of 110.5 ms suggests that SIFT may not be as efficient as ORB for real-time applications.

SURF (Speeded-Up Robust Features): The SURF feature extractor had a processing time of 104.7 ms, which is also relatively high compared to ORB. SURF is designed to improve upon the speed and accuracy of SIFT, but it still requires more computational resources compared to ORB. The processing time of 104.7 ms indicates that SURF may offer a balance between speed and accuracy but is still slower than ORB.

6.6 System Evaluation

6.6.1 Evaluation of Time for Quality Checking Module

The Quality Checking Module is a vital component of the system, responsible for ensuring the accuracy and reliability of the assembly process. This section evaluates the time performance of the Quality Checking Module, specifically focusing on the time taken for the Checking process, which includes cropping the Region of Interest (ROI), histogram matching, and similarity checking.

Result

The Quality Checking Module demonstrated efficient performance with an average checking time of 0.03 ± 0.005 seconds, ensuring a responsive and real-time assistance system. The outlier observed during the first checking session was a result of the ORB object initialization, which took slightly longer than the subsequent runs. As this issue occurred only once during the initial run and did not affect the subsequent checks, the checking process consistently maintained an average time of 0.03 seconds per iteration.

Discussion

The Checking process exhibited reliable and efficient performance with an average checking time of 0.03 seconds, confirming the system's capability to provide real-time assistance to the user during the product assembly. The observed outlier, attributed to the ORB object initialization, did not significantly impact the overall performance, as it was a one-time occurrence.

6.6.2 Evaluation of Time for Load Steps Module

The LoadSteps function is responsible for loading the required steps, which are used as the reference images for similarity comparison during the checking process. When setting up the system for a new product, the user of the assistance system is required to capture and place the sample (reference image) into the designated folder. The performance of the LoadSteps function was evaluated to understand the time taken for loading the reference images.

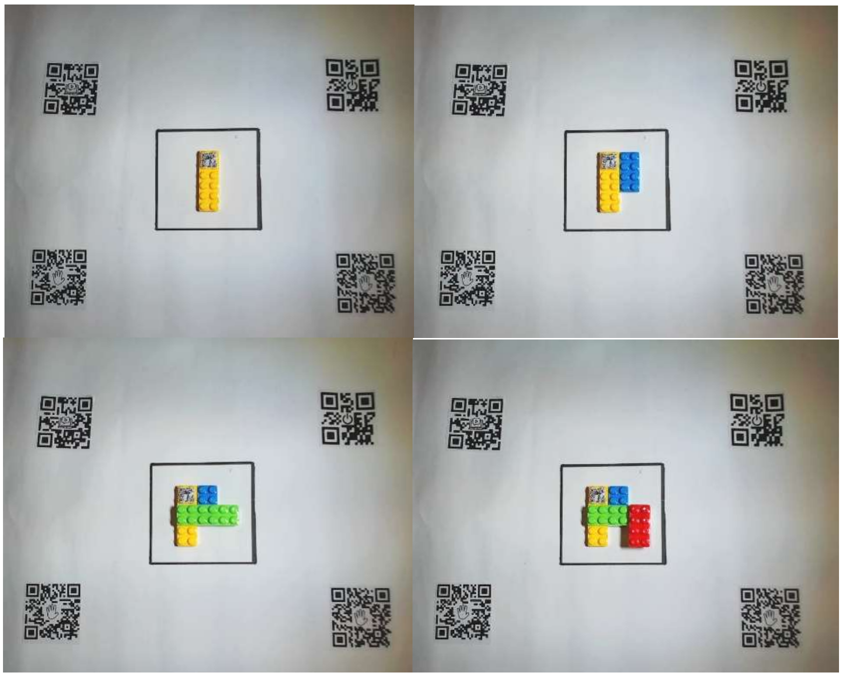


Figure 6.7 An example of steps image used in the system.

Result

The average time taken to load the 4 steps was approximately 0.06 ± 0.01 seconds.

Discussion

The LoadSteps function demonstrated efficient performance with an average loading time of 0.06 seconds, making the system responsive and suitable for real-time assistance. This quick loading time ensures that the user can easily set up and switch between different products without experiencing significant delays in the process.

