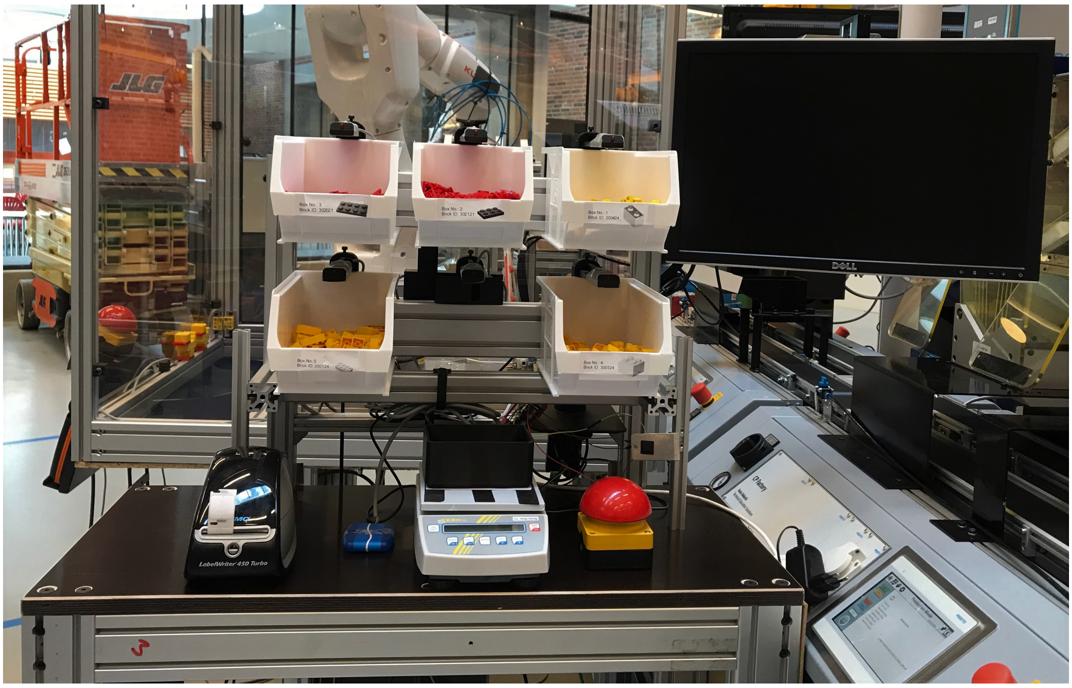
Intelligent Assistive Manual Station in Smart Factory

- Developed an Intelligent Manual Station for the LEGO Smart Factory Demonstrator under MADE Digital WP5.4 -



Master's Thesis Report

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This project is written in Overleaf, the figures are drawn in draw.io. The CAD model is made in Solid Works 2018 © and rendered in PhotoView 360. The UML Sequence diagram is created in Lucidchart and the electrical Schematic diagrams are drawn in fritzing. The project is only published in a digital format.

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AALBORG UNIVERSITY
STUDENT REPORT

Title:
Intelligent Assistive Manual Station in Smart Factory

Theme:
Developed an intelligent manual station for the LEGO Smart Factory Demonstrator under MADE Digital WP5.4.

Project Period:
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Project Group:
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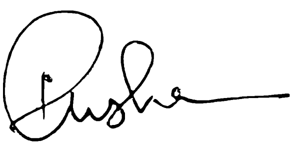

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Abstract:

For providing customer the benefit of personalised product organization requires a flexible and adaptable factory with smart tools and technology showcasing transparency, interoperability and autonomous behaviour through communication between the industrial components and rigorous data exchanges. MADE provides a platform to carry out the research activity related too industry 4.0 and smart factory. This Project is a part of MADE Digital WP5.4 where a smart factory physical layout is developed in collaboration with LEGO group. The smart factory has 4 components as counting machine, cyber physical factory setup, flexible robot and a manual station.
This thesis project focuses on developing a smart assistive manual station which can receive the order from MES and can guide the operator to complete each customised order. It can detect the operator's error and assist the operator to rectify it while working on an operation. The manual station has a raspberry pi, controlling components as visual guide, pick-by-light, weighing scale, printer and RFID reader. An interactive Graphical User Interface was developed using python programming language with PySimple tkinter toolkit. It has the ability to communicate with the MES over OPC/UA communication protocol as OPC/UA client and transmit data to KUKA cloud as OPC/UA server.

Contents

Summary

Customer demands are changing rapidly towards customized product. Industries need to follow the pace of changing demands and incorporate technologies to cater it. Industry 4.0 lays the background to create a smart factory environment with integration of industrial system and digital communication. Factory tend to become smart, flexible and adaptable with rigorous data exchanges and automation. The 9 pillars of Industry 4.0 forms the backbone of 21^{st} century manufacturing industry. MADE Digital initiative provides a platform to work on this revolutionizing technology for the development of Danish manufacturing companies. Within WP5.4, the LEGO smart factory project is one such initiative to develop and demonstrate a physical smart factory to showcase transparency, interoperability and autonomous behaviour. With the help of MADE's academic and industrial partners such as SDU, DTI, Danfoss, KUKA, Siemens etc. along with AAU, a physical factory is established at AAU facility. The physical layout is decided to work on the pre-packing process of LEGO with a flexible robot station, existing counting machine from LEGO, a cyber-physical factory and a smart manual station.

This lays the background for this Thesis project with an objective to design and develop a smart assistive manual station which can guide the operator for each customised order, detect the operator's errors and ensures quality control. It can also communicate with the MES to exchange information related to the process and order. The 3 task expected from the operator to perform on this manual station was used to determine the possible area of errors and detail flow of operations. The system was designed which can guide the operator through user interactive Graphical User Interface to pack the order and detect the error while operator performs the operation thus improving the productive output. Operator is expected to create the customised brick with specific design required by the customer. Smart manual station also ensures correct type of brick with correct quantity is picked by the operator maintaining the quality of the product. Lastly, an RFID tag is attached to each packed bag which contains the order number and it gives access to the customer to track the order location in the value chain.

The station has a Raspberry pi model 3 which controls the individual components i.e. pick-by-light, weighing scale, printer, RFID reader and touch screen. The

Programming code is developed on Python Language and PySimple GUI with tk-inter toolkit is used to create the user interface. The system communicates with the MES over OPC/UA communication protocol where Raspberry Pi act as OPC/UA client. It also trasmits data to KUKA cloud while acting as a OPC/UA server. Collection of data on the cloud is used for data analytic. Lastly to support the operator for opening the bag to fill up the brick, a small automated bag opening tool is designed and developed which can lift the zipper plastic pouch from the bag holder and opens the bag.

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Preface

This is a Master's Thesis project report developed in the 10.semester 'Manufacturing technology' at Aalborg University. The project has been developed during Spring Semester 2019. It is developed by a VT4 student Tushar Agarwal.

Thanks to the AAU project supervisor for the guidance and sharing the knowledge: Casper Schou.

Motivation

The motivation for this project was to work on a new age technology of developing a smart factory. To learn and practice the concepts and tools of Industry 4.0 and build the factory while merging the new and existing industrial systems. In the 21 century, industries are either planning or already researching on the implementation of Industry 4.0. This project gave an hands on experience of using this technology, developing the industrial system and testing it usage physically.

Research activity surrounding the industry 4.0 technologies and results generated from it can help the industries to grow and lead in the competitive market of manufacturing. MADE has created multiple platforms to research and contribute to the Danish manufacturing business. This project gave the platform to perform it in collaboration with LEGO Group. Also with limited understanding of the programming language, this project gave an opportunity to learn and simultaneously implement the learning to test it physically. With the ongoing increase in the usage of automation and robots in the industry has created a debate about the role of humans in the smart factory. This thesis project provides an opinion about incorporating the humans within the smart factory where machines can interact and guide the operator to process the task.

The code developed can be found on GitHub account at **Manual station code**

Reading directions Here, the important information for the reader to understand the report are collected.

Glossary and Abbreviations

Here can be found a list of words used throughout the whole report. It should be understood in the way mentioned in this section to simplify the reading and understand the report as intended.

- SDU - University of Southern Denmark
- DTI - Denmark Technological Institute
- AAU - Aalborg university
- IOT - Internet of Things
- CPS - Cyber Physical System
- OPC/UA - OPC Unified Architecture
- MES - Manufacturing Execution System
- GUI - Graphical User Interface
- CAD - Compter Aided Design
- PLC - Programmable Logic Controller
- BOM - Bill of Material
- Smart Factory Project - LEGO Smart Factory Demonstrator

Appendix

Here are the lists of appendix attached with the project:

A. Schematic diagram of Pick-by-light.

B. Pinout diagram of Raspberry pi.

C. Images of the Developed GUI

Aalborg University, June 2, 2019

Chapter 1

Outline on Industry 4.0 and Smart Factory

This chapter gives an overview on the history of industrial revolution with a brief introduction to Industry 4.0 and the smart factory. Then an outline over the components of Industry 4.0 has been laid out by explaining its 9 pillars. Later in this chapter, a technological framework has been explained which is required to create a smart factory. Lastly, the journey of an organization to transform from a traditional to a smart factory has been displayed.

1.1 History of Industrial Revolution and Introduction to Industry 4.0

There have been many significant industrial revolutions in the manufacturing industries but the four major industrial revolutions have transformed the industries to its core by increasing the productive output and improving the quality of the product to manifolds. Figure 1.1 shows the timeline of the four industrial revolution.

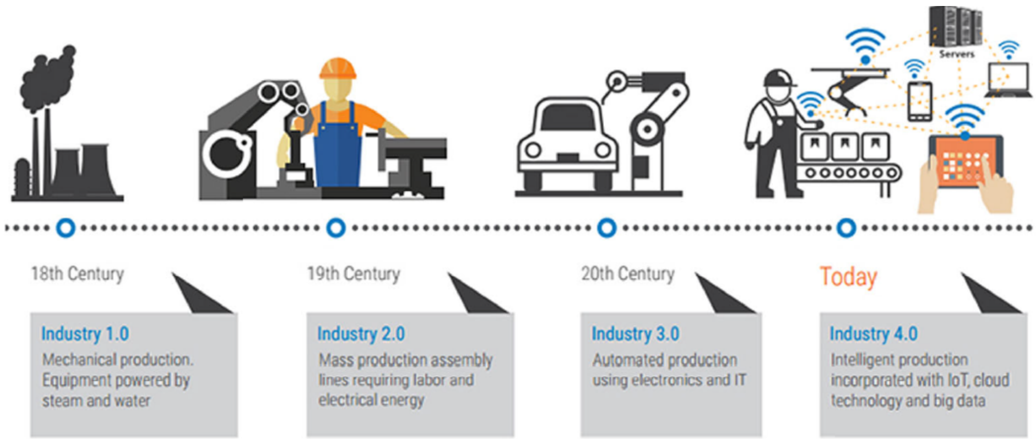


Figure 1.1: Four Industrial Revolutions.[32]

The first revolution took place in the beginning of nineteenth century when the concept of mechanization was introduced for the first time. From textile to coal, all industries were benefited and were highly efficient. The power of steam engine helped to develop a power loom for the cotton industry and acted as a new source of energy for the masses. Process such as forging was also developed in this era to develop a cost efficient way to process the Iron.

Nearly a century later, advancements were made technologically with emergence of new sources of energy such as electricity, gas and oil. This shift from conventional forms of energy lead to innovations in sector such as communication and transportation. Some famous historical creations such as telephone by Alexander Graham Bell, light bulb by Thomas Alva Edison and even air flights by Wright Brothers were made in this era. Innovation by Henry Ford led to setting up of a assembly line for mass production leading to a decrease in cost of the product. This revolution made a large change in the manufacturing industries. [19]

In the late twentieth century, the third industrial revolution started to emerge. This century witnessed the rise of electronics with not just transistors and microprocessor but also the computers. This gave a boost to the production as the usage of robots and automations increased largely in the manufacturing industry. Most of the manual repetitive task was replaced by the robots and automatic machines. [19]

All these industrial revolutions have changed the functioning of the manufacturing industry. But now as the consumer trend is changing rapidly, a demand of another industrial revolutions has been coming up over last few years. Industry 4.0 is the next emerging industrial revolution. Over the years many researchers have explained Industry 4.0 in many different ways . Henning and Johannes explains it as “a new level of value chain organization and management across the lifecycle of products” [18]. According to the Consortium II, it is “the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes" [25]. It is difficult to suggest as which definition explains it the best or what is the actual purpose of this revolution. But with a collective understanding of Industry 4.0 or the fourth industrial revolution it can be summarised as a initiative to create digitization, optimization, customization along with increasing the adaptability and flexibility of the industry through rigorous communication and data exchanges [25]. It has a purpose to integrate communication technologies and industrial technology, and build a smart factory to provide a highly flexible production setup for customised products and services [44].

Industry 4.0 make the production facilities smart, efficient and flexible by equipping the machines with sensors, actuators and autonomous systems, and value added integration within the manufacturing processes. Machine can achieve high level of automation and self optimization capability. Intelligent and digital interconnection of data of raw material acquisition to manufacturing system and product life cycle is utilised by smart factory to achieve adaptability and agility. Within smart factory premises a coordination between the product and service flow is required.[25] In Industry 4.0, manufacturing technologies are upgraded by Cyber-Physical Systems(CPS), Internet of Things(IOT), cloud computing and more. [36]

1.2 Pillars of Industry 4.0

The following section explains about the building blocks of Industry 4.0. Industry 4.0 focuses on intelligent and communicative devices for machine to machine and human to machine interaction. It delivers interoperability, agility, decision making capability, efficiency and even flexibility. Several researchers have described industry 4.0 with 9 building blocks even called as 9 pillars to showcase its framework.[43]

The 9 pillars of Industry 4.0 transformed manufacturing processes into an integrated and automated production setup with optimised data flow. This forms an automated exchange of information between production and businesses. These pillar fulfills the basic need of Industry 4.0 to monitor real time data, track the status and position of the product life cycle, and even holds the instructions to control production processes.[39] The 9 pillars is depicted in figure 1.2

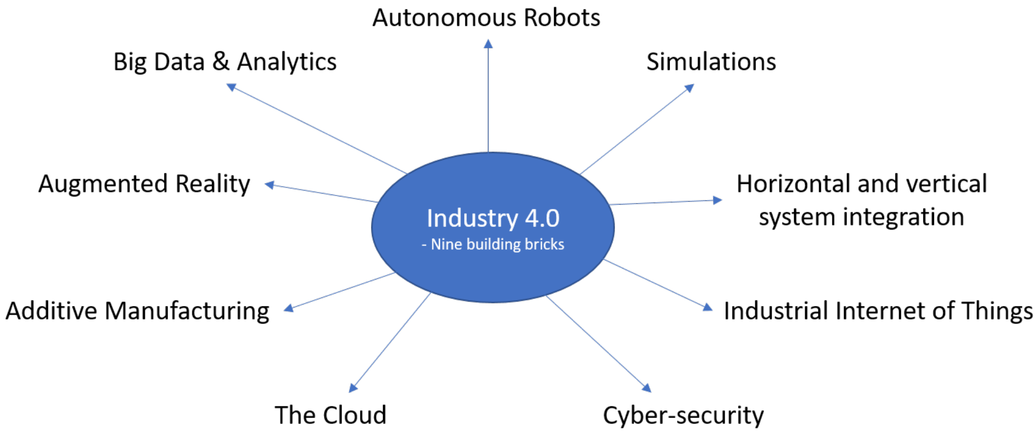


Figure 1.2: The Nine Pillars of Industry 4.0

A. Internet of Things(IOT) - IOT is an interconnected network of various physical objects, machines or systems embedded with various electronics devices as sensor and actuators. It enables object to object communication and gateway to collect and exchange informations.[36] It increases the possibility of object interaction within the existing surrounding conditions by providing the information related to physical conditions of the object or machine. Usage of IOT is not limited to industries where it is termed as Industrial Internet of Things(IIoT) but also in services as Internet of Services. It has applications in smart cities, smart consumer devices, manufacturing industry and health care etc.[39]

B. Big Data Analytics - Big Data Analytics is the comprehensive collection of data from multiple sources as production equipment, resource planning, enterprises and customer management to evaluate and support the decision making capabilities of the organization based on the trends and outcome from the data. Increased use of IOT devices has made data much more easily accessible and in abundance. Large quantity of raw data does not give any sensible output. These collection of data need to be processed to deliver the right information for the right purpose at the right time. Based on advanced analytic techniques, hidden pattern, trend or even correlations can be made clearly visible. [2] Big data can be characterize using 5 dimensions specified as

   (a) Volume - data size.
   (b) Velocity - rapid production, analysis and delivery of data.
   (c) Variety - various types of data or multi dimensional data.
   (d) Veracity - unreliability in data sources.

(e) Vision - meaningful data should be generated.

C. Autonomous Robot - Usage of robots in the manufacturing industries have increased since Industrial revolution 3.0. To adapt to the flexible demand robotic abilities of communicating, control and autonomy can be achieved by using Artificial intelligence(AI) with its controller. AI gives the ability to robot to take decisions without operator interference. They can interact with each other and work safely with humans simultaneously. Robots can even access to the workplace which is not accessible by human operators. [43]

D. Cloud Computing - Cloud based IT infrastructure act as a connection and communicating platform between I4.0 Pillars. As industry 4.0 requires large amount of data sharing, cloud computing can increase the speed of data transfer. All the devices connected through cloud computing can be accessed from any world locations. It can be layered depending on the visibility or access such as public, private or community. In manufacturing industry it can offer usage as web based application access and even computer aided design deployment. The product life-cycle can be connected at a single platform and any user can access the detail ranging from design, manufacturing or services. [23]

E. Simulation - For successful implementation of plant setup or analysing the product before manufacturing, a powerful tool to customise product manufacturing environment is required. Complex conditions with uncertain effects which are difficult to analyse mathematically can be analysed using simulation softwares. Real time data or imagined model is mirrored into a virtual model for better assessment through its behavioural analysis. It allows analysing product, process or system design and helps to make support decision. This tends to decrease the manufacturing cost, development time and increases the product quality. [11]

F. Augmented Reality - With the increase in the usage of Augmented reality(AR), high human performances is aimed to be achieved. It act as powerful tool to provide the needed information of a specific task to the user at the real time by using artificial information with the real object and showcasing a perception to the operator. It combines the real and virtual object on a real environment or align it over each other. It can interact with the operator in 3D at real time. [9]

G. Additive Manufacturing(AM) - Additive Manufacturing is a process of creating a 3D object by deposition of material layer by layer. With high cost and slow lead time conventional manufacturing process are becoming obsolete slowly as the potential of using additive manufacturing are tested in the industry. With AM, prototypes can be created without any value chain element, and thus reducing the design and manufacturing time. Also complex geometries can be manufactured with ease as compared to traditional manufacturing process. [30]

H. Cybersecurity - With increased use of communication platforms, it has become critical to protect the internal industrial information from cyber threats. As a result , a secure and reliable communication is required to remove the vulnerabilities and protect the information from attacks. [22]

I. Horizontal and vertical system integration - Production, engineering, market, suppliers, supply chain and operations all need to be connected for real time data sharing. It can be achieved by two ways: Horizontal Integration and Vertical Integration.
Horizontal Integration correspond to integration of companies which caters through product life cycle. This ensures interoperability of systems and exchanging information.
Vertical Integration is a intra-company network surrounding organizations hierarchy. With vertical integration real time data flow within operations, production and quality control can help to produce customized products. [43]

1.3 Smart Factory Technological Framework

Tools and technologies within Industry 4.0 requires a standardised framework to implement it as a smart factory. All these tools will be placed within this framework. A hierarchical architecture including networks, IOTs, virtualization services, and smart technologies need to be connected together to handle increasing amount of customized customer requirement. Figure 1.3 shows an ideal outlook of a smart factory. These technologies increase flexibility through smart design and development.[36]

- Smart Design - With increase use of augmented reality and virtual reality for design purpose, old design softwares such as computer aided design or computer aided manufacturing can be upgraded to use these technologies with the machines in the real time.

- Smart Monitoring - For operation and scheduling, monitoring is utmost important. For this purpose, various types of sensors are deployed across production which can collect data in the real time.

- Smart Machines - Advanced automated machines and robots can mutually interact with each other, sense the working condition and take the appropriate decision without the interference of human operator. Along with sensors, smart machines can also transfer data to the cloud server for monitoring.

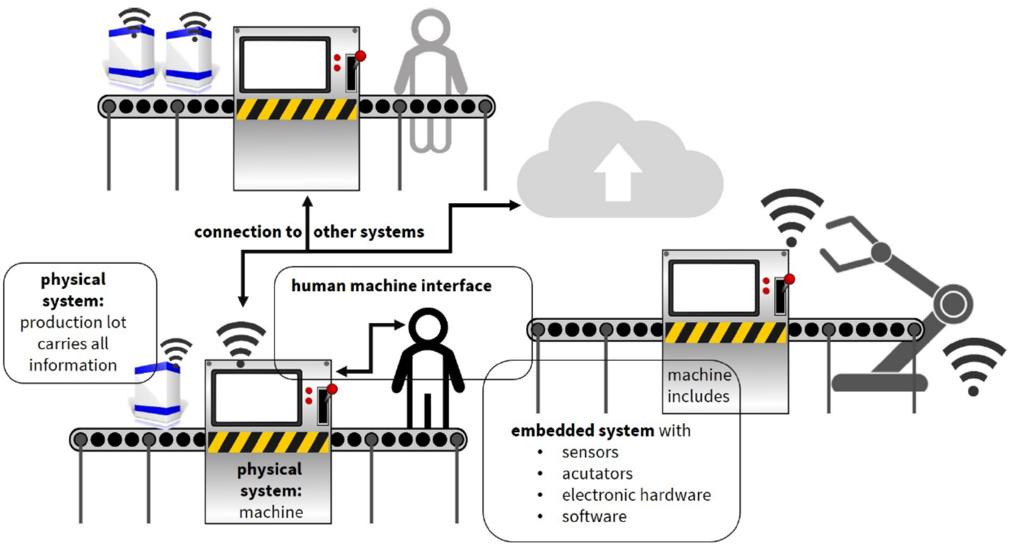


Figure 1.3: Outlook on Smart Factory.[20]

1.3.1 Data Driven factory

In smart factory environment, data plays an important role. With increased use of smart machines and sensors, large amount of raw data is collected which can be used for decision making. Taking right decision at the right time is crucial to succeed in the market. IOT can be a tool to transfer production status to the management in the real time which reduces the time between the occurrence of the problem and taking decisions. These large quantities of raw data need to be analysed. It can provide information related to machines behaviour, maintenance services or even efficiency. Also these data can prevent from machine breakdown as monitoring the data can predict when it goes out of range.[40]

1.3.2 Cyber Physical System (CPS)

Cyber Physical System (CPS) is a decentralized system which can help machine to adapt it behaviour and functionality based on the incoming orders and surrounding operating conditions. It has the capability to reconfigure and restructure its working based on the perceived information. Based on the collected data, finding are derived and machines transform its behaviour to maximize efficiencies. In this setup it is also feasible to monitor the physical process and make informed decision based on the real time information exchange between operators, machines, sensors and forth using "digital twin". It acts like collaboration model where each smart component can take self adaptive decisions. CPS is basically large embedded system that can recognize components , monitor production system and moves components.[24]

1.3.3 Human Machine Collaboration

Using smart technologies such as speech recognition, computer vision or even machine learning in industrial environment can help machines to interact with humans. It is important that both human and machines understand each others behaviour such that they can complement each other while working. With coordinated understanding between human and machines, and using smart technologies machines can support humans in manufacturing sites with production activities. Though safety might be an issue but with machine learning and intelligent control system it can behave as a human while working with a human. As the human-machine interaction can improve in the production site, the gap between operators and automated machines can be fulfilled and irrespective of the position whether robot or a manual station, all can be connected together in industry 4.0 network.[31]

1.4 Digital Transformation from Present Environment into a Smart Surrounding

With increasing trend of Industry 4.0 and fusion of industrial production with information technology, a phenomenon of convergence of physical and virtual space as Cyber-Physical System is taking place. This enables the transformation of traditional factories into smart working environment. It adds real-time capability, interoperability, horizontal-vertical integration of production system to the response of current competitive challenges faced due to volatility of the market demands, short product life cycle and increasing complexity of production processes. [12]

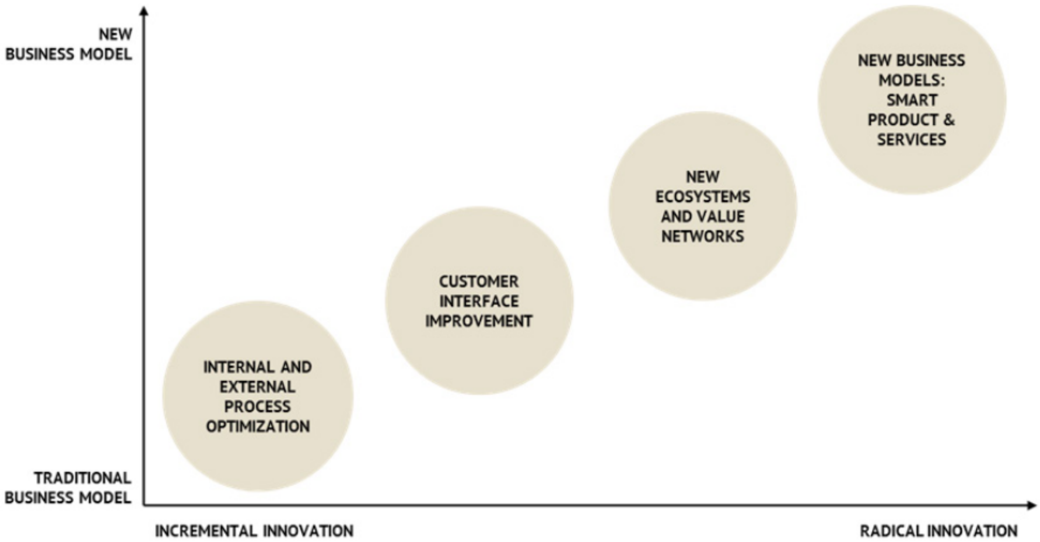


Figure 1.4: Ladder of Digital Transformation.[12]

This digital transformation for manufacturing companies contains four elements. Figure 1.4 shows the relation between the innovation and growth in business model. The degree of innovation starts from few elements of incremental innovation to radical changes of all the elements.

4 Elements of digital transformation [12]:

A. Internal and External Process Optimization - New technologies such as cloud computing, collaborative robots or Big Data are introduced in the traditional setup to optimize it and increase the efficiency towards mass customization. This creates a data driven intelligent manufacturing surrounding with cost optimization due to efficient process.

B. Improving customer interaction - With new technologies , new ways of interaction are created to better understand the customers' needs and demands and fulfilling customer experience. Big Data can be crucial to segment customers data and focus on predictive marketing or digital sales.

C. Upgrading Value chain - Connecting the business stakeholders and share holders to share the uncertainty and prospect technological innovation, and acquiring knowledge from both customers or partners. Real time information collection and sharing of information related to sales , inventory, availability etc.

D. Smart Product and Services - Full implementation of tools and technologies applied earlier for delivering a innovative and smart product or services.

This leads to disrupt the existing market and creating a way for the new generation of products. It provides firms to diversify and expand.

Since industry 4.0 and smart factories, lacks the common definition, the industrial digitalization depends on the needs and work culture adopted in the industry. The feature related the smart factory is an internal issue related to the existing business model. As an example if company expects to achieve the "interoperability" where people related to the factory and smart factories are connected with each other, the present barrier need to be reduced to a network of people from within the factory and external suppliers. To attain this, standardization of the products, system, platforms, tools and protocol among others must be the priority beside focusing on agility or flexibility.[12] With goal of achieving interoperability, a horizontal and vertical integration of value chain are fulfilled. So digital transformation journey requires a consideration of the management and the people of the company to decide the need and expected output by following this digital transformation journey.

Chapter 2

LEGO Smart Factory Model

This chapter explains about the role of MADE for establishing collaborative research projects. Then an overview of smart factory demonstrator designed and developed for LEGO Group is laid out. Lastly, the objective of the smart factory project, its planned architecture and the working methodology will be briefed along with working scope of this thesis project.

2.1 MADE

Manufacturing Academy of Denmark(MADE) launched in 2014, provides a platform for research and development with objective to improve Danish manufacturing companies. Various industries, research communities came together to create an organization which can build bridges between the industries and educational universities. Through various collaborative projects and research activities, new solutions are developed and spread across Danish companies to back them in the global competition. [27]

MADE has several research themes depending on the Danish industries requirements and global demand which focuses on specific area. Some of the fields are as follows:

- Danish Manufacturing companies can quickly introduce new products and production equipment.
- They have the ability to optimize their production processes and value chain.
- The can control and manage complex manufacturing companies with ease. [27]

This research are carried out in work packages. These work packages are a part of MADE platforms. Currently there are 2 different platforms:

A. MADE SPIR - Strategic Platform for Innovation and Research (SPIR) was introduced in 2014. There are 9 different work packages which were carried out within this platform. [27]

   (a) High Speed Product Development.
   (b) Modular Production Platforms for High Speed Ramp-Up.
   (c) 3D Print and New Production Processes.
   (d) Model Based Supply Chain Development.
   (e) Digitalisation of Supply Chain.
   (f) Lifelong Product Customization.
   (g) New Manufacturing Paradigm.
   (h) Hyper Flexible Automation.
   (i) Sensors and Quality Controls.

B. MADE Digital - It is the current MADE platform which was launched in 2017. Based on the research outcome from MADE SPIR, MADE Digital was introduced to accelerate the digital transformation of the manufacturing companies. Similar to German's Industry 4.0, MADE digital was launched but with more suitability to Danish companies. With 3 different focus area i.e. Rapid Product and Production Development, Model Based Production and Complexity Management and 3 different levels i.e Value Chain and Business Systems, Integrated Production Systems and Enabling Technologies, 9 work packages were defined:

   (a) Digital Design.
   (b) Smart Industrial Products.
   (c) Digital Manufacturing Processes.
   (d) Intelligent Supply Chains.
   (e) Smart Factories.
   (f) Digital Assistance Tools.
   (g) Organising Digital Production.
   (h) Automation with Collaborative robot.
   (i) Sensor Technology and Production Data. [27]

This project is based on work package 5 which focuses on Model Based Production and using digitization to create a Integrated Production System.

2.1.1 Work Package 5

Work package 5 aims to design, implement and operate a smart factory by integrating systems and building the digital infrastructure. Production systems are connected and they have the capability to communicate with each other and quickly respond to the changes of the production.

The goal of this work package is defined as to understand the potential impact of smart factory solution, potential barriers in implementation and the mechanism to implement it. The principles for designing a innovative factory solution also need to be identified along with the requirement of suitable competencies.[27]

To achieve the goal of the work package 5 it is divided into 7 part projects out of which this project is based on WP 5.4 i.e the 4th part project which aims to develop smart and integrated factories. The 5 main industrial partners for this part project are Danfoss, Lego, Linak, Eltronic and KUKA.

WP 5.4

Within WP 5.4, digital technologies are connected into a production work environment to build smart factories. There are different smart factory demonstration which need to be carried out at participating partners workspace i.e. (Linak, Lego, Danfoss, Eltronic, Danish Technological Institute (DTI), University of Southern Denmark (SDU), Aalborg University (AAU)). This work package will provide a hands on experience to integrate digital technologies and assess the potential benefit of it.

The goal of this WP 5.4 is to understand the benefit of digital technologies within manufacturing companies and procedure to integrate it within existing or new production environment.

For the successfully achieving the goal, 3 sub task are defined as the metrics for the completion of WP 5.4 . The first is to design a physical smart factory demonstrator which showcase transparency, interoperability and autonomous behaviour. Second task is to develop a method to design an innovative smart factory and the last is to define methods to asses the system maturity level. [27]

This thesis project is a part of WP 5.4 where a smart factory demonstrator is designed and developed for LEGO Group. It is estimated that the smart factory demonstrator project will be carried out for 4-6 months.

2.2 LEGO Group

A privately held family owned Danish toy production company with headquarter at Billund, Denmark. Founded by Ole Kirk Kristiansen in 1932, it is one of the leading manufacturers of play material. Playing Toy mostly consists of interlocking plastic bricks, gears, figurines known as mini-figures and many others. From object, vehicle to buildings these bricks can be assembled in many variants. [17]

Ever since its foundation, the motto of the group says as 'Only the best is good enough'. Being widely used by children, high quality and safe products are delivered by LEGO group. Being able to create by innumerable ways of assembling the bricks and figures, the large variants of bricks gives exponentially large options to think creatively.[17]

Despite variation in the design and purpose, each new pieces remains compatible to the existing pieces. Two pieces must be engaged and disassembled easily. High precision design with limited tolerance make it possible to do so. LEGO has state of art manufacturing technology to produce the designed parts. Over the years, LEGO group have expanded and upgraded to modern day manufacturing technologies to deliver high quality, high variant product with limited time frame. With this developing mindset, LEGO is planning to showcase the fourth generation of industrial revolution within their domain.

With this initial wave of Industry 4.0 in the manufacturing industry, LEGO group is leading ahead to understand the possibility of implementation of smart factory setup with some of its existing machines and see the path leading to Industry 4.0.

2.3 LEGO Smart Factory Demonstrator

As mentioned in section 2.1, based on WP 5.4, a smart Factory setup is designed and developed. As Aalborg University (AAU) being one of the project partner for this work package, a joint collaborative project is initiated for LEGO Group with an objective of experimenting open innovation and agile development, engaging technologies, system integrators and the end users together in a combined framework, and to evaluate the outcomes.

The aim of this demonstrator is to build a small LEGO pre-packaging production line which included features as customized product where customer can select the product which need to be packed. Other elements include a reconfigurable robot, a reconfigurable production line, digital twin model, IoT, a smart manual station and an OPC/UA communication.

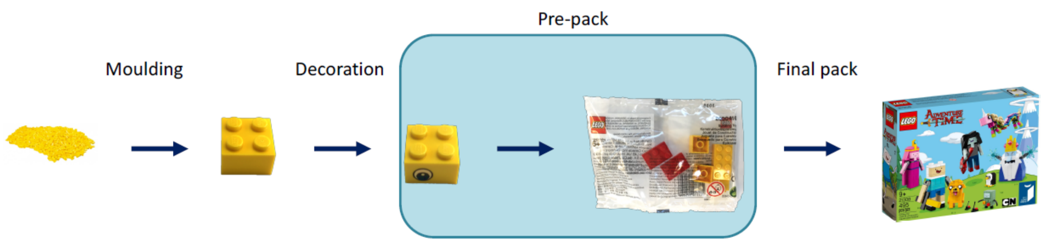


Figure 2.1: Current Process Flow at LEGO

Figure 2.1 shows the outline of the current process flow which takes place at LEGO. The smart factory demonstrator will be designed for pre-pack process. Current production setup is a mass production setup which is highly automated but can configure just one product and produces in bulk. The demo setup is aimed to have mass personalization setup which is highly flexible and can produce personalised products through digital technologies.

As mentioned in section 2.1 there are several other project partners both academic and industrial involved in this project. As AAU has the role of developing the smart factory setup at their site, others members i.e. DTI, SDU, KUKA, Siemens and Eltronic have their own role defined structurally to contribute directly or indirectly. They will be contributing in this project based on their capabilities and conditions. Specific roles of these members are defined in subsection 2.3.1 .