6.6.3 Evaluation of Time for Load Instruction Module

The LoadInstructions function is responsible for loading the instruction images, which are crucial for visual guidance to assist the user in assembling the product. In this project, LEGO is used as the product, and the instructions were generated using the Studio.io application.

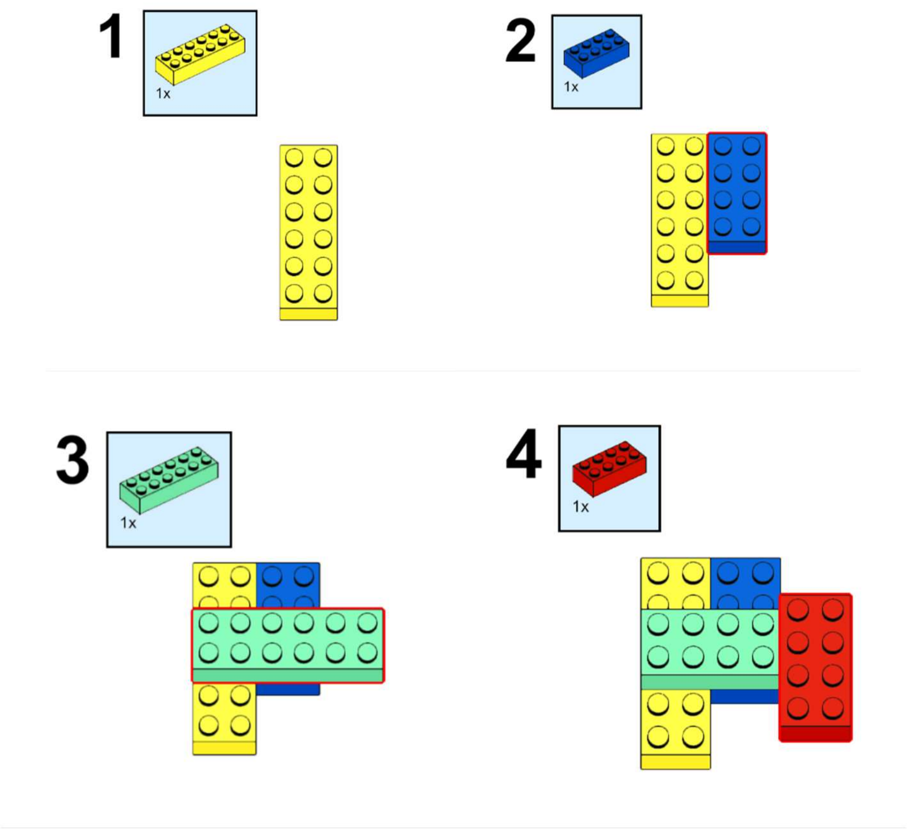


Figure 6.8 An example of instruction image used in the system.

Result

The average time taken to load the instruction images was approximately 0.03 ± 0.01 seconds.

Discussion

The LoadInstructions function demonstrated even more efficient performance compared to LoadSteps, with an average loading time of 0.03 seconds. This quicker loading time is attributed to the smaller file sizes of the instruction images. The fast loading ensures that the user can easily understand and follow the assembly process, enhancing the overall user experience

6.6.4 Evaluation of Time for Generate Report Module

The Generate Report module is an essential component of the system, serving to provide a detailed performance report of the operator. This section evaluates its performance and efficiency, focusing on the time taken to produce the report and its impact on the overall system performance. The report is generated using the seaborn library, and the module also includes updating the latest performance data to the text file.

Result

The Generate Report module retrieves the previous performance data of the operator from a text file and combines it with the latest performance data recorded during the current session. The average time taken to generate the report is approximately 4 seconds, and the time taken for updating the performance to the text file is less than 1 second. The report primarily focuses on four variables: the duration of the task, the number of incorrect attempts made by the operator, the name of the operator, and the date and time the report was generated.

Discussion

The Generate Report module effectively fulfils its purpose by providing a comprehensive performance report of the operator. The average time taken of around 4 seconds is relatively short but crucial for providing valuable insights into the operator's performance. As a post-system function, the report generation occurs only once after the operator has shut down the system, ensuring it does not interfere with the overall efficiency and productivity of the assembly process.

The quick update time of less than 1 second for updating the performance to the text file further demonstrates the efficiency of the Generate Report module, ensuring that the latest performance data is readily available for future reference and analysis.

6.7 Objective Evaluation

6.7.1 Evaluation on Objective 1: Measuring Operators Performance

The primary objective of this system is to measure the performance of operators by providing detailed performance metrics during the task execution. This section evaluates the achievement of this objective by examining the system's capability to record the time taken for each process and the number of incorrect attempts made by the operator. This feature aims to streamline the management process by eliminating the need for manual recording, thereby saving time and reducing operational costs.

The system records the time taken by the user for each process and the number of incorrect attempts during the assembly task. This data is stored in a text file, which is subsequently retrieved when the operator uses the system again. The system then combines the old and new records to generate a comprehensive performance report and graphs, allowing managers to effortlessly measure the operators' performance without requiring additional time or manual intervention.

The system has successfully achieved the objective of measuring operators' performance by providing detailed performance metrics. The performance data, including the time taken for each process and the number of incorrect attempts, is stored in a text file. Upon generating a report, the system retrieves both the old and new records to create graphs that display the overall performance, average time taken, and number of incorrect attempts. This feature enables high-level management to assess operators' performance efficiently without the need for additional time or manual measurements.

The system's ability to automatically record and analyze operators' performance metrics demonstrates its efficiency in achieving the stated objective. By storing and comparing the old and new records, the system provides a comprehensive overview of the operators' performance, allowing managers to easily identify areas for improvement and ensure the consistent quality of the assembly process. This feature not only enhances the efficiency of performance evaluation but also minimizes the need for manual intervention, thereby streamlining the management process and saving time and operational costs.

The system has successfully achieved the objective of measuring operators' performance by recording and analyzing the time taken for each process and the number of incorrect attempts. The integration of this feature enables the system to generate comprehensive performance reports and graphs, facilitating efficient and effortless evaluation of operators' performance by high-level management. This accomplishment underscores the system's capability to streamline performance assessment and improve the overall quality of the assembly process while eliminating the need for manual recording and reducing operational costs.

6.7.2 Evaluation on Objective 2: Assisting Operator in Assembly Processes with 2D Instuction Materials and Tutorial Video

The objective of assisting operators in the assembly process is fully achieved by the system. This section evaluates the system's capability to provide guided instruction images and tutorial videos to facilitate the assembly process for operators. By offering an intuitive and user-friendly interface, the system aims to enhance the efficiency and convenience of the assembly process by eliminating the need for traditional instruction books and providing dynamic tutorial videos tailored to the operators' current assembly step.

The system displays guided instruction images on the screen, allowing operators to easily follow the assembly steps without flipping through thick instruction books. Additionally, the system offers tutorial videos that are triggered by clicking the tutorial button. These videos are recorded based on the assembly steps, ensuring that operators only view the relevant instructional content for the current step. This feature provides operators with the flexibility to watch the tutorial video while simultaneously following the assembly steps, enhancing the efficiency and convenience of the assembly process.

The system has successfully achieved the objective of assisting operators in the assembly process by providing guided instruction images and tutorial videos. The instruction images displayed on the screen allow operators to follow the assembly steps effortlessly, eliminating the need for traditional instruction books. Moreover, the tutorial videos, which are triggered by clicking the tutorial button, offer dynamic and relevant instructional content based on the current assembly step. This feature enables operators to access the necessary guidance quickly and conveniently without having to go through the entire video, thereby enhancing the efficiency and effectiveness of the assembly process.

The system's capability to provide guided instruction images and tutorial videos demonstrates its efficiency in assisting operators during the assembly process. By offering an intuitive and user-friendly interface, the system eliminates the need for traditional instruction books and provides dynamic tutorial videos tailored to the operators' current assembly step. This feature not only enhances the convenience and efficiency of the assembly process but also improves the operators' overall experience by offering flexible and relevant instructional content. As a result, operators can easily follow the assembly steps and access the necessary guidance, thereby facilitating the assembly process and ensuring the consistent quality of the assembled products.