2.3.1 Proposed Setup

Using the existing Festo Cyber physical system module present at AAU in a Festo designed smart factory setup following physical layout is proposed as shown in figure 2.2

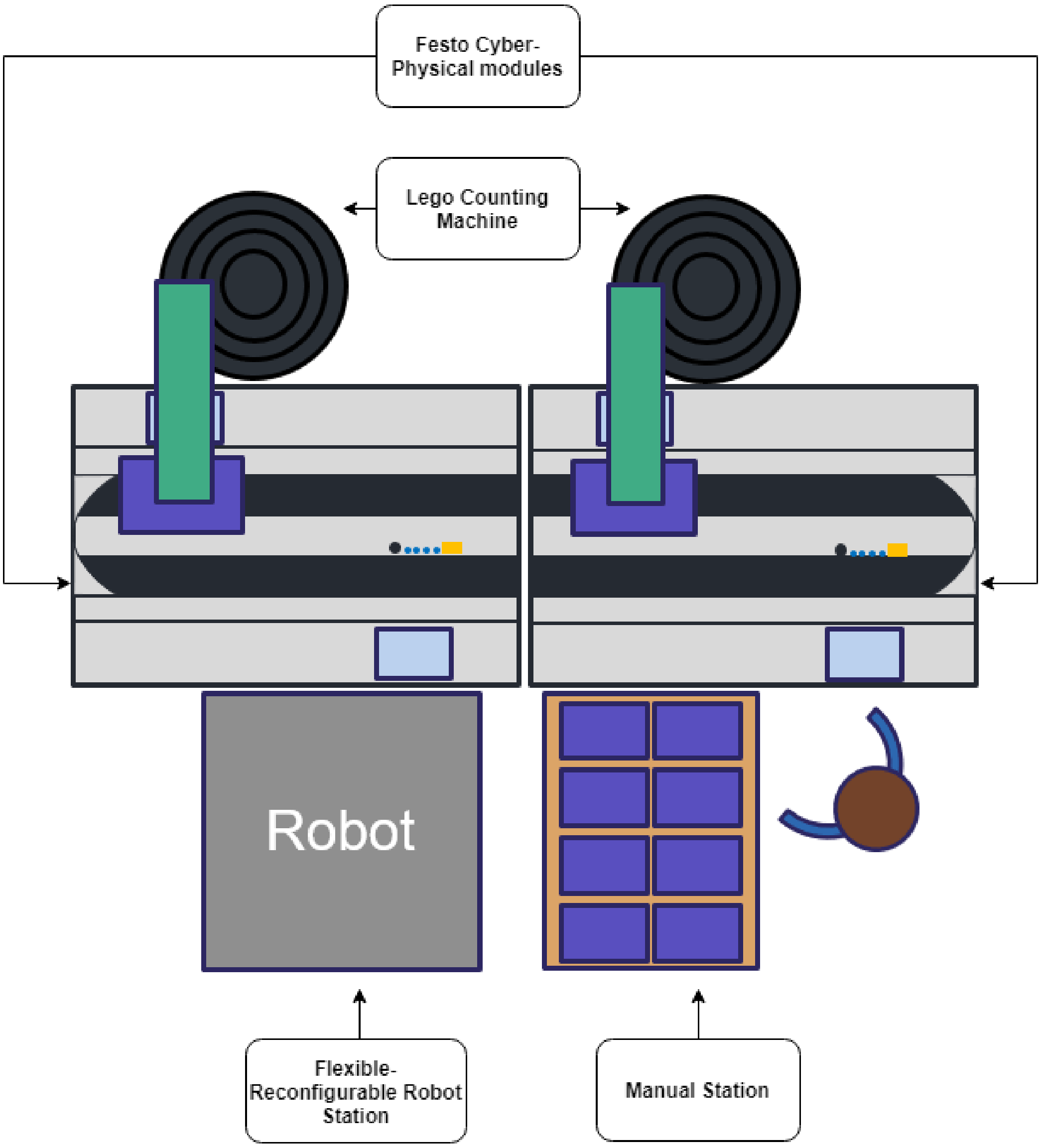


Figure 2.2: Proposed Layout of the Smart Factory Setup

It consist of:

A. 2 Festo CP modules i.e. 4 stations

B. 2 LEGO counting machines

C. Reconfigurable-flexible robot station

D. Manual station

Figure 2.3 shows the expected flow where customer will choose the desired product to be packed from the configurator and the smart factory will create the pre-pack order and dispatch it to the customer. Task flow for this scenario is:

A. selecting Design

B. Customizing Content

C. Personalised design brick

D. send order to MES/ERP

E. Order planning and execution

F. Order tracking by customer

G. Customer received order.

H. Meanwhile, Data is transmitted to the Cloud for analytics and digital twin is used to estimate the capacity needs.

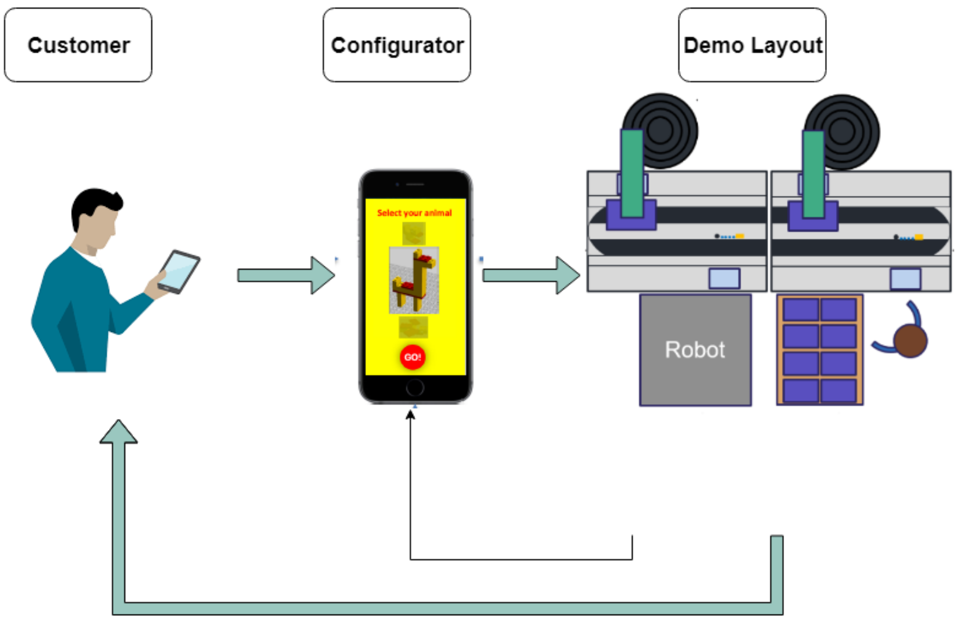


Figure 2.3: Expected Scenario with Smart Factory Demo

With the help of others existing MADE partners a large System Architecture was designed covering the major elements of Industry 4.0.

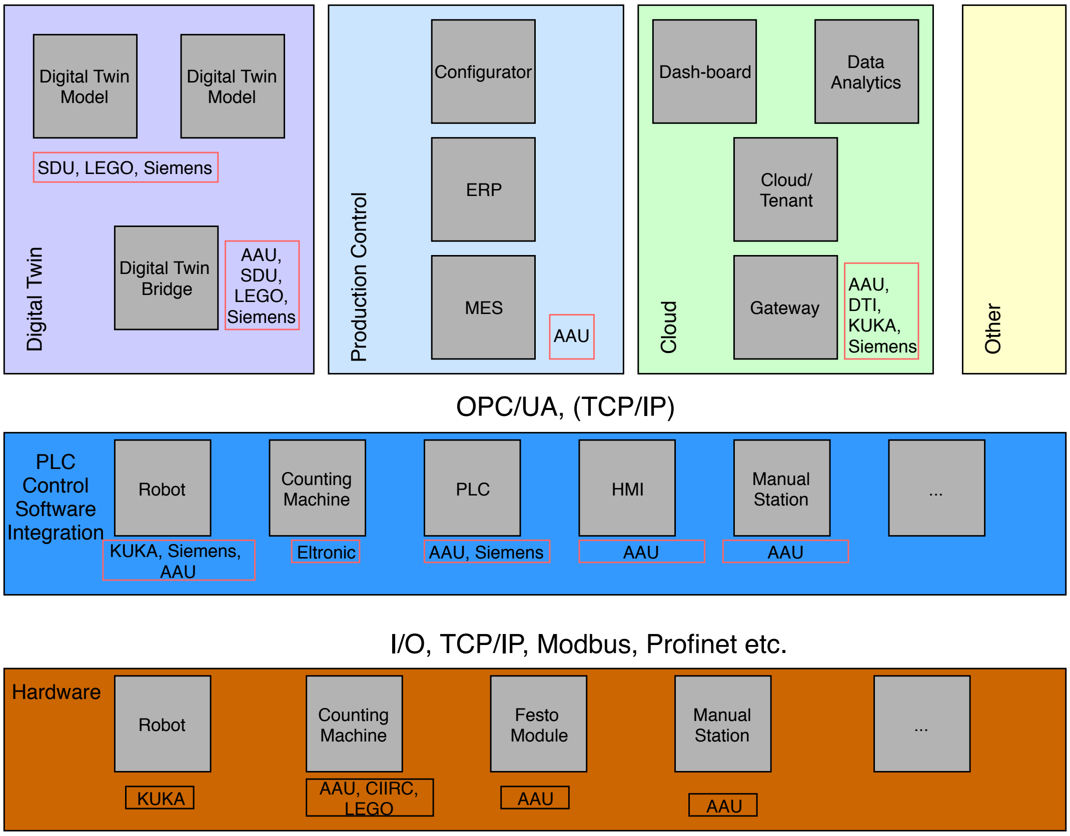


Figure 2.4: Proposed System Architecture

Figure 2.4 shows the components of the system architecture with the respective contributor or group of contributor in the smart factory project. Beside AAU other academic contributor i.e DTI and SDU have a role to work on IoT and Digital twins respectively. While KUKA will be providing its Cloud Server for analytics and support setup of KUKA Smart production tenant. Siemens has a role to provide PLC for a reconfigurable robot and counting machines, and to deliver support in digital twin model to SDU. CIIRC along with LEGO provides support on counting machine and Eltronic will be responsible to interface and control counting machines. Here, LEGO Kladno a part of LEGO group is the project owner while LEGO Billund is the pre-pack process owner.

The system architecture can be divided into 3 horizontal layers i.e. intelligent, control and hardware.

Intelligent Layer

The top intelligent layer contains 3 individual parallel vertical layer as Production control, Digital Twin and Cloud.

Production Control Layer

The Production Control layer contains the configurator connected to Enterprise Resource Planning (ERP) module which connects to Manufacturing execution System (MES).

- Configurator - A software tool which allows customer to design and select their customised order based on their own requirements and prescribed solution space.
- Enterprise Resource Planning(ERP) - A business management software to integrate various offices of a business either, sales, inventory, production, marketing or even finance. Common platform to share data related to individual departments and taking decisions collaboratively.[4]
- Manufacturing Execution System (MES) - A computerized tool to track information of production related data such as inventory, finished goods, production process and understanding the working condition of the production setup. Data collected can be used to analyse the setup and improve production efficiency. It act as link between ERP and PLC or any other production control.[4]

Digital Twin Layer

The other vertical layer in intelligent layer is digital twin with a digital model and a bridge to connect digital model with the physical world. Digital twin is known as a virtual model of a physical world which can be simulated to understand the real world physical setup behaviour based on the sensed data from enabling technologies. It uses artificial intelligence, software analytics to create live digital simulation and can be used to control the physical world and understand the working condition or behaviour of the physical setup. [5] It can be divided into two stages:

- Digital twin model - A digital model of physical real world such as, machines, layout, people and devices. The model includes both static and dynamic movement and can be used as representation of product life cycle within manufacturing.
- Digital twin bridge - A common connection point to connect the model with the physical developed model. A tool or software platform to connect it through a communication package.

Cloud Layer

The last vertical layer in intelligent layer is Cloud. It contains 4 components divided into 3 levels:

- Dashboard - a front end user interface visible to user which showcase all the data.
- Data Analytics - Using the data collected in the cloud, analytic is performed to extract considerable useful information from raw data. These information can be used for the improvement of the process.
- Cloud - A virtual platform for hosting the data seamlessly. This data is not located at a physical server present within the premises. Cloud server make the data easy accessible through the globe. [23]
- Gateway - A key integration element between the platform generating data and cloud server. It is responsible to transfer data from technological level to higher level in the system architecture. [23]

Control Layer

The control layer forms the second layer of the architecture. All the components are controlled by an individual controller mostly PLC except manual station where single board computer i.e Beaglebone or Raspberry pi is used. Each Festo module has their own PLC fitted from Festo while PLC for KUKA robot was provided by the Siemens. This controls the behaviour of their respective hardware. Each controller either PLC or single board computer can communicate through OPC/UA communication platform. OCP/UA communication protocol is used for all the communication medium either between controller-controller or MES-controller. Detail of OPC/UA is explained in subsection 7.3.3

Hardware Layer

The final bottom layer includes where all the hardware components including, robot, manual station, Festo module and counting machine are placed.

- Counting Machine - A special machine used by LEGO to count and deliver required number of bricks in the packaging process but of a particular size.
- Robot - A reconfigurable robot capable to adjust its work ability based on the customised order received from MES or feedback from the cyber-physical system.
- Manual station - To increase product variants in the package, instead of using multiple process setup a manual station with all the odd shape bricks which is not handled either by existing robot or counting machine can be packed. Also some processes can’t be automated and need to be done by manual operator or atleast for the initial stages of the implementation, manual station

is used. But this setup need to be technologically advanced to get integrated into industry 4.0 platform with other smart components present in factory layout.

- Festo Module - Reconfigurable production line which adds flexibility to the production process. Each module is connected through transport module i.e. a set of conveyor belt running parallel which act as a carrier to transport box for transporting order from one station to another.

2.4 Working methodology

When developing a complicated system design, a project management methodology plays a crucial role in the success of the project. Traditional methodology are not suitable for non repeatable and empirical processes[6]. As traditional method follows a linear approach, it is assumed that if a phase is completed it need not to be reviewed again. If the sudden changes in the project arises by the client, traditional approach can't adapt to the changes and can fully block the project or it can make the team start all over again.

Agile on the other hand reduces this risk of adaptability by focusing on short iterations of clearly defined goals and focuses on regular interaction between the stakeholders of the project. This make the project team capable to adapt rapidly to unpredictable challenges faced while working on a project. Agile has multiple variations in which it can be applied in a project such as Scrum, adaptive or dynamic. In this project Scrum model will be used.

2.4.1 Scrum Model

As working on new innovative technology without the pre-defined idea of the final result, Scrum model helps to iteratively develop it with the team consisting of Product Owner, Scrum Master and members.

Product Owner

The Product Owner defines and prioritize the output as being the eventual user of the product which in the smart factory project is the LEGO group.

Scrum Master

The Scrum Master who are the Post-docs related to the smart factory project present at AAU, manages the working ability of the development team together. The team is a group of cross functional people who are self organized and responsible to develop the project. These team involves various members including individual student or a group of student working on a specific part of the project along with the staff members from academic partners and industrial partners . Total task of the project can be divided into 4 activities as kickoff, planning, sprint and review. [8]

Kickoff Phase

During kickoff phase the team defines the overall goal of the project and all the major elements to be implemented in the project. During this phase, the aim of the smart factory project was decided as "To understand the possibility of implementation of smart factory setup with some of its existing machines of LEGO and see the path leading to Industry 4.0" with major element as "customized product where customer can select the product to be packed, Collaborative robot, reconfigurable production line, digital twin, IoT, smart manual station".

Planning Phase

In the planning phase, the outcome of each iteration is decided where team decides the elements which need to be implemented during each iteration and the overall goal of an iteration. Since the duration of each iteration is of one month, this planning takes place before the start of every new iteration. Also during this, it is intended to roughly forecast the time requirement for implementation of each task to achieve the goal of the iteration.[10]

Sprint and Review Phase

As mentioned, different to traditional project each phase runs for a month long iteration in scrum methodology called "sprint" in which the functionality of the project is expanded within the domain of decided goal. Finally at the end of each iteration, functionality created during the sprint is demonstrated to the product owner for review. For this project, a video demo of the updated setup is made on 1st of every month for the Lego team and other project partners to showcase the improvement made in the project as compared to previous demos.

Using this methodology, roles are clearly defined within a team, giving a sense of ownership to each member and the developed features can be tested in short cycles. Also detailed communication lead to a organized team working effectively thus increasing the productivity.[10] On the task allotted to AAU, multiple small teams or individuals are working collectively towards the implementation of the project.

2.5 Manual Station

Within the defined set of components allotted to AAU and based on the previous competences, it was chosen to work towards the setting up of manual Station for this thesis project. Manual station is expected to be a smart station which can interact with the operator and assist the operator with the process flow to handle the bricks and pack the order.

Chapter 3

Objective and Requirements

This chapters defines the objective of this thesis project and the potential requirements expected to achieve the laid objective.

3.1 Objective

The partial objective from the overall aim of the setup mentioned in section 2.3 can be formulated for the aim of this Thesis project as:

"To design and develop a smart assistive manual station which can guide the operator for each customised order received from MES, detect the operator's errors and to communicate with the MES to exchange information about the packaging and order."

3.2 Functional Requirements

This section list the requirement of functional capabilities which manual station is expected to perform as to fulfill the defined objective. These objectives will be explained in detail in the chapter 5.

A. Mechanical setup to hold various kind of LEGO bricks.

B. Receiving information from MES for each customised order.

C. Display information to the operator

D. System to detect the error by an operator.

E. Pack the order.

F. Transmit data to the KUKA cloud server.

Chapter 4

Existing Smart Manual Station Solutions

Similar to the requirements mentioned in chapter 3, there are few existing solutions which are designed and developed by companies working in the research purpose of Industry 4.0. Some of these solutions are developed with the research intentions and some for industrial application.

4.1 Solutions for Research Background

The solutions explained in this section were developed for research purposes.

Augmented Reality by motionEAP Project

The project focuses on usage of Augmented reality tool in the production workplace to make an interactive scenario between operator and digital machines. The project aims to increase the efficiency and to assist the operator in production process using motion detection and In-Situ Projection.[14]. It consists of a top mounted RGB and depth camera as well as a projector. The RGB and depth camera is used to detect the parts and motion of the operator's hand, and the projector displays the animation and instructions which need to be followed by an operator to perform the task.[33]

Plant@Hand by Fraunhofer Institute for Computer Graphics Research (IGD)

The System was developed to provide mobile information to the operator for the task where greater mobility and flexibility is expected for the assembly process. As a setup, a mobile workshop trolley is used which contains tools and materials in the drawers, and all the hardware and software components are built within the trolley. It uses a cognitive architecture to analyse specific task using the mounted sensors and make decisions to assist the operator for that task. The behavioural outcome of the operator helps to improve the cognitive decision making capability.[1] The mobile display mounted on the trolley is used to display guided information to the operator. The focus area of this research remains as to provide correct explanation and instruction automatically at a given situation by bridging the knowledge gap [33].