The system has successfully achieved the objective of assisting operators in the assembly process by providing guideful instruction images and tutorial videos. By offering an intuitive and user-friendly interface, the system enhances the efficiency and convenience of the assembly process by eliminating the need for traditional instruction books and providing dynamic tutorial videos tailored to the operators' current assembly step. This accomplishment underscores the system's capability to facilitate the assembly process and improve the operators' overall experience by offering flexible and relevant instructional content, thereby ensuring the consistent quality of the assembled products and enhancing the overall efficiency of the assembly process.

6.7.3 Evaluation on Objective 3: Enhancing Manufacturing Quality and Efficiency by Integrating Quality Control.

The objective of enhancing manufacturing quality and efficiency by integrating quality control into the assembly station has been fully achieved by the system. This section evaluates the system's capability to embed quality control step-by-step within the assembly process, as compared to traditional manual assembly stations where quality checking typically occurs at the final stage. By integrating quality control with the assembly station, the system aims to provide early flaw detection and stop the processing of defective products, thereby increasing the probability of producing error-free products, reducing the cost of poor quality, and improving overall efficiency and productivity.

The system embeds quality control step-by-step within the assembly process, as opposed to traditional manual assembly stations where quality checking is conducted at the final stage. This integrated quality control approach facilitates early flaw detection and enables early stops to the processing of defective products, thereby increasing the probability of producing error-free products and reducing the cost of poor quality. The system's capability to provide fast quality detection, with an additional time of only 0.03 seconds for quality checking at each step, ensures that the assembly process is not significantly slowed down. Furthermore, the ergonomic design of the quality function trigger contributes to the effective and efficient execution of the quality control process.

The system has successfully achieved the objective of enhancing manufacturing quality and efficiency by integrating quality control into the assembly station. By embedding quality control step-by-step within the assembly process, the system provides early flaw detection and enables early stops to the processing of defective products, thereby increasing the probability of producing error-free products and reducing the cost of poor quality. The integrated quality control approach has successfully improved the efficiency and productivity of the assembly process. Despite the additional time of 0.03 seconds taken for quality checking at each step, the assembly process is not significantly slowed down, thanks to the system's ergonomic design and efficient execution of the quality control process.

The system's capability to embed quality control step-by-step within the assembly process demonstrates its efficiency in enhancing manufacturing quality and efficiency. By providing early flaw detection and enabling early stops to the processing of defective products, the system increases the probability of producing error-free products and reduces the cost of poor quality. The integrated quality control approach not only improves the efficiency and productivity of the assembly process but also ensures consistent product quality by facilitating fast quality detection without significantly slowing down the assembly process. Furthermore, the system's ergonomic design of the quality function trigger enhances the effective and efficient execution of the quality control process, thereby contributing to the overall improvement in manufacturing quality and efficiency.

The system has successfully achieved the objective of enhancing manufacturing quality and efficiency by integrating quality control into the assembly station. By embedding quality control step-by-step within the assembly process, the system provides early flaw detection and enables early stops to the processing of defective products, thereby increasing the probability of producing error-free products, reducing the cost of poor quality, and improving overall efficiency and productivity. Despite the additional time of 0.03 seconds taken for quality checking at each step, the assembly process is not significantly slowed down, thanks to the system's ergonomic design and efficient execution of the quality control process. This accomplishment underscores the system's capability to facilitate the assembly process, improve the efficiency and productivity of manufacturing operations, and ensure consistent product quality by integrating quality control into the assembly station, thereby contributing to the overall enhancement of manufacturing quality and efficiency.

6.8 System Reliability and Potential System Interruptions

This section aims to identify and discuss potential circumstances that may disrupt the system's smooth operation and the corresponding recovery procedures to mitigate these issues. Understanding these scenarios is essential for maintaining the system's reliability and ensuring uninterrupted operation during the assembly process.

6.8.1 System Viability

Camera Index Unavailability

If the system is unable to access the camera or the camera index is unavailable, the system will notify the user with a message stating, "No frame is readable," and gracefully end the system, indicating that no camera index is available.