Manual Working Station of SmartFactory^{KL}

This prototype is based on a modular and flexible architecture which can be integrated into a automated production line. It consist of sensors, augmented reality solutions, 3D camera for tracking the process and visual tools. Using RFID, information related to parts and assembly instruction can be retrieved directly from incoming part. After performing process task, RFID tag is updated. Sensors equipped 3D camera allows the tracking of the production process and operators movement, and the instructions are displayed to the operator using visual display such as tablets.[42]

4.2 Solutions for Industrial Application

The solutions explained in this section were developed for commercial industrial applications. Figure 4.1 displays the 4 systems explained below.

ActiveAssist Assistant System by Bosch Rexroth

A configurable software based platform that support operator with information and guide them through assembly process. Thus making it capable to assemble a multi variant product. It has a web based software with standardised interface. It consists of a touch screen, 3D cameras for hand tracking and quality control, projectors, pick-to-light and a RFID. It is connected to web based configurator which creates the guidelines for the process based on the order information. It can communicate with MES/ERP systems.[33]

Der Assistent from Ulixes

It consist of multi-sensor camera, sensors and projector to display information related to process. A compact design with all the component fitted to a projector size setup which can be mounted on any manual station. The software enables the operator to provide information about the stored component and work flow for assembling task. Based on the information stored, it can guide even the new operator to handle the system.[33]

Cubu:S by Schnaithmann Maschinenbau AG

With in-situ projection, it can project task and steps on the table. Pick-by-light system highlights the component which need to be handled for the assembly step. If the operator picks from the incorrect box a visual sign displays.[33]

Schlauer Klaus by OPTIMUM Data Management solutions

An image processing software which focuses on image recognition. After image processing data is displayed on the monitor for the operator. Setup consist of a camera which captures the image and it can transfer data to ERP directly.[33]

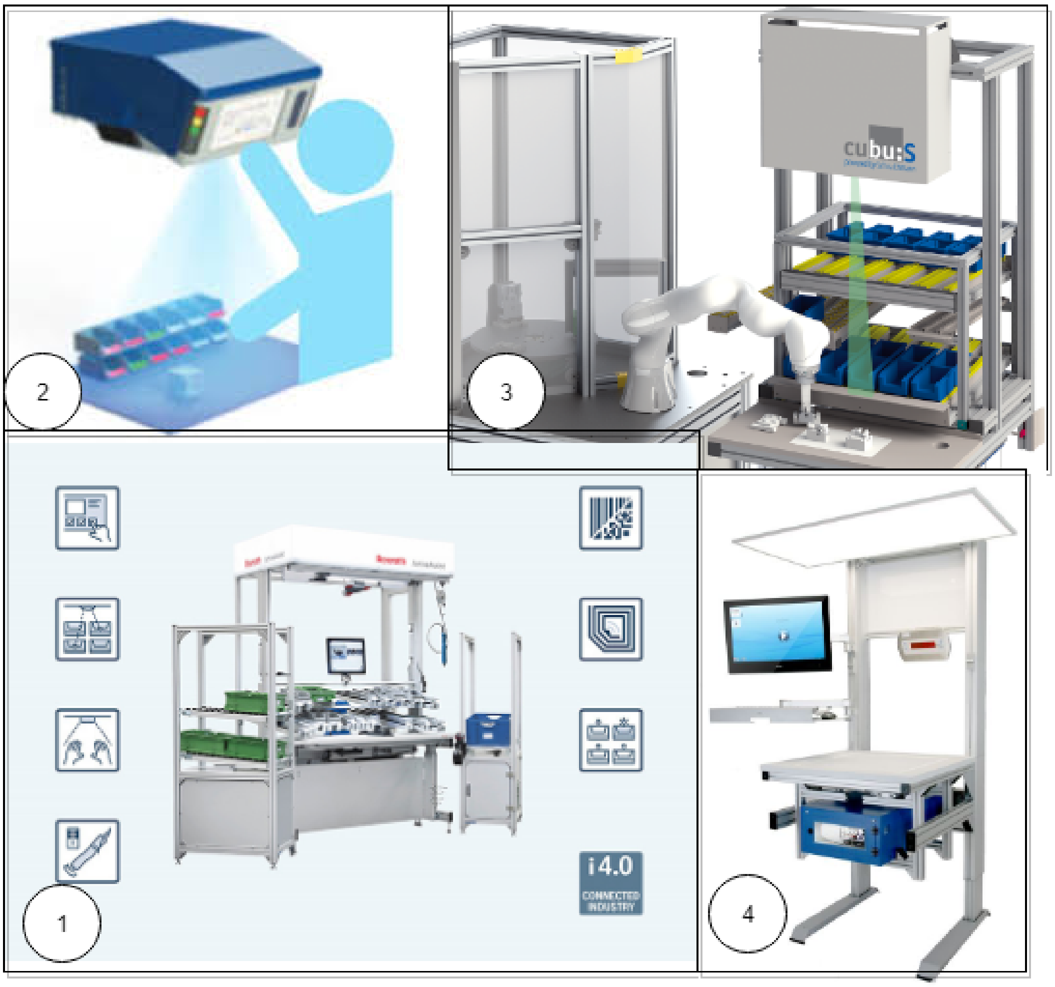


Figure 4.1: Assistive system designed for Industrial Application. 1.[7], 2.[16], 3.[15], 4.[41]

4.3 Aspects of Smart Assistive Manual Station

Based on these manual station developed either for research background or industrial applications a common features can be deduced into six aspects which is expected to be implemented in a smart manual station.

A. Guided Work Instructions: An aspect of an intelligent system is to guide the operator during the process. To provide information about the part, process and tools to perform the task with minimal error. This information can be provided to the operator by using visual display or verbal guidance.

B. Detection of Information Related to Worker: For optimal guidance to the operator it is important to detect the movement of the operator and their working flow. It can also detect the error caused by an operator and guide them to prevent it. Also it can differentiate between the skilled operator or a new operator based on the ease of doing process and number of errors.

C. Recognition of Components and Products: It is important for intelligent system to have the knowledge of the setup on which operator operates. It make it easier to generate work plan. Also, system information can help to locate the location of the materials and tools.

D. Flexible Integration with the Production: System should be capable enough to be attached to the extended production line or any other production line working with same process without the need of the specialised engineer.

E. Work Plan Generation: For each customised order created in the configurator by the customer and received in the MES, a system should be intelligent enough to create a work plan/instruction for the operator. These plan must include information related to the type of material, quantity and operation sequence. It need to be created automatically using data from MES.

Chapter 5

Expected Process at Manual Station

The broad aspects of smart manual station explained in section 4.3 need to be deconstructed into list of tools which is required in the setup. But to create a list of tools, it is important to understand the process task and operations in detail. Based on the objective and requirement of the system as mentioned in chapter 3, detailed process task is defined. Operator is expected to perform this task in order to create the order and complete the packing process on LEGO smart factory setup.

5.1 Task, Problem and Possible Solution

5.1.1 Task

A detailed task of the system can be defined as "MES receives the order information from the configurator. Since MES can communicate with all the individual stations either manual, robot or counting, it checks the availability of the station and carrier box to start the process. A carrier box is the box which moves from station to station on conveyor belt to collect the bricks and process the order. When the carrier arrives at manual station, Operator receives the order information for required bricks either customised or plain which need to be added to the box and/or pack the content of the box."

Table 5.1 shows the different type of bricks which can be chosen from the configurator with their respective dimensions, colour and brick ID. The last brick i.e. 30032401 showcase the customisation of bricks which need to be made at the manual station if required by the order. Currently, design is expected to be printed on a paper and sticked on the brick 300324.

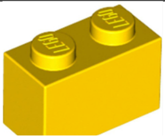
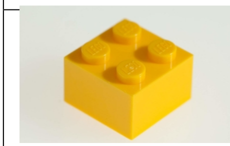
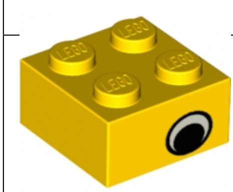
Brick	Brick ID	Dimension	Colour
	300424	1 X 2	Yellow
	300324	2 X 2	Yellow
	300124	2 X 4	Yellow
	302121	2 X 3	Red
	302021	2 X 4	Red
	30032401	4 X 2	Decorated - Yellow

Table 5.1: LEGO Bricks Handled by the Manual Station

5.1.2 Sub Tasks

For clear depiction of task it is divided into 3 individual sub tasks with step operations also shown in figure 5.1. Either one or all, any number of sub task need to be performed by the operator
Sub Task 1: Create customised brick.

A. Print the Design required for customised brick.

B. Pick the correct type of brick on which it need to be printed in correct quantity.

C. Paste the sticker on the brick

D. Place the bricks in the box

Sub Task 2: Add normal bricks.

A. Pick correct type of brick in correct quantity.

B. Place the bricks in the box.

Sub Task 3: Pack the order.

A. Pick the box full of bricks.

B. Empty it in a bag.

C. Place the box back and let the carrier release.

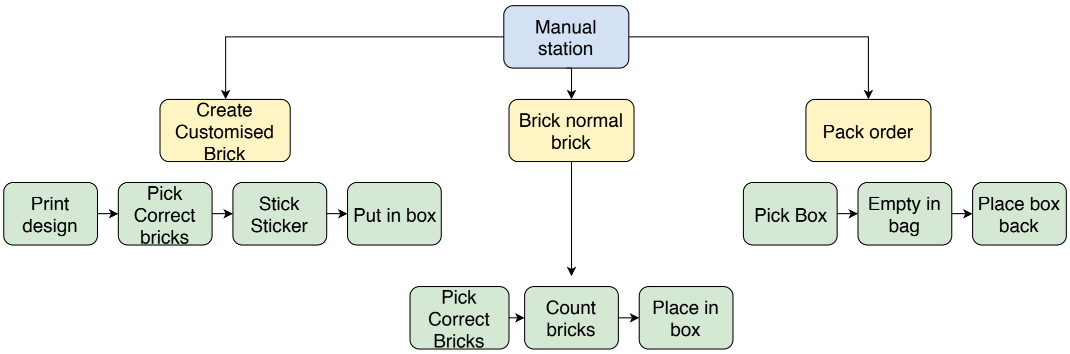


Figure 5.1: Flow of task which can be carried out by Manual Station

5.1.3 Possible List of Errors

While working on these task, some error might occur which need to be considered to detect and eliminate while developing the setup. Following is the list of errors which need to be checked by setup. Setup need to be intelligent enough to detect these while working and guide the operator for correct process.
Task 1:

A. Is sticker printed?

B. Is the Design-Order Combination correct?

C. Is sticker Pasted?

D. Is the Quantity of customised bricks correct?

E. Is the brick-design combination correct?

F. Is the Brick placed in correct box?

G. Does the picked brick is put in the box by the operator?

Task 2:

A. Is the Quantity of bricks correct?

B. Is the type of bricks correct?

C. Is the brick-Order Combination correct?

D. Is the Brick placed in correct box?

E. Does the picked brick is put in the box by the operator?

Task 3:

A. Is all the bricks from the bag packed in bag?

B. Is box placed back on the conveyor?

C. Is box placed in right carrier?

D. Is the bag from right order?

E. How to track the bag later in the process?

5.1.4 Tools for Smart Manual Station

Considering the aspects of Smart Assistive Manual Station mentioned in section 4.3 and these set of task, sub tasks, operations and possible errors from the operator on this manual station, a list of tools is created. These tools are divided into 3 categories based on level of requirement in the setup ranging from "Must Have" to " Can be". Table 5.2 shows the list of tools required in the smart manual station.

	Level of Requirements		
Tools	Must Have	Good if exist	Can be
Information Guide to Operator	X		
Printer	X		
Brick Location	X		
Quantity Check	X		
Check brick type		X	
Locate bricks in the process (on table or in box)		X	
Locate box in the process (on table, on carrier or in hand)		X	
Operator movement			X
Locate brick in bag			X
Track packed bag		X	

Table 5.2: List of tools with level of requirements

Based on this list of tools and its level of requirement a root level architecture of the setup will be designed along with the mechanical hardware.

Chapter 6

Design and Development

Based on the category of tools mentioned in table 5.2, the whole setup need to be designed. This chapter deals with the designing of the system architecture for the manual station and the selection process of each tool mechanism.

6.1 Root Level Architecture

While designing the setup, beside mechanical hardware, root level structure design of the controller with necessary electronic hardware and communication protocol need to be created.

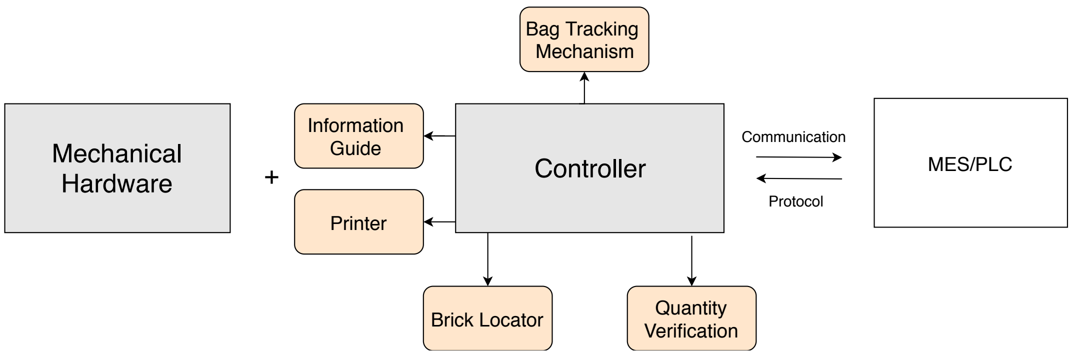


Figure 6.1: Root Level Architecture of the manual Station

Figure 6.1 shows the basic architecture which will be used to design the manual station. Out of 10 tools listed in table 5.2, 5 are included in the setup. Time constraint of the project was the crucial factor to decide the set of tools which will be implemented in the setup along with the level of requirements. With the root level architecture determined for the setup, Individual components need to be selected.

6.2 Controller and Components

As the individual mechanisms are selected a detailed System architecture can be determined to lay out the final hardware design of the manual station. In the following subsections selection of mechanism for each tool will be discussed.

6.2.1 Information Guide

As an intelligent station, it is important to guide the operator through the process at every steps. For this, some kind of aid mechanism either visual or audio is required.

Efficiency of operator by using the audio aid highly depends on the clarity of the sound, surrounding sounds and pronunciation of the voice. Due to one or more these factors, it might become problematic for the operator to work on the manual station and be highly efficient. Also it might take a long time for the operator to familiarize with the setup with sound communication. Though it might be suitable for the visually challenged operator. In this project it is assumed that there won't be any visually challenged operator.

On the other hand visual aid does not depend on any of these factors except the clarity of the displayed information which can be controlled with suitable use of hardware. It also gives time to operator to read the information on its own speed. There are multiple ways to display information. Few of them are:

A. Mounted Display - Screen or monitor can be a medium to display the generated information related to the work flow. It is an easy tool for the operator to operate and interact with not much training required for the same. It can be mounted on the manual station at a suitable viewing distance from the operator. It can communicate with the controller through HDMI port.

B. Projector based display - Similar to display technology, projector is another method to display the information where instead of using a screen, a flat light colour surface on the table can be used to project information from the projector. Colour of the table and level of tidiness might cause some clarity issues.

C. Head Mounted Display (HMD) or Augmented Reality Glasses - One of the most advanced tool to merge virtual information with the reality can be created with Augmented Reality. This device is worn over the head with display area over the eyes to see the information. As the operator moves around the surrounding, each related information is displayed as overlapping to the real condition. The major problem is that it can stressed the operator for wearing HMD over a long period of time and concentrating on displayed information with minimal freedom of movement.

For this project it is chosen to use the mounted display i.e either screen or monitor with a touch screen to make it interactive for the operator.

6.2.2 Printer

In the order there might be some bricks which requires customised design. These designs need to be printed on the plain available bricks. LEGO has special laser printing technology to create this customised bricks in mass volume. For manual station it is not viable to setup a large printing setup just to create customised bricks. So an option of Label printer is chosen to print the design on small stickers and paste it on the bricks. It is used to signify the usage of customised brick while creating an order.

In this project, DYMO LabelWriter 450 is used as shown in figure 6.2. It is a compact size professional label printer which uses thermal printing technology. With thermal printing, the cost of ink toner gets eliminate and even compact design can be printed. It can communicate with controller over the USB port. [13] Beside this, a colour label printer Brother VC-500W was also considered but due to printing size constraint i.e. small size as 13mm x 25mm and driver compatibility DYMO's printer was chosen.

Figure 6.2: Label Printer for Customised Bricks [13]

6.2.3 Brick Locator

For operator to pick the correct type of brick as displayed in the guided information, it is crucial to highlight the box containing the bricks by some method. A projector display can be used project the light on the box from which the operator need to pick the brick to complete the order.

Another way is to use a pick-by-light mechanism. As the name suggest, By using this mechanism operator can pick the brick from the required box with the help of a lightning device. A light device as small LED can be mounted on the box and it can glow to highlight the box. In this project a small 3D printed stick is used for each box containing bricks. In these stick, a LED light and a motion sensor is mounted. The light will guide the operator towards the selected box and motion sensor will detect whether the operator has put their hands in the correct box or not. If the operator put their hand in the incorrect box despite the glowing LED, it can warn the operator through the mounted display and/or other medium. Development of pick-by-light mechanism will be explained in following section.

6.2.4 Quantity Verification

Considering that the operator has picked correct type of brick with the help of pick-by-light mechanism mentioned in subsection 6.2.3, its now turn to verify the quantity of picked brick.

A. Web Camera and Image Processing - Image processing techniques and image generated from the web cam can be used to count the bricks present in the viewing angle of the camera. A camera can be placed on the top of table below which the picked bricks need to be placed. As the picked bricks are in the viewing angle of the camera, it captures an image and processes the image with image processing techniques. Using this it can detect the quantity of the coloured bricks present in its frame and can even detect the type of the brick. So using this technique, it can help to verify not only the quantity but also the type of brick picked by an operator.
   If instead of a web camera, a depth camera or a 3D camera is used along with the image processing techniques then along with the quantity check and type check of the bricks, the motion of the operator can also be tracked for each process. It can be used to detect the operator's error at each step of the process and can make the manual station highly efficient.

B. Weight check - A digital weighing scale can be used to detect the weight of the bricks. As each brick has its own weight which doesn't fluctuate in a room environmental condition, it can be compared to the weight of brick picked by the operator. It can be easily used to detect the quantity of the brick by comparing the weight of the picked brick with the expected weight of the brick. The only problem which lies with this method is that it is unable to detect the type of bricks. There can be a brick which has a same weight as another brick and weighing scale can't differentiate between the two.

Using an image processing processing technique on a real time captured image requires a lot more time and resources as specified for the completion of this thesis project. It can be implemented if either there have been more number of candidates working on this project or it is the only requirement expected from this project in the specified time period. Due to this constraints it is chosen to implement weight check method and it is assumed that the operator will pick the correct type of brick with the help of pick-by-light mechanism mentioned in subsection 6.2.3. In this Project, a digital weighing scale by KERN & Sohn GmbH is used, as shown in figure 6.3. It communicate with the manual station's controller through serial communication protocol using USB port. Table 6.1 shows the technical information of the weighing scale.

Model Number	Weighing Range	Readability	Stabilization Time
KERN KB 10K0.05N	0,000 g - 10,000 g	0.05g	3s

Table 6.1: Detail of Weighing Scale [21]

Figure 6.3: Digital Weighing Scale used in Manual Station [21]

6.2.5 Bag Tracking Mechanism

Once all the brick is picked and packed in a bag, there should be way to track the package in the value chain and verify the order information. For this purpose, a mechanism widely available in the market i.e. an QR sticker or a RFID sticker can be used. These sticker can stick to each bag and it can store the information related to the packaged order. In this way a unique QR code or RFID code can be generated for each order and by scanning the code in the value chain, package can be tracked.

It is chosen to use RFID-RC522 (MF-RC522) reader. The reader and the tags communicate with 13.6MHz electromagnetic field. Tags with these frequency range are known as High Frequency Range tags. Tags working on any other frequency can't communicate with RFID reader. It uses Serial Peripheral Interface (SPI) communication protocol to communicate with manual station controller. Figure 6.4 show the RFID-RC522 Reader.

Figure 6.4: RFID Reader

6.2.6 Controller for Manual Station

In this thesis, Raspberry Pi is used for controlling the manual station. It is a System on Chip (SoC) hardware developed by Raspberry Pi Foundation. It is credit card sized computer developed with a purpose of spreading basic computer science knowledge in the developing countries. It is a low cost device commonly used for automation purposes. It has a ARM compatible central processing unit with an on chip graphic card. Also Raspberry Pi is an open source hardware.[35] Open source hardware can be modified for multiple application purposes as it has no dependency over the vendor of any kind.[38] As there are multiple pre built libraries available for Raspberry Pi, time can be saved on designing the software instead of building it from bottom up. This time and resources can be used to increase the complexity and features of the application instead of just building the platform.

Raspberry Pi has multiple variants depending on the different processing unit and other technical specification, few of them are Raspberry Pi 3, Raspberry Pi 2 and Raspberry Pi 0 etc.

Board –>	Raspberry Pi 3	Raspberry Pi 2	Raspberry Pi 0
Processor	64Bit Quad Core	32Bit Quad Core	32Bit Single Core
Speed	1.2 GHz	900 MHz	1GHz
Memory	1 GB SDRAM @ 400MHz	1 GB SDRAM @ 400MHz	512 MB SDRAM @ 400MHz
USB 2.0	4 Ports	4 Ports	1 micro USB Port
GPIO	40 pins	40 pins	HAT compatible 40 pin
Ethernet	Yes	Yes	No
Wifi	Built In	No	No
HDMI	Full HDMI Port	Full HDMI Port	mini HDMI

Table 6.2: Specification Raspberry Pi Boards [35]

Table 6.2 compares the technical specification of 3 types of Raspberry Pi boards. It can be seen that though the memory between Raspberry Pi 2 and Raspberry Pi 3 is same, Raspberry Pi 3 has the fastest processor among three. Since printer and weighing scale requires a USB port connection to communicate with the controller, a HDMI port for the monitor and an Ethernet cable for MES communication, it was chosen to use Raspberry Pi 3. Figure 6.5 shows the Raspberry Pi 3 model.

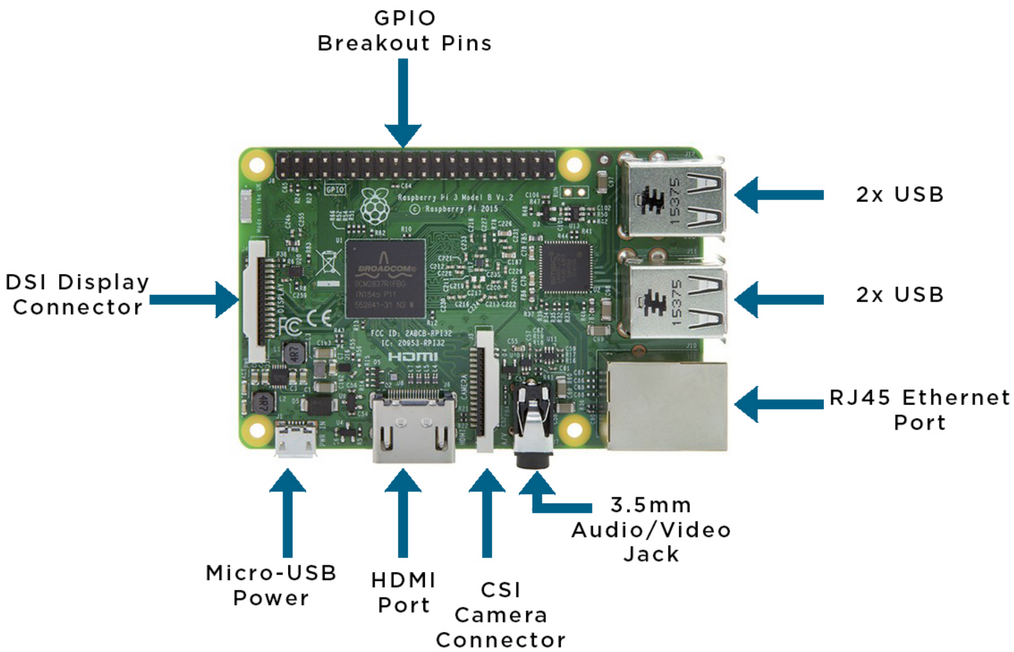


Figure 6.5: Raspberry Pi Model 3 [35]

6.3 Development of pick-by-light

The pick-by-light mechanism mentioned in 6.2.3 has an aim to guide the operator towards correct brick through a source of light and verify it using a motion sensor.

6.3.1 Construction

The frame of the pick-by-light mechanism will be the centered part of the whole manual station since it will hold all types of bricks in different boxes. The frame is constructed of T-slot Aluminum profile . T-slot profile can increase the modularity of the setup as other components of the manual station can be connected to T-slots easily and frame can also be expanded in the future by adding additional T-slots profiles. The design of the frame has a dual advantage. Depending on the space on the table in the manual station, the pick-by-light frame can either be placed on the table or it can be fastened to the frame of the table. Figure 6.6 shows the frame of pick-by-light mechanism.

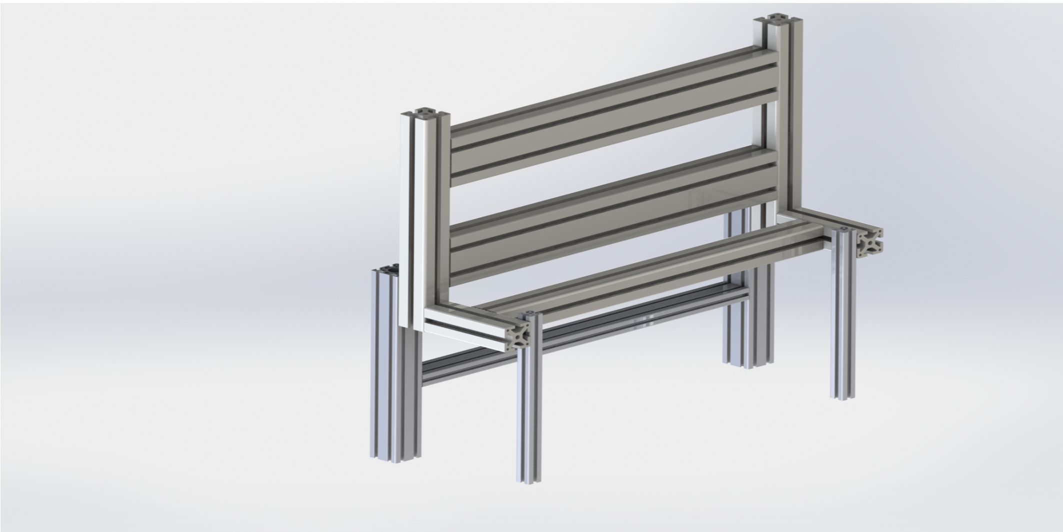


Figure 6.6: Frame of Pick-by-Light

Box for Bricks

Box which act as storage for each type of bricks in the pick-by-light mechanism is a standard size container available at Danish Supermarkets, as seen in figure 6.7. Instead of designing a custom size box for each brick, it was chosen to use a standard size container as it is easily available in the market, it will be cheap to use and can save a resources as compared to designing a custom one. Table 6.3 shows the dimension and name of the box used.

Name	Size	Colour
RS PRO Plastic Stackable Storage	130mm x 150mm x 240mm	White

Table 6.3: Detail of Storage Box [34]

Figure 6.7: Storage boxes in Pick-By-Light [34]

Brackets

A 3D printed bracket is used which is designed in a way that a box containing bricks which has a trailing edge on its back side can be hanged and sensors can be mounted on it. It is designed in two parts with one as a bracket which is mounted on the T-Slot frame and box is hanged on it, and another as a sensor stick which contains LED and a motion sensor which is fastened into the bracket. Figure 6.8 and 6.9 shows bracket and sensor stick respectively.

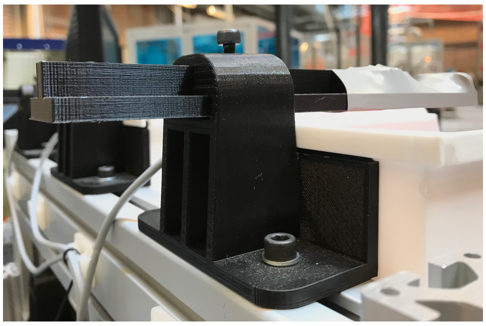


Figure 6.8: Bracket to Handle Storage Box

Figure 6.9: Sensor Stick Containing LED and Motion Sensor

As there are 5 types of bricks which need to be handled by an operator currently, so 5 of these brackets are required with 5 sets of sticks each containing a LED and a motion sensor. Figure 6.10 shows the assembled pick-by-light system with sensors, frame and box.

Figure 6.10: Pick-by-Light System

6.3.2 Controller and Sensors for Pick–by-Light

Controller

Controller of the pick-by-light is required to communicate and receive an information from the controller of the manual station about the type of brick as an ID number which is required for the package and send the output back to the controller of the manual station whether the operator has picked the correct brick or not. Based on the received information about the brick as an ID number the pick-by-light controller activates the LED and the motion sensor checks if the operator has inserted their hand in the correct box. Figure 6.11 shows the UML Sequence diagram for the pick-by-light mechanism based on which programming code is created.

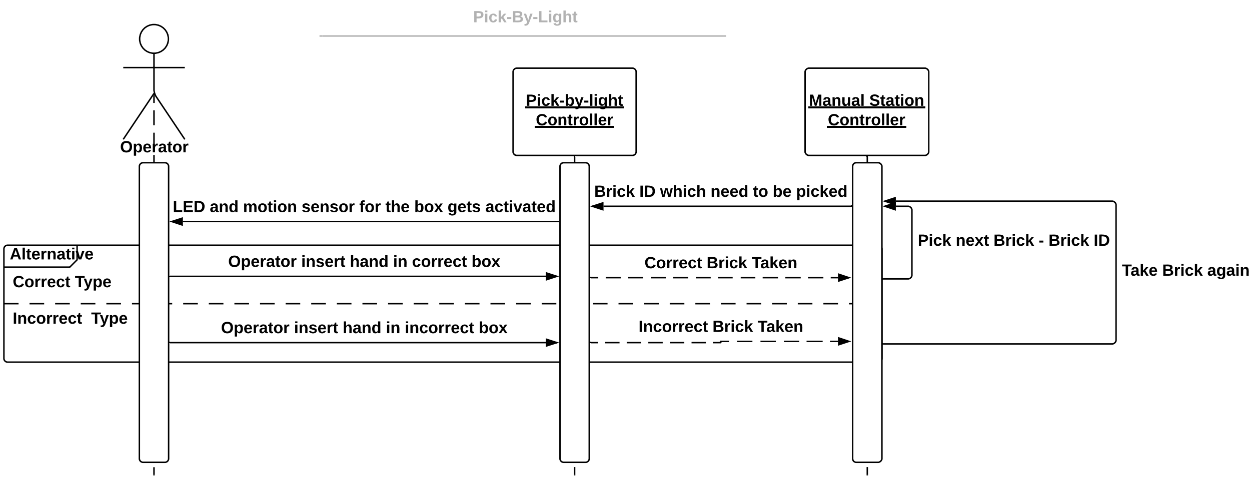


Figure 6.11: UML Sequence Diagram for Pick-by-Light Mechanism

To control this, it is chosen to use an Arduino MEGA 2560 Rev3 as shown in figure 6.12. It is a microprocessor based controller which has 54 digital I/O pins. It has a USB ports for serial communication which can also be used to power the board. It has an operating voltage of 5V and a flash memory to store the code is 256 KB. [3] As manual station has its own controller, Arduino of pick-by-light can be connected to it so it does not require any additional power supply.

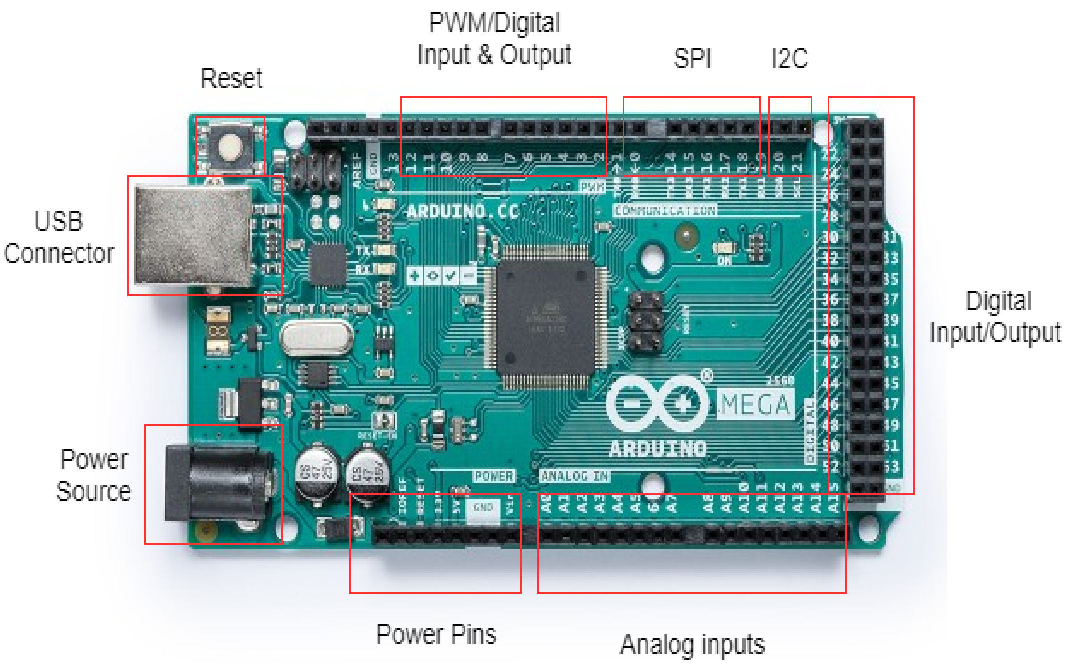


Figure 6.12: Controller for Pick-By-Light [3]

LED and Sensor

A red coloured LED light is used which can work on the power supply from the Arduino board. A HC-SR501 PIR sensor is used as a motion sensor. It is an infrared based sensing technology which has LHI778 probe. It has a sensing range of less than 120 degree and 7 meters, and a recommended input voltage is +5v which can be supplied through Arduino board. Even the sensitivity can be controller using the knob on the sensor.[37]. Appendix A shows the schematic diagram of Arduino with LED and PIR.

6.4 Final System Architecture with Controller and Components

Based on the chosen components of manual station a final layout is designed. Beside mechanical hardware and communication network with MES/PLC a Raspberry Pi controller with chosen component (as shown in figure 6.13) will be integrated together to develop a functional smart manual station.

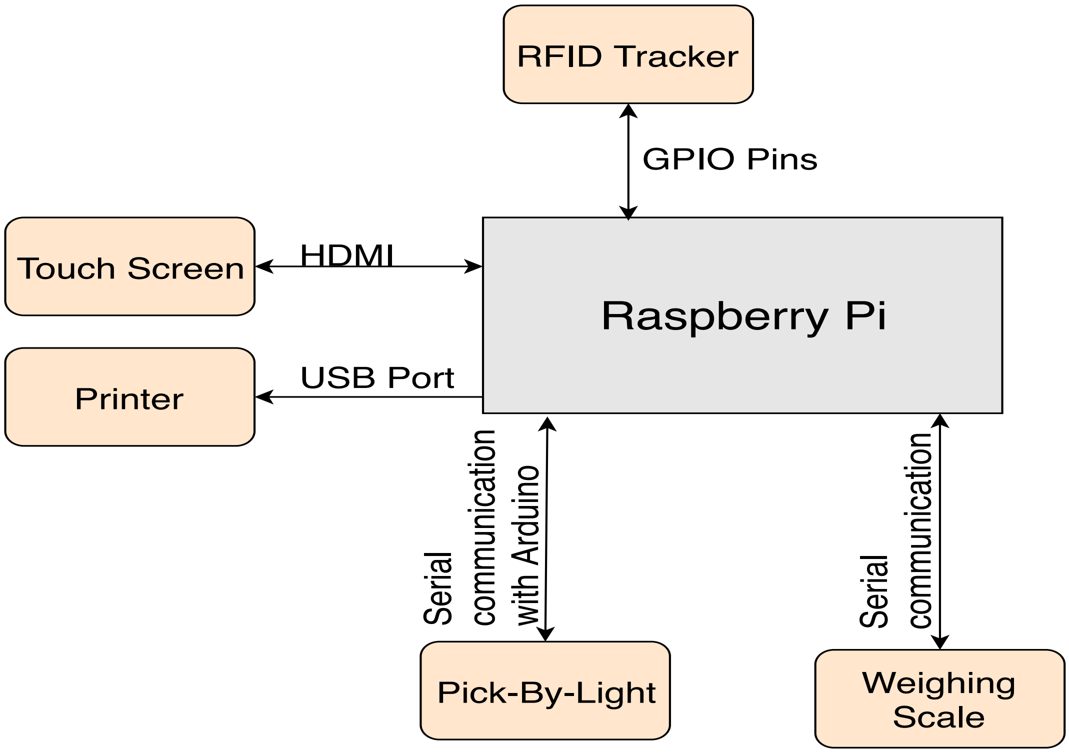


Figure 6.13: Final Components of the Manual Station

Chapter 7

Development

Based on the process task mentioned in chapter 5 and selected components mentioned in chapter 6, the Mechanical hardware for the smart manual station need to be designed.