QR Code Issues

The QR codes may be accidentally covered by objects on the assembly desk, rendering them unreadable. In such cases, the system will prompt a message to the user, stating, "No readable QR codes in the frame," informing them of the issue.

Load Steps and Instruction Image Function Issues

In the load steps and instruction image function, if there are no instruction images available or an unexpected image format is loaded into the system, the system will prompt an error message to notify the user of the issue.

Cropping Function Issues

In some cases, the cropping function may encounter issues where no contour is available, possibly due to the rectangle border being blocked by an object, preventing the contour from detecting the rectangle border and resulting in no image being cropped. This situation may cause errors in subsequent processes such as histogram matching and similarity score computation. To handle this exception, the system will prompt the operator with a message stating, "Border is blocked, please try again."

Similarity Function Issues

The calculation of the similarity score in the similarity function is computed by the number of good matches divided by the number of matches. There is a possibility that no keypoint is matched, resulting in a division by zero error. In this case, the system will return a message stating, "Failed, please try again," and require the user to retry the process.

6.8.2 Potential System Interruptions and Recovery Procedures

Power Failure

The system requires a stable power supply to operate effectively. If implemented on a computer or a Raspberry Pi, it must be connected to a reliable power source to ensure sufficient power for running the code. In the event of a power failure, the system may shut down unexpectedly, causing potential data loss and disrupting the tracking system. The recovery procedure for this scenario involves checking the power supply and manually restarting the system once the power is restored.

Environmental Issues

Given that the system relies on computer vision technology, environmental brightness is of paramount importance. Insufficient lighting can impede the camera's ability to capture useful frames for image processing and subsequent steps. To address this issue, a small lamp is attached to the system to provide consistent lighting for the camera, ensuring optimal performance even in low-light conditions. Since the lamp is not battery-operated, it must be connected to the power supply to function properly.

Hardware Issues

The webcam serves as the primary data source for capturing and recording real-time video. The system relies heavily on the camera to provide vision data, making it a critical component. Issues such as camera failure, which may result in suboptimal video streaming quality (e.g., blurry or non-HD video) or complete camera breakdown, can occur. These issues can only be resolved by replacing or repairing the camera components and conducting a performance test to ensure proper functionality.

6.8.3 System Resilience and Viability

It is important to note that the system does not rely on network connectivity, as all functions use local libraries and do not require any resources from online sources when operating. This enhances the system's resilience and reduces the risk of disruptions due to network issues.

6.9 Expected Cost

The table below shows the expected cost need for this project implementation:

Table 6.5 Expected cost.

Item	Quantity	Price (RM)
Logitech C922 Pro HD Stream Webcam	1	390
Overhead Tripod Stand	1	14.90
Lamp	1	14.30
Paper and QR codes sticker	1	2.5
Total Cost		421.70

Compared to custom smart stations sold by companies, which cost approximately $1200 (around RM7200) per station annually, our system offers a significantly more affordable solution. With a price that is 95% lower, users also gain greater control and flexibility over the system, allowing them to design it according to their needs. Additionally, this system's maintenance is simplified and cost-effective. If the paper and QR codes become damaged or are not in good condition, they can be easily replaced, reducing both cost and downtime.

Besides, QR codes offer high error correction capabilities, making them readable even with up to 30% damage. This is a significant advantage over traditional buttons, which can be time-consuming and costly to replace when they wear out or become damaged.

CHAPTER 7

Conclusion

In this project, a comprehensive system has been developed to enhance the assembly process through automated guidance and performance tracking. The system utilizes QR code triggers for event activation and integrates advanced image processing techniques, including histogram matching and feature matching using ORB, to ensure accurate and efficient quality checking.

The system also incorporates a two-handed safety measure for QR code activation, enhancing operational safety by reducing the risk of unintentional system activation or shutdown. Additionally, the system requires operators to display their unique Operator ID for accountability and performance tracking, contributing to improved efficiency and quality control.

Furthermore, the system has the capability to record and store performance metrics such as the operator's name, date and time, incorrect attempts, and round durations. This data is stored in a Word file and can be retrieved to generate insightful graphs, providing management with valuable insights into the operator's performance.

Overall, this system offers a comprehensive solution for enhancing the assembly process, ensuring accuracy, efficiency, and safety, while also providing valuable performance insights for management to facilitate continuous improvement and quality control.

7.1 RECOMMENDATION

7.1.1 Linking Operators Database

Linking operators' database is a pivotal enhancement aimed at delivering personalized performance tracking and historical data for each operator, facilitating targeted training and continuous performance improvement. This feature is particularly valuable in scenarios with a larger number of operators, as it enables the development of Personalized Training Modules tailored to each operator's specific needs and performance metrics. By analyzing historical data, the system can identify trends and pinpoint areas for improvement, allowing for more effective and targeted training programs for a diverse group of operators.

The system will incorporate a comprehensive Historical Performance Tracking mechanism to store and track each operator's performance over time. This data-driven approach provides valuable insights into each operator's progress, enabling supervisors to monitor performance trends, identify strengths and weaknesses, and implement strategies for improvement across a larger workforce.

Furthermore, the Operator-Specific Settings feature allows operators to customize their user experience by setting their preferred display brightness, language preference, and other personalized settings. This customization enhances user comfort and efficiency, contributing to a more intuitive and user-friendly interface for a diverse group of operators.

The integration of a Linking Operators Database not only enhances the overall performance tracking and training capabilities but also fosters a more personalized and adaptable user experience. This feature is essential in promoting continuous improvement, empowering operators with the tools and insights needed to optimize their performance and contribute to the overall efficiency and productivity of the assembly process, even as the number of operators increases.

7.1.2 Integration with Manufacturing ERP Systems

Integration with Manufacturing ERP Systems is a pivotal enhancement for the system, aiming to provide seamless integration with existing Manufacturing ERP systems for automated data exchange and process optimization. ERP is a popular system in manufacturing and production floors because of its ability to centralize and streamline various processes, ensuring efficient operations and improved decision-making. This integration will facilitate Automated Data Logging, enabling the system to automatically log quality checking results and operator performance metrics into the ERP system. Additionally, the system will be capable of providing Process Optimization Recommendations by analysing the data to identify potential areas for process optimization and efficiency improvement.

As the manufacturing process becomes more complex in the future, leveraging the capabilities of Manufacturing ERP systems will be essential to ensure scalability and adaptability to evolving manufacturing requirements. This integration will enable the system to handle more complex manufacturing processes by utilizing the advanced functionalities and capabilities offered by Manufacturing ERP systems, ultimately enhancing the efficiency and productivity of the manufacturing process. This seamless integration will streamline data exchange, eliminate manual data entry processes, reduce the risk of human error, and ensure accurate and real-time data availability for analysis and reporting purposes.

In conclusion, the integration with Manufacturing ERP Systems will foster a more intelligent, data-driven manufacturing environment, contributing to enhancing the efficiency, productivity, and competitiveness of the manufacturing process. This integration will empower organizations to achieve operational excellence, implement targeted improvements, and continuously optimize their processes to meet evolving business objectives and market demands.

7.1.3 Augmented Reality (AR) Integration

Augmented Reality (AR) Integration employs cutting-edge technology to elevate the assembly process by superimposing digital instructions directly onto the physical environment through a projector. This setup allows for AR-Assisted Assembly, where digital instructions are precisely projected onto the assembly table, overlaying guidance directly onto the physical components. By leveraging this technology, operators can focus solely on the assembly table, eliminating the need for an additional screen and minimizing distractions. This focused approach significantly enhances accuracy and efficiency.

Additionally, the system incorporates a Virtual Parts Inventory using AR technology. This feature visualizes a virtual inventory overlay directly on the assembly table, assisting operators in swiftly identifying and locating the necessary components. This real-time visualization ensures operators have immediate access to the required parts, further streamlining the assembly process.