7.1 Mechanical Hardware

The smart manual station will consist of a table on which all the components will be placed or mounted. The dimension of the table is taken as 110cm X 50cm. Components such a Pick-by-light structure developed earlier as mentioned in chapter 6.3, a digital weighing scale mentioned in subsection 6.2.4, a printer mentioned in subsection 6.2.2 and a screen as mentioned in subsection 6.2.1 mounted on pick-by-light is placed on the table. Figure 7.1 is the CAD model of the mechanical structure of the manual station will all the components installed.

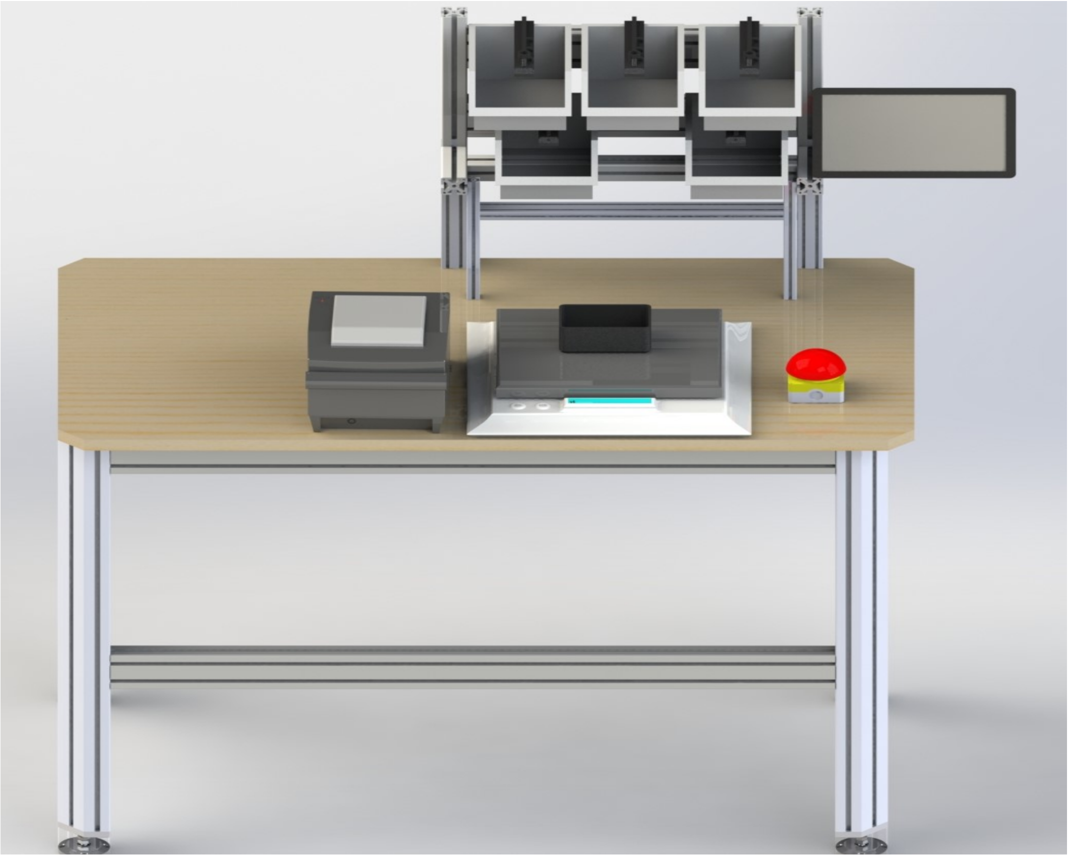


Figure 7.1: Mechanical structure of Manual Station

7.2 Setting up a Controller

As mentioned in section 6.2.6, controller of a manual station is Raspberry Pi. This section deals with initiating the controller and usage of libraries and drivers for this thesis project.

To initialize the Raspberry Pi few hardwares are required such as a SD card, 5V Power adapter micro USB, a monitor with HDMI cable, a mouse, a keyboard and an Ethernet cable. SD card is the memory stick where all the softwares and operating system will be installed.

7.2.1 OS, Drivers and Libraries

The Raspbian is the official Operating System(OS) for Raspberry Pi which can be installed either directly or through NOOBS. NOOBS is an easy operating system installer designed to ease out the complexity of installing an operating system. Being an open source hardware various types of Operating System such as windows

10 IoT core or UBUNTU Core are also compatible with Raspberry Pi which are an image file created for a Raspberry Pi from an original OS .[28] In this project NOOBS was used to install Raspbian OS.

Being a Linux based platform which can support multiple coding languages, Python was used to program the controller. Being a new user of programming language, Python can act as a primary level programming structure which can host multiple functionality including designing of Graphical user interface(GUI) which was an important feature to create in this thesis project.

CUPS

As Raspberry Pi does not work by just using a printer USB connection, an intermediate application is required which can act as a printer management software on the Raspberry Pi computer to manage the printing task. Common Unix Printing System (CUPS) is a Unix-like operating system which makes the host computer a printer server. CUPS acts a bridge between the computer and the printing system. CUPS receives the print information and convert this information into a format compatible with the printer and direct the print job towards a USB or a networked printer. CUPS contains a list of printer's models with a compatible driver for each of them.

Graphical User Interface

Graphical User Interface (GUI) is an interactive dashboard visible to operator which consist of multiple icons, buttons and/or menus. GUI ease the task of an operator to use an operating system and perform task without using any programming language. Each of these icons acts as program working in the background which was developed by the GUI developer while operator can perform the task by just clicking these icons. In Python programming there are multiple toolkit available to design and create a GUI. Some of them are:

- tkinter - It is an open source library which is most widely used for GUI development in Python. It a robust and matured library to use as its has 25 basic widgets and other tools which are customizable as a module package instead of string commands. The tkinter is the only toolkit which is a part of Python's standard IDLE environment while others are a third party extensions. Despite having an easy structure, it has multiple features which can be used to create a GUI. Beside widgets it also features 3D visualization, animation and text. [26]

- PyQt - It is Python version of Qt toolkit initially developed by Nokia. It is a library packed with features for GUI but it is complex and stringent as compared to tkinter. There are various classes and multiple methods and functions in it. But a major setback of using PyQt is that it is not an open source toolkit creating a limited environment to use. [26]

Despite tkinter being a simpler version of toolkit to create a GUI, there are multiple string of codes required to design it. PySimple GUI is simplest form of package wrapped around either tkinter or Qt. It makes the package a compressed version of these toolkits but retaining their existing features. A feature can be used in PySimple GUI by just coding one or two line of codes for which it will auto generate a string of codes in tkinter or Qt in the background. Due to its simplest architecture, it is widely used by the beginners. For this thesis project, PySimple GUI is used with tkinter toolkit. The images from the developed GUI can be found in Appendix C.

7.3 Connection and Communication protocol

7.3.1 Connection with Components

As mentioned in subsection 6.2.5 for bag tracking feature RFID-RC522 (MF-RC522) reader is used. Figure 7.2 shows the schematic diagram with Raspberry Pi, RFID Reader, a button and an LED. LED is used to highlights the active state of the button. Beside this components, a monitor will be connected to the the HDMI port, and a printer, weighing scale and a pick-by-light's arduino will be connected using a USB port with a Raspberry Pi. Pinout Diagram of Raspberry Pi and can be be found in Appendix B.

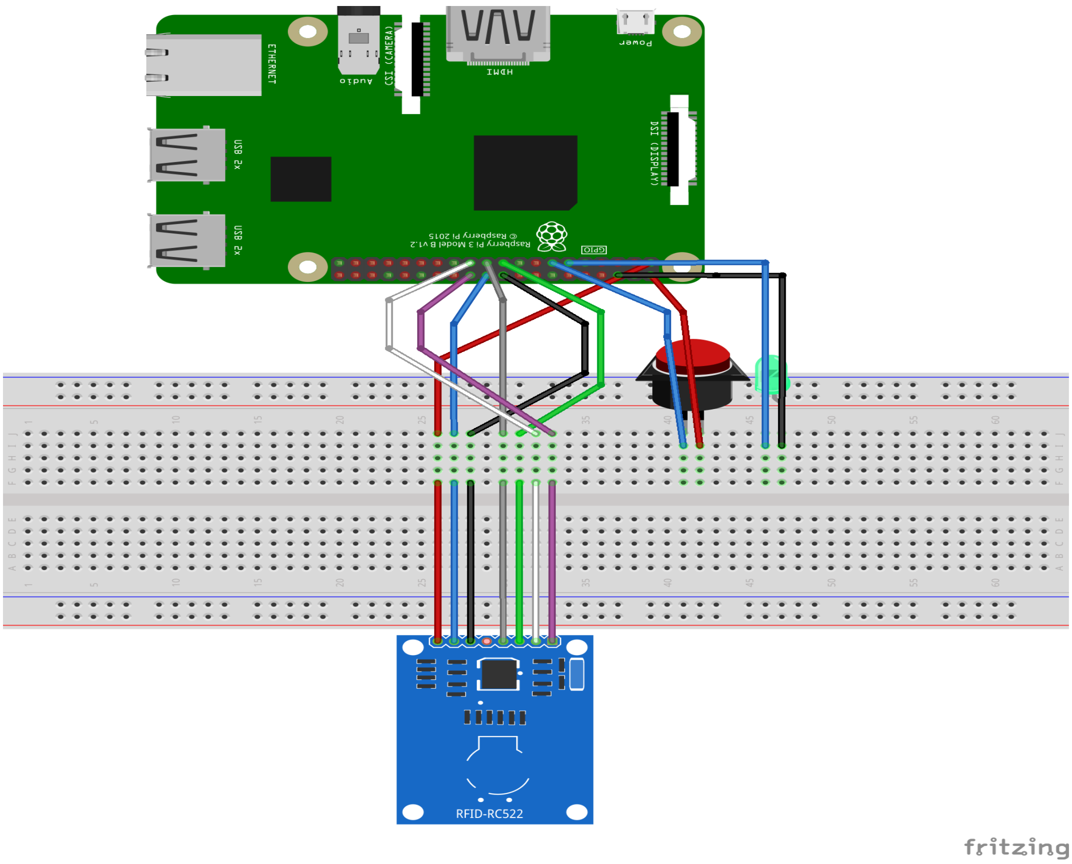


Figure 7.2: Schematic Diagram of Manual Station

Where table 7.1 shows the pin of RFID reader corresponding to Raspberry Pi.

Pin in RFID	PIN in Pi
SDA	24
SCK	23
MOSI	19
MISO	21
GND	20
RST	22
3.3V	1

Table 7.1: Pin Connection of RFID with Raspberry Pi

7.3.2 Serial Communication between Manual Station and Pick-by-Light

Raspberry pi will send the information about the requirement of the brick for an order and pick-by-light will be activated based on the received information. On the other hand, arduino will sense the input from the operator using motion sensor . If the operator performs the task correctly, arduino will send the information back to raspberry pi that correct brick has been picked. For this exchange of information both Controller of pick-by-light i.e. Arduino and controller of manual station i.e. Raspberry Pi need to communicate with each other. There are 3 communication protocols over which Arduino and Raspberry Pi can be connected.

- I2C - It a master-slave based serial bus architecture which utilizes just 2 wire i.e SDA and SCL. SDA is used to transmit data to and from the slaves while SCL is used to manage the clock of in and out of data from the slave. Master in I2C can be any component which initiates the communication. It can act as both transmitter and receiver depending on the situation while slave is a component which is referred by the Master and slave can also act as receiver or transmitter with regards to Master. In most cases Master is a microcontroller/micro processor based device while slave can be any controller or peripheral devices. It is Multi-Master bus where it can communicate with Master-Master, Master-Slave with any number of Master and Slave.[29]

- SPI - Serial Peripheral Interface (SPI), similar to I2C it is also a Master-Slave architecture but with some key differences. As in I2C multiple Masters and Slaves can be used while in SPI only 1 Master can be used with 4 Slave. It is faster protocol than I2C due to simple design and can ramp up the speed of the communication.[29]

- UART - Universal Asynchronous Reception and Transmission (UART) is used to communicate between serial devices. As Arduino has an onboard USB to serial convertor, Arduino can directly be connected to a computer through a USB port. The connection design is simple as compared to I2C and SPI as it does not require any clock. Only the baudrate i.e. the data transmission frequency of the both the devices need to be same.

In this thesis project, it is decided to use UART communication protocol between the Arduino and Raspberry Pi. As only one-to-one communication is required and there are no multiple devices acting as master or slave, UART will be the simplest communication protocol for this scenario with moderate speed of communication.

7.3.3 OPC/UA Communication between Manual Station, Festo PLC and KUKA Cloud

In an industrial process environment it is important that a secure and reliable communication protocol is used. Open Platform Communication(OPC) is a open source protocol which has an inbuilt security. It has a multi system interoperability where information can exchange between multiple industrial systems and softwares. Compare to previous versions of OPC, OPC/UA servers gives the ability to integrate it into a controller of existing industrial components instead of using an additional hardware for the same. Also if industrial components are not connected to an internet connection, it enables to connect industrial components together and communicate within one. Being an open source protocol it a scaleable communication standard. [38] As mentioned in subsection 2.3.1, OPC/UA communication protocol is used in LEGO Smart factory Demonstrator to communicate between all the hardware and software components, controller of manual Station i.e. Raspberry Pi will also be communicating with the Festo Module's PLC through an OPC/UA connection.

The FESTO's PLC is only acting as OPC/UA Server and can communicate with the MES which is acting as OPC/UA client. The PLC will extract the data from MES and will communicate it to the manual station i.e. Raspberry Pi. Raspberry Pi is hosted as OPC/UA client which can receives data related to the order such as order ID, bricks ID and quantities. It will also exchange a special communication tag i.e OPC tags which is a unique identifier established for a particular set of pre-defined instructions. Raspberry Pi can read and write these tags value from and to the data source i.e. PLC. In the UML sequence diagram displayed in figure 7.4, the coloured line depict the OPC tags communication between Raspberry Pi and PLC. There are the 4 tags value pre-defined for communication:

- 1001 - Carrier arrived, Execute the process.
- 1002 - Carried passed the station , No work to do.
- 1010 - Process is executed by an operator.
- 1100 - process is completed by an operator.

Beside this Raspberry Pi will also act as a OPC/UA server and will write the data to the KUKA cloud which is acting as OPC/UA client. Figure 7.3 shows the OPC/UA communication flow between all the the smart factory layout components i.e. MES, Hardware components as mentioned in subsection 2.3.1 and KUKA Cloud.

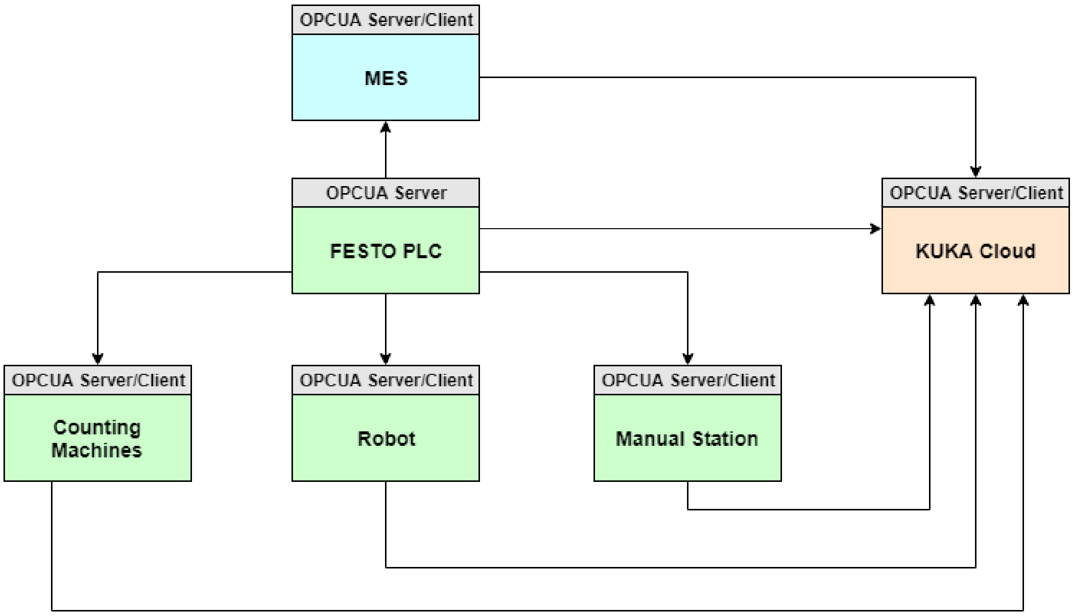


Figure 7.3: OPC/UA Communication Flow

7.4 Programming

For Raspberry Pi to control its hardware components and to create a GUI for Human Machine Interface, a programming file is required which can run in background and performs all the task. As mentioned earlier in section 7.2, Python 3.5 is used to create the code.

Since the code is required to perform multiple functionality running parallel, a UML Sequence diagram is created to lay the background work of the code. It gives a clear understanding of the flow of the code and gives an overview to developer about the expected behaviour of the system. Figure 7.4 shows the complete UML sequence diagram of the smart manual station. The code is then formulated based on this sequence diagram. The code developed can be found on GitHub account at **Manual Station Code**

7.4.1 Brief Summary of UML Sequence Diagram

In this UML sequence diagram i.e. figure 7.4 there are 4 lifelines and 1 Actor which is working as an operator. 4 lifelines depicts the MES, Festo's PLC, Controller of manual station i.e. Raspberry Pi and hardware components as manual station.

As it can be seen the first message is initiated by MES which is communicating with the PLC to check the availability of the carrier and if the carrier is available the order information is transferred to the PLC. Meanwhile Raspberry Pi is looking for data from the PLC. As soon as the data arrives at PLC, it informs the Raspberry pi about the arrival with communication tag as 1001. Raspberry Pi after reading the tag as 1001 writes the tag to 1010 and PLC get the information that manual station has started working on the order.

The next part of the operation work within the smart manual station between the hardware components, controller and an operator. As soon as the data is received the controller displays the information about the details of the order on the screen. There might be 3 alternatives on which order can be depicted as :

- Create an order with bricks
- Just pack the order created by other stations at smart factory layout.
- Trash the order if problem occurred in an order.

As soon as Raspberry Pi receives an information about creating an order with bricks it activates the Pick-by-Light mechanism. The operator need to pick the brick from displayed box number, of the displayed type and quantity. If the operator commits a mistake about the type of the brick this step is repeated. If not, system checks the weight of the collected brick to verify the quantity. If the quantity is correct operator moves to next step to pick the brick of another kind or else the step is repeated again. This loop keeps on repeating until all the bricks are collected. For trashing and packing, operator just need to performed the task as per the displayed operation and finish the task.

When either of these tasks are completed operator need to press the button which in turn informs the PLC that the order has been executed and the tag value changes to 1100. In case of order created with bricks, once the task is executed and informed to PLC, it again checks the requirement of packaging with the MES. If MES informs the PLC that the created order need to be packed, then process gets repeated and operator receives the information to pack the created order. Once the order is packed the RFID code value is transferred to MES to track the package in the value chain.

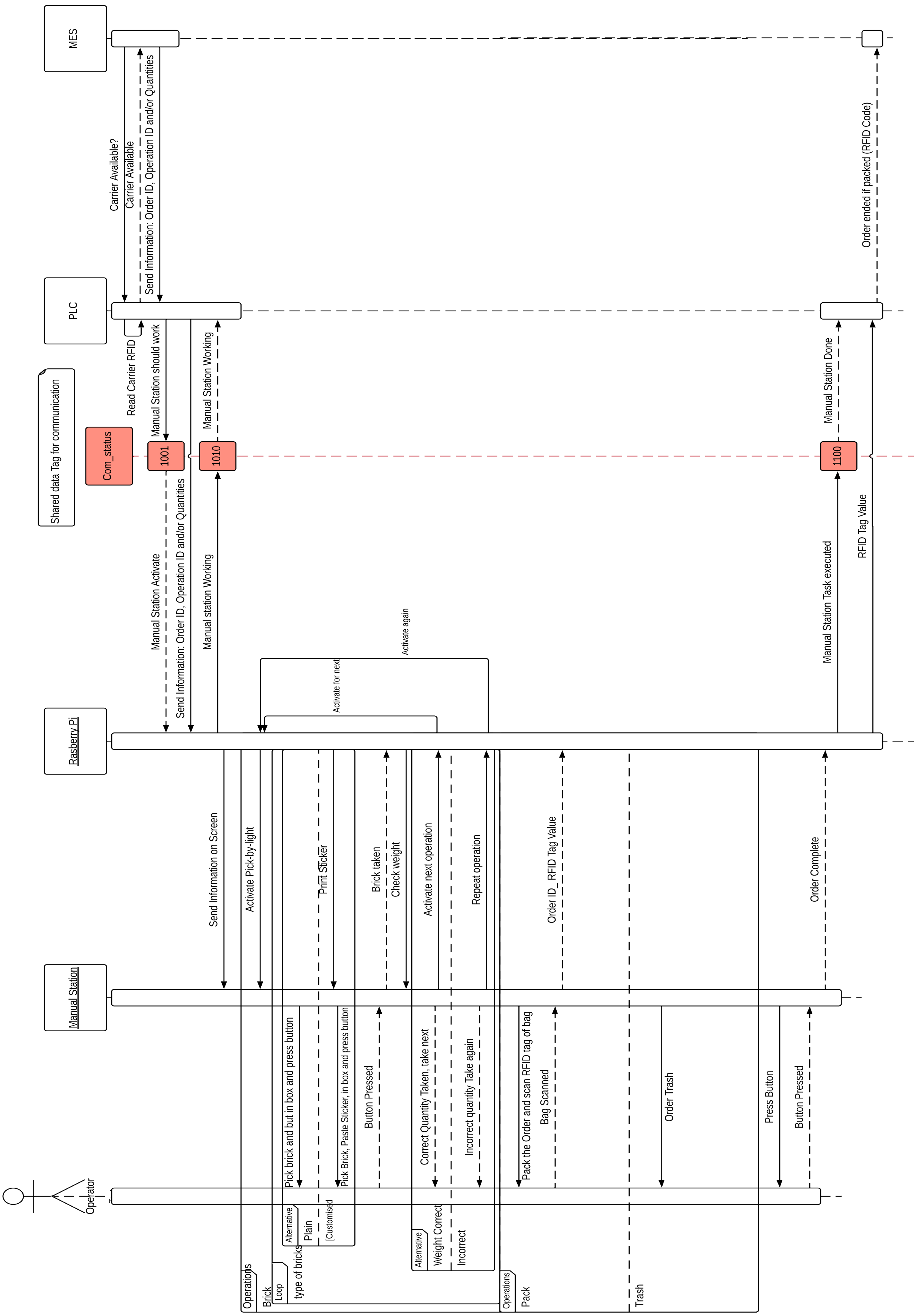


Figure 7.4: UML Sequence diagram for Manual Station Process

7.5 Final Smart Manual Station

Using the CAD design displayed in section 7.1 and incorporating all the components of the smart manual station i.e pick-by-light, screen, printer, RFID reader, weighing scale and a button, a final model is developed. Figure 7.5 shows the final developed setup of the Smart Manual Station with table 7.2 contains the bill of material (BOM) of all the parts and components required to develop it. Miscellaneous items in the BOM signifies nuts, t-slot nuts, bolts, electrical wire and wood.

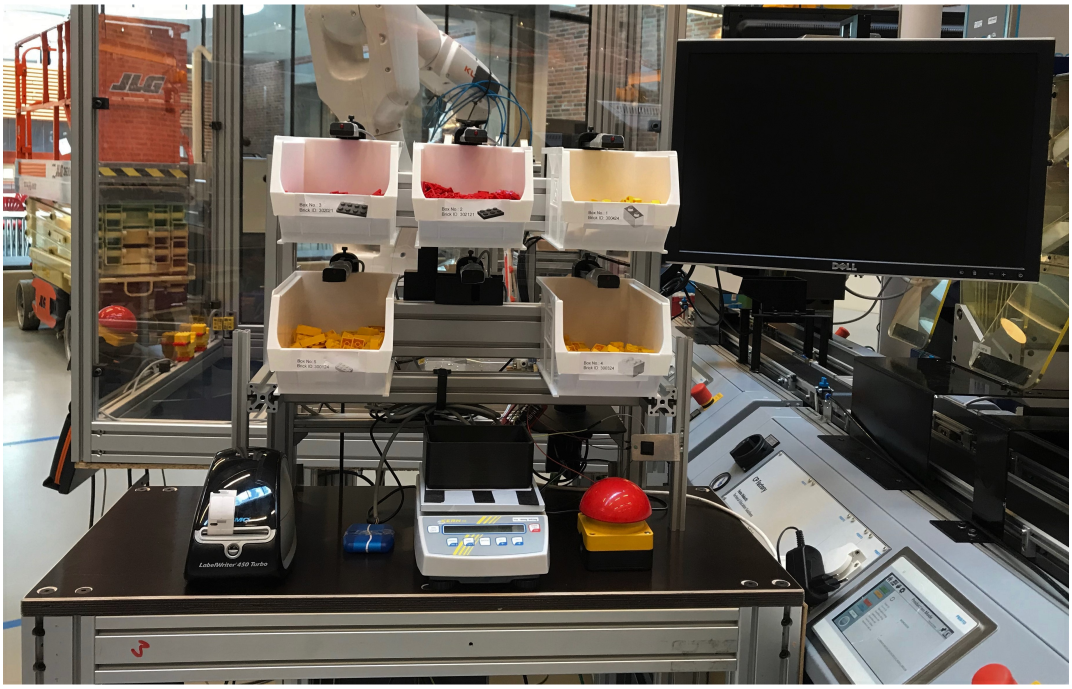


Figure 7.5: The Developed Smart Manual Station.

Item	Quantity	Specification	Price	Amount
Aluminium Frame for Table	620 cm	40x80mm	515/2m	1596
Aluminum Frame for Pick-by-light	260 cm	40x40mm	270/2m	351
Aluminum Frame for Pick-by-light	100 cm	40x80mm	515/2m	258
Aluminum Frame for Pick-by-light	52 cm	20x20mm	59/1m	31
Pick-by-light boxes	5	RS Pro Bearing Box White	23.20	116
Motion Sensor	5	PIR Sparkfun JST	100	500
RFID Reader	1	RFID FRC522	70	70
Sticker	100pc	13.6Mhz RFID Sticker	2	200
Printer	1	DYMO Label Turbo 450	756	756
Label	2	13x25mm	60	120
Button	1	Red Push Button	600	600
Weighing Scale	1	KERN KB 10K0.05N	3676	3676
Touch Screen	1	Raspberry Pi Touch Screen	600	600
Raspberry Pi	1	Model 3	320	320
Arduino	1	Mega 2650	300	300
Miscellaneous		Wires, nuts and bolts	200	200
			Total	9694

Table 7.2: Bill of Material of Smart Manual Station

Chapter 8

Bag opening Setup for Packaging

One of the sub-task of the operator as mentioned in subsection 5.1.2 is to pack the content of the order. For the packaging process a zipper plastic pouch of dimension 100x150mm is used. This requires an additional operation by the operator to open up the bag manually before each packaging task. This could take an additional time of the operator on an operation which is not adding a significant value to the process. It was also required to use a fixture which can hold up the bag wide open, meanwhile operator can pick the box containing bricks and fill the bag.

Based on this requirements, it was decided to design and develop an automated bag opening tool which can pick the bag from the storage and can open the bag wide open for the operator. The operator just need to pick the box, fill the bag with bricks and close the bag for dispatching.

8.1 Development

8.1.1 Hardware

Figure 8.1 shows the designed CAD model for the tool. It has box which can hold the bag vertically. Beside this, there are two suction cups, one is mounted on a fixed side i.e suction cup 2 while other is mounted on a linear actuator of 50mm stroke i.e. suction cup 1. The linear actuator along with the suction cup 1 is fixed on a pneumatic rotary actuator. The rotary actuator helps the linear actuator to rotate and pick the bag from the box. Once the bag is picked it will rotate back to it position in front of the suction cup 2. The linear actuator will expand towards the suction cup 2. Vacuum created on both the suction can hold each side of the bag. The linear actuator will move back to its position keeping the bag wide open.

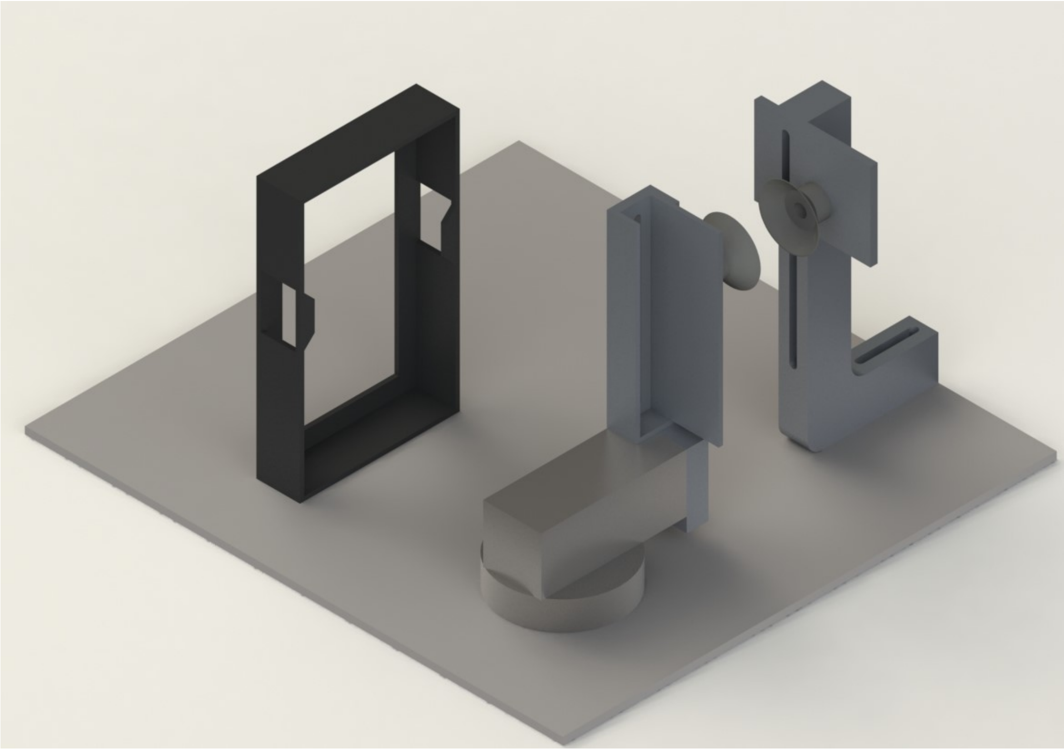


Figure 8.1: CAD Model Bag Opening Tool

Two frame structure on which the suction cups are mounted are designed using aluminium using CNC milling. It is designed in a way that it can accommodate different sizes of bags by adjusting the height and the distance between the frames by fastening the nuts. Frame 1 is mounted on a linear actuator. It can move as the linear actuator moves while frame 2 is fixed. The black coloured box is a 3D printed box on which bag will hanging vertically. Linear actuator will rotate and it can pick the bag from the box. Figure 8.2 and 8.3 shows the frame 1 and frame 2 respectively.

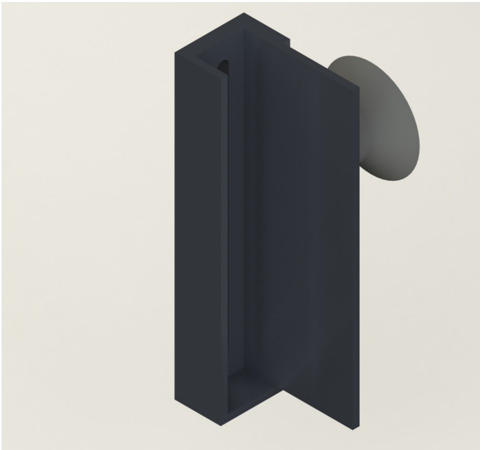


Figure 8.2: Frame 1 - Moving

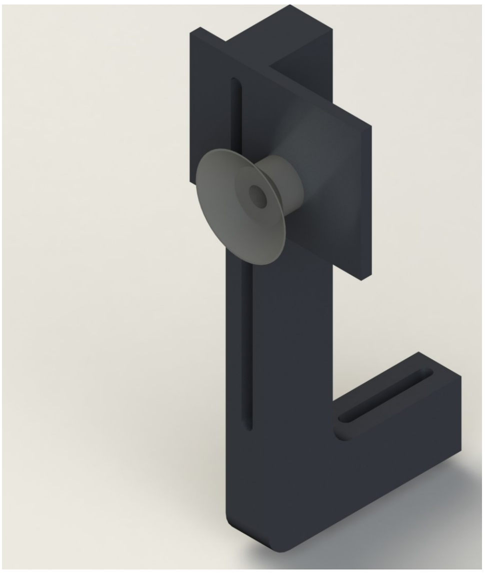


Figure 8.3: Frame 2 - Fixed

8.1.2 Control

It has 2 actuator, i.e. linear and rotary, and 1 vacuum ejector which will create vacuum for two suction cups. For this 4 solenoid valve is required. For both the actuators a 5/2 double acting valve is used while for each suction cup 5/2 single acting solenoid valve is used. To control this pneumatic actuators using these electronic solenoid valve, an Arduino Uno is used. These solenoid valve requires 24V as input voltage so a 24V relay board is used which operates on 5V input from the Arduino Uno. A total of 6 relay boards is used for each side of solenoid valve.

Item	Model	Quantity	Specification	Price	Amount
Pneumatic Linear Actuator	SMC CDQ2B25-50DZ	1	50mm Stroke	254	254
Pneumatic Rotary Actuator	SMC MSQB7A	1	Rotary angle 0-190 degree	1650	1650
Vacuum Pump	VMECA VTM5-B	1	Max vacuum -85kPa	428	428
Suction pads	Aventics BSG	2	20mm dia.	84	168
Suction relay		6	5V - 24V	7	49
Pneumatic valve 1	AZ Pneumatik AZ521	2	5/2 Double valve	389	778
Pneumatic valve 2	SMC SYJ3000	2	5/2 Single Valve	113	226
Arduino Uno	Rev 3	1		159	159
Aluminium Parts		5	frame	100	500
Miscellaneous			Hose pipes, wires etc.	400	400
				Total	4605

Table 8.1: Bill of Material for Bag Opening tool

Table 8.1 shows the bill of material required to develop the bag opening tool where miscellaneous parts includes, hose pipes, electrical wires, jumpers wires and electrical boxes for circuit connection. Figure 8.4 shows the model developed to fit with the smart manual station.