This pioneering integration of AR technology with a projector not only simplifies the assembly process but also provides real-time guidance and assistance, thus enhancing the operator's experience. As this technology is still in its early stages within the market, it holds vast untapped potential. As it continues to evolve and mature, it is anticipated to uncover further innovative applications and benefits for the manufacturing industry, reshaping the assembly process and establishing new standards for efficiency and productivity.

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APPENDIX

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Trimester 3, Year 3	**Study week no.:2**
Student Name & ID: Ch'ng Shin Joe 20ACB0188	
Supervisor: Dr Ooi Boon Yaik	
Project Title: Automated Manual Assembly Station with Computer Vision	

1. WORK DONE I reviewed the comments provided by the moderator during the sembreak and addressed the issues raised.
2. WORK TO BE DONE I reviewed the image stitching method and tested it out.
3. PROBLEMS ENCOUNTERED The captured images exhibit variations in brightness and exposure, and there is noticeable light flickering across the images.
4. SELF EVALUATION OF THE PROGRESS Progress is good.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Trimester 3, Year 3	**Study week no.:4**
Student Name & ID: Ch’ng Shin Joe 20ACB0188	
Supervisor: Dr Ooi Boon Yaik	
Project Title: Automated Manual Assembly Station with Computer Vision	

1. WORK DONE
I attempted to address the flickering issue, but unfortunately, the flickering remains unresolved. Initially, the plan was to use image stitching to capture a larger image and read small-font text. However, with the webcam I have, the smallest readable font size is 18, which is already legible. Therefore, this approach did not yield satisfactory results.
2. WORK TO BE DONE
I worked on implementing the crop function to isolate the Region of Interest (ROI).
3. PROBLEMS ENCOUNTERED
There is a significant amount of noise in the frame, and the crop function misidentifies the QR code, as it is also square.
4. SELF EVALUATION OF THE PROGRESS
Progress is good.

Supervisor’s signature

Student’s signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Trimester 3, Year 3	**Study week no.:6**
Student Name & ID: Ch'ng Shin Joe 20ACB0188	
Supervisor: Dr Ooi Boon Yaik	
Project Title: Automated Manual Assembly Station with Computer Vision	

1. WORK DONE
I have completed the crop function, and it now accurately crops the image.
2. WORK TO BE DONE
Adjusted the brightness of the reference image to match that of the target image.
3. PROBLEMS ENCOUNTERED
Matching the brightness did not yield significant improvements.
4. SELF EVALUATION OF THE PROGRESS
Progress is good.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Trimester 3, Year 3	Study week no.: 8
Student Name & ID: Ch'ng Shin Joe 20ACB0188	
Supervisor: Dr Ooi Boon Yaik	
Project Title: Automated Manual Assembly Station with Computer Vision	

1. WORK DONE
Instead of matching the brightness, normalized the brightness using histogram matching.
2. WORK TO BE DONE
Checked on methods for comparing similarity.
3. PROBLEMS ENCOUNTERED
Pixel-by-pixel comparison shows significantly different results at different brightness levels. Discovered that the LED light flickering issue occurs in the school lab.
4. SELF EVALUATION OF THE PROGRESS
Progress is good.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Trimester 3, Year 3	**Study week no.: 10**
Student Name & ID: Ch'ng Shin Joe 20ACB0188	
Supervisor: Dr Ooi Boon Yaik	
Project Title: Automated Manual Assembly Station with Computer Vision	

1. WORK DONE

Tried using SIFT and ORB. ORB yielded better results on color images and showed consistent feature matching.

2. WORK TO BE DONE

Solve the flickering issue.

3. PROBLEMS ENCOUNTERED

Hard to differentiate product using SIFT as it feature on gray scale image.

4. SELF EVALUATION OF THE PROGRESS

Progress is good.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Trimester 3, Year 3	**Study week no.: 12**
Student Name & ID: Ch'ng Shin Joe 20ACB0188	
Supervisor: Dr Ooi Boon Yaik	
Project Title: Automted Manual Assembly Station with Computer Vision	

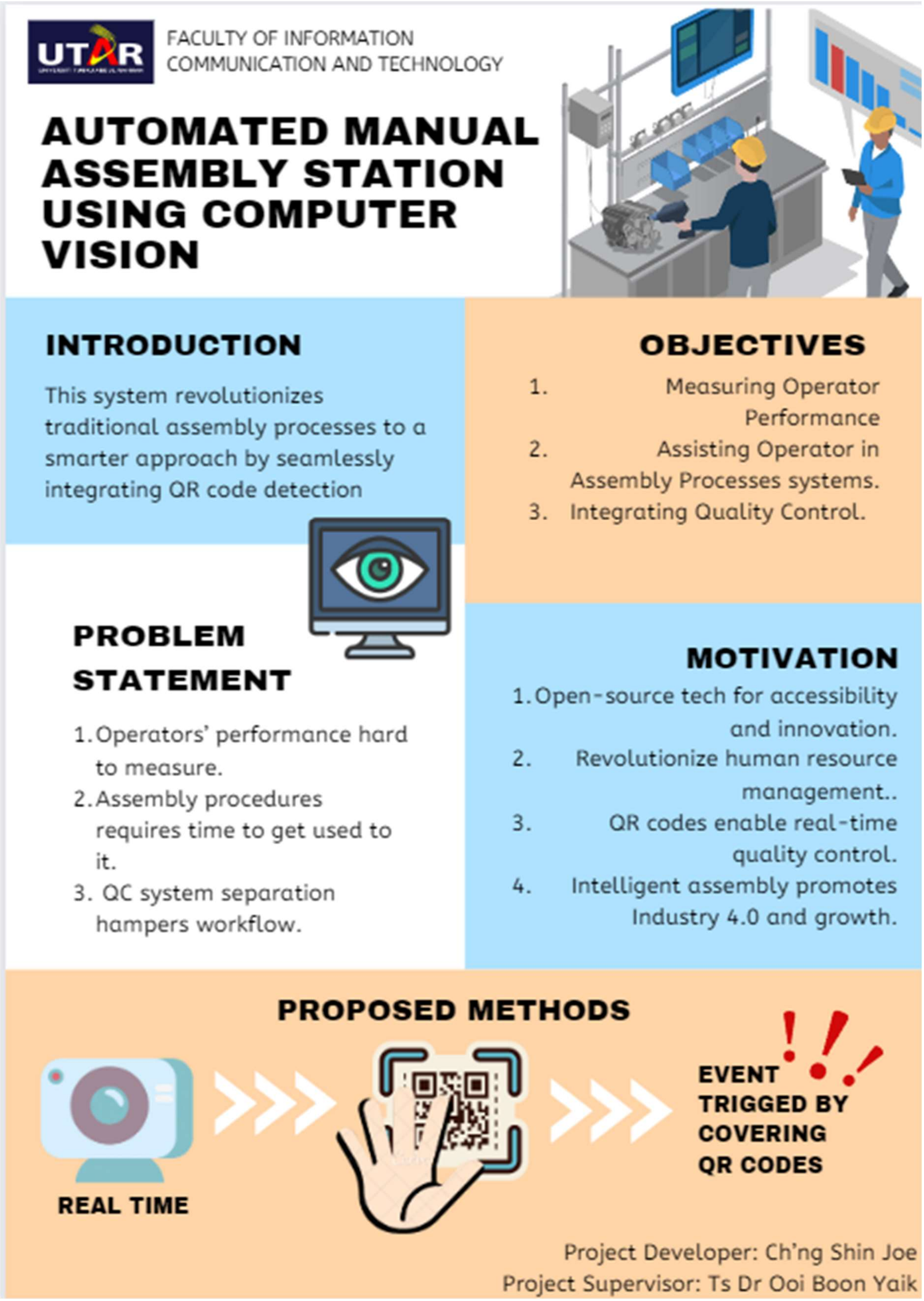
1. WORK DONE Solved the issues last week, added the performance report function, and began writing the report.
2. WORK TO BE DONE Finalise entire code. Finish system testing.
3. PROBLEMS ENCOUNTERED Hard to measure accuracy.
4. SELF EVALUATION OF THE PROGRESS Need to be faster and complete everything.

_________________________ Supervisor's signature

_________________________ Student's signature

APPENDIX

POSTER



Ch'ng Shin Joe FYP2

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