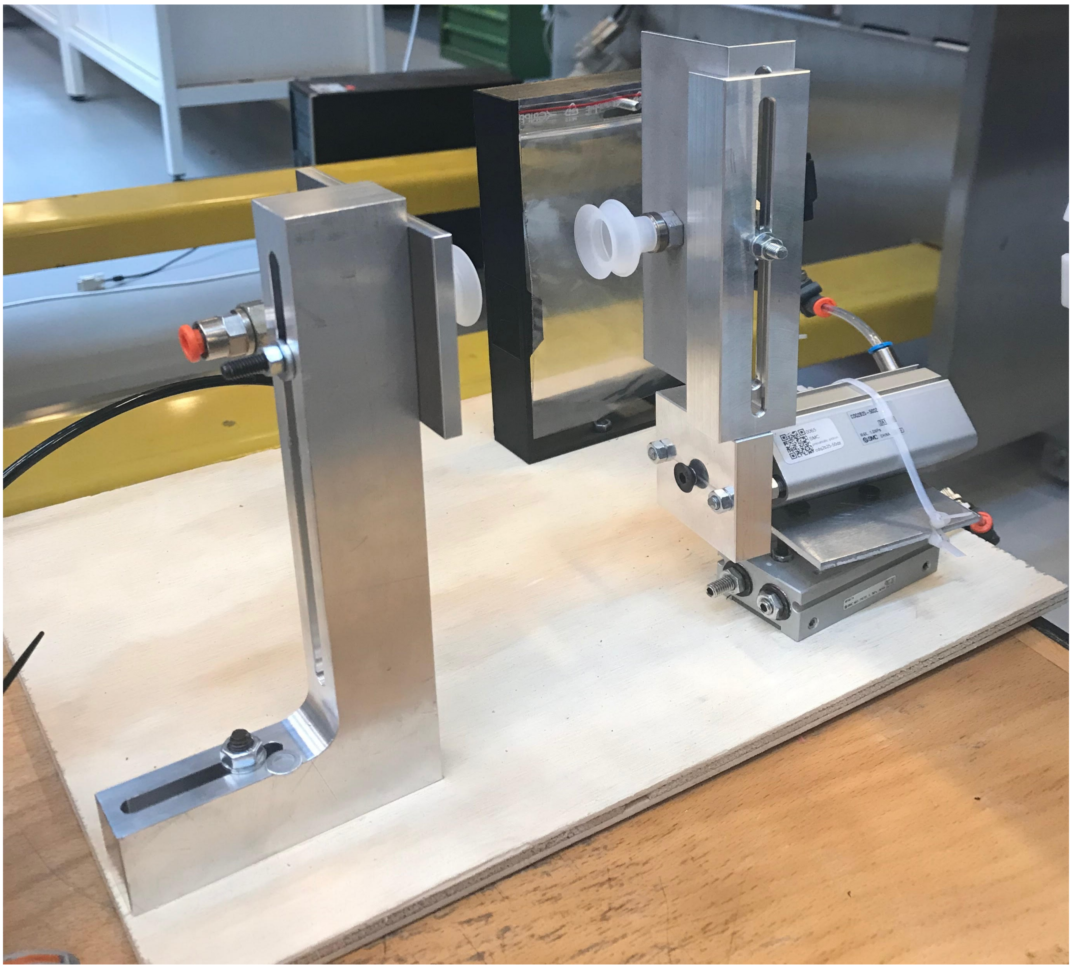


Figure 8.4: Developed Setup of Bag Opening Tool

Chapter 9

Data Collection and Analytic

This chapter explains the insights about the collection of data from the manual station and overview on the data analytic.

9.1 Data Collection

As mentioned in chapter 2, Cloud is one of the layer in the architecture which need to established in the LEGO Smart Factory Demo. The Cloud layer is divided into 4 components Dashboard, Data Analytic, Cloud and Gateway.

KUKA being one of the industrial partners in Demo project, it has provided its own gateway and cloud platform. All the individual components of smart factory are integrated with each other and with the KUKA Cloud. The KUKA Connectivity Box is used to collect the data and transfer it to the cloud.

The LEGO packaging line is added as an Asset Group in the software under which all the individual components is added as an Asset. Dashboard is created to make the service interactive and access the individual components of the factory from any visual display. Figure 9.1 shows the designed dashboard for the smart factory developed by the team working on the setting up of smart factory. All individual components of the smart factory can be seen in the dashboard. User can access each of these station to visualize the data generated from individual stations.

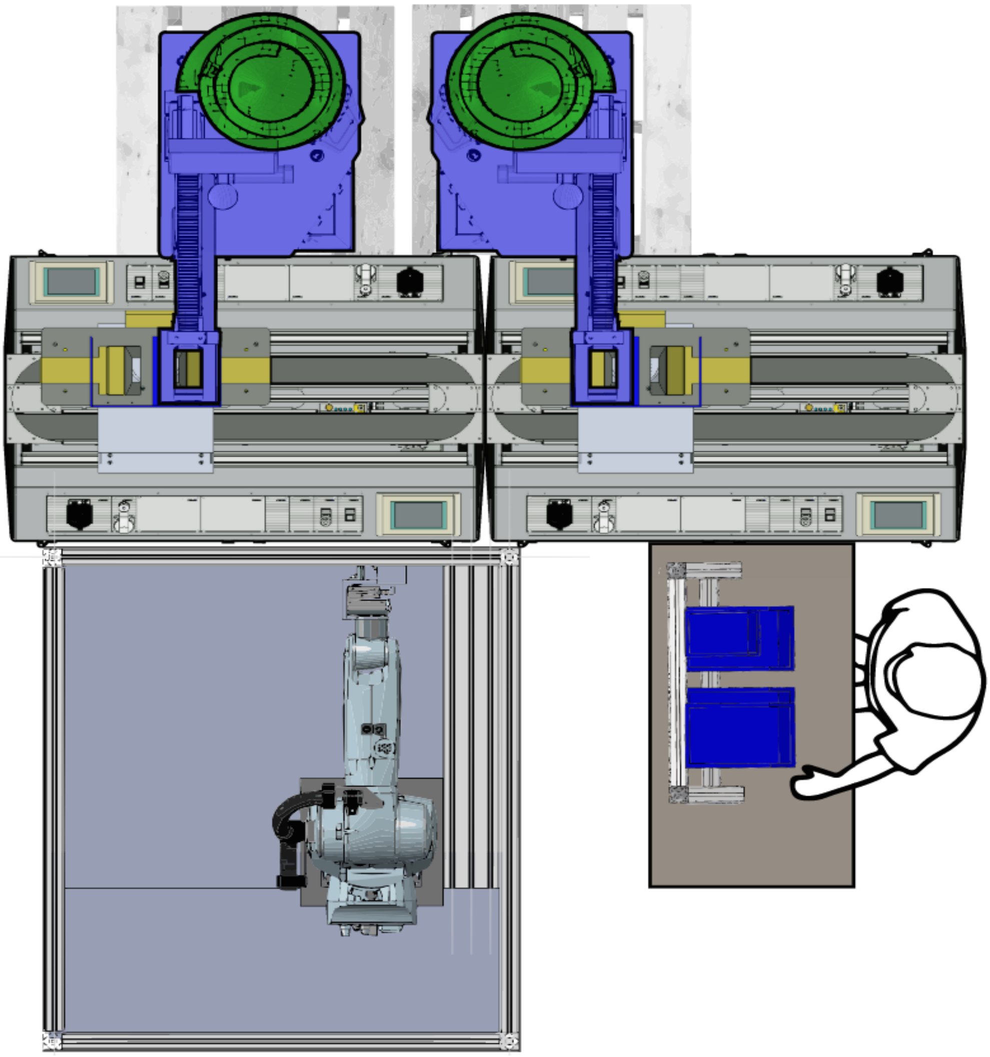


Figure 9.1: Dashboard of the Cloud Service.

Individual Components of the smart factory are connected to the connectivity box through standard OPC/UA communication protocol. Manual Station act as a OPC/UA server and trasnmits data to the connectivity box. Within the OPC/UA server all the data points can be created which need to be transferred to the cloud. Presently 5 data points has been created from the manual station to transfer data to the cloud. These are:

- Brick ID
- max_weight_s_exp - Maximum expected weight of the each type of brick picked for an order.

- min_weight_s_exp - Minimum expected weight of the each type of brick picked for an order.
- Quanitities - Quantity of each type of brick picked for an order.
- Single_set_Bricks - Weight generated from the digital scale for each type of brick picked for an order.

Figure 9.2 shows the data points and collected data as current value along with data type. It also show time stamp.

Parameter.Brick_ID	-	Integer	30032401
Parameter.max_weight_s_exp	-	Decimal	1.20
Parameter.min_weight_s_exp	-	Decimal	1.10
Parameter.Quantities	-	Integer	1
Parameter.Single__set_Brick	-	Text	2.05

Figure 9.2

Presently, the establishment of the KUKA Cloud server in the smart factory is at initial phase. Cloud and the stations are able to communicate with each other to collect the data but not much analytics can be performed on these data. Teams working on the functionality of the Cloud are trying to establish a workable platform. But currently it is difficult to generate any crucial information from the raw data. Beside data collection, there are many features of the cloud which are yet to be explored. It would be beneficial to use to cloud for not just collection of data or analytic but also for monitoring station working conditions.

Chapter 10

Conclusion and Future Work

10.1 Conclusion

The study stated that smart factory initiative can transform the industry to increase the agility, flexibility and improve autonomy of the industrial systems. The idea of developing a smart factory model lay behind the understanding of the benefit of implementing industry 4.0 tools and technologies in a custom made environment for LEGO. This research based project gives the understanding of tools and methodology to create a smart factory. creating a layout depicting the actual process and building a learning factory with digital tools such as IoT, Cloud and digital twin. The developed model gives a plan for the adoption of new technologies by assessing the competencies and capabilities with the maturity of the setup.

This thesis project focuses primarily on to develop a smart assistive manual station which will be a part of the smart factory layout developed for LEGO Group under MADE Digital WP5.4 in collaboration with MADE and its partners along with AAU. The objective clearly defines as *"To design and develop a smart assistive manual station which can guide the operator for each customised order received from MES, detect the operator's errors and to communicate with the MES to exchange information about the packed bag."*

This objective laid out the goal of the functionality of the manual station and its role within the smart factory setup. On the requirement of Mechanical Structure, Communication with MES, Guided instructions to operator, preventing errors of the operator, handle customised order and collection of data on the cloud server, a system was developed with modular understanding fulfilling each of these requirements either working together and individually. The detailed task and sub tasks gives a clear understanding to about the station from operator's perspective. While developing the structure, possible errors was considered and matched with the operations to prevent the errors simultaneously while working on the task. The developed pick-by-light system can guide the operator but also verify the operation in a same step. If an error occurred in the operation, it ask the operator to rectify it before moving to the next step. Thus, reducing the defect in the final product and improving the output. Verifying the operations in the later stage of task might have lead to discard the whole task and repeat the same task again, even if the error have occurred in just 1 operation.

In a customised order, it is important to deliver the product which has correct type, quantity and design. Since pick-by-light verifies the type of the brick, digital weighing scale verifies the quantity simultaneously with the pick-by-light operation. The system is designed to be robust with easy performing steps to make the operators adjust to the functionality with ease. The information which are critically significant for the operator are displayed with clear understanding reducing the chances of miss out. The usage of RFID tags ideally makes the customer more aware about the status of their order and expected deliver time.

Being a station which is physically operated by an operator leaves a gap of improvement with increased usage. The data transmitted to the KUKA Cloud generates a sequence of charts to understand the behaviour of the system and the operator. If there is any discrepancies between their behaviours, it can help to detect it and improve the process over the long run. Usage of the system by multiple operator can generate different sets of data which can be used to predict the behaviour of the system on the basis of the operator and operator can be deployed based on their efficiency and performance.

10.2 Future Work

This section revolves around the ideas which can be improved in the smart manual station if the project will be continued and it signifies the role of a manual station in a smart factory.

- The mechanical structure developed for smart manual station is robust but lacks the flexibility to integrate it with the real production system. The structure can be modular with a compact design which can integrate with any production facility.
- The features established in the station is most required features which are important to fulfill the objective. Beside this, applying the feature such as operator's motion tracking can make the system much more functional and productive.
- As mentioned in chapter 6, beside digital scale a depth camera and image processing techniques can verify every instance of the operator in the process, and can assist the operator with better work instructions and prevent the error.

- Incorporating a augmented reality technology through digital glasses can provide the operator with instruction with better understanding of the system in the real time. The information can overlap with the real world and can guide the operator with precise information.
- The system lacks the cognitive understanding of the operator's behaviour which can help to understand the operator during each operations and make the system adaptable to the operator.
- The code developed for the system though performs every functionality but its lacks efficiency and preciseness. Since the understanding of the development programming codes was very limited before the starting of this project, the developed code can be improved both on the clarity and flow.

Beside this improvements, the role of a smart manual station with human machine interface in a smart factory can be justified. Since the increased role of automated machines and robots in the production facility, and integrating digital tools from industry 4.0 with the production layout are providing autonomy to the system to collaborate and perform. Humans also have significant role in the industry which can't be replaced by machines. Instead the facility can be developed which can accommodate the human-machine interaction and facilitate the operator during the production. A smart manual station can be one such production system which can understand the operator's behaviour, interact with them and can guide them through the process. Also the missing chain of data collection based on operations performed by the manual operator can be solved by using it.

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Appendix A

Schematic Diagram of Pick-by-Light

Figure A.1 shows the schematic diagram of Arduino with LED and PIR.

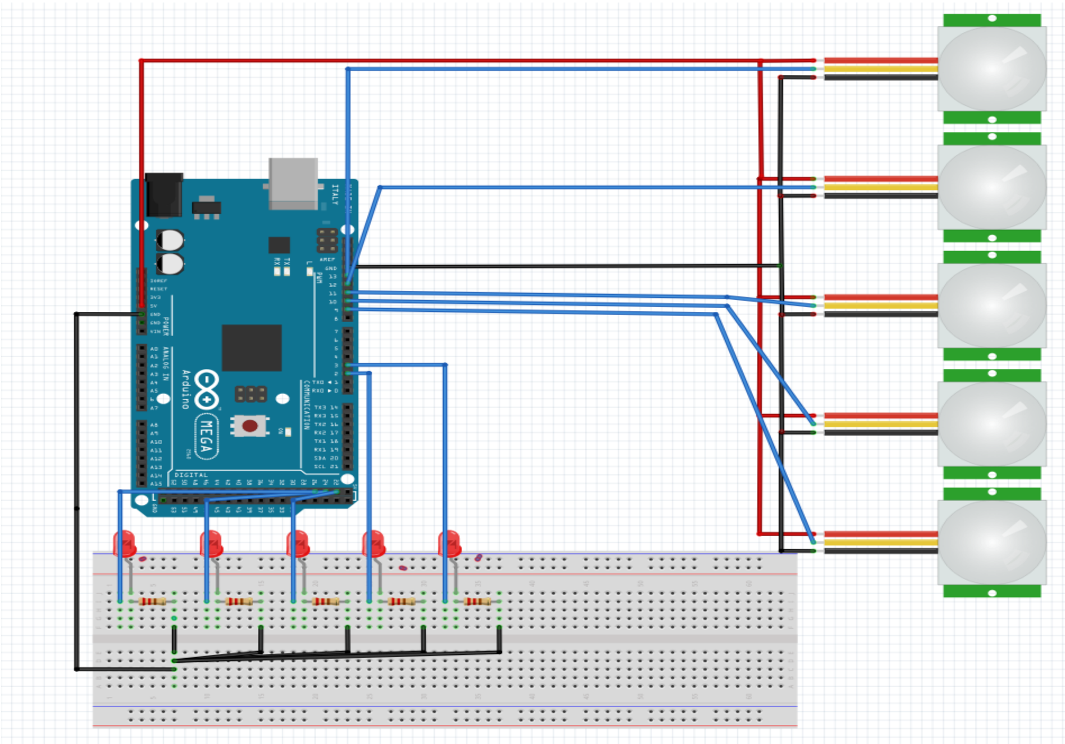

Figure A.1: Schematic Diagram of Pick-by-light

Appendix B

Pinout Diagram of Raspberry Pi

Figure B.1 in this appendix displays the pinout diagram of Raspberry Pi 3 model.

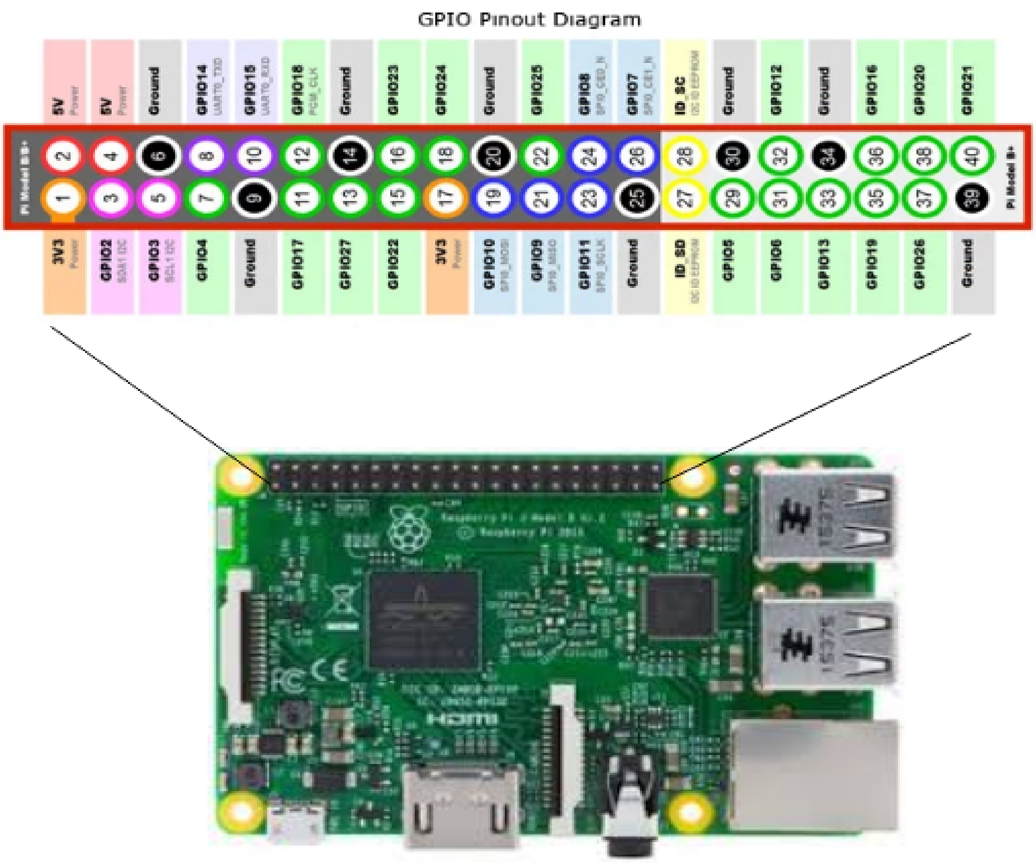

Figure B.1: Pin Out Diagram of Raspberry Pi

Appendix C

Images of the Developed GUI

Figure C.1, C.2, C.3, and C.4 are the few images from the developed GUI. As it can be seen there are instruction with blue text for the operator. It displays the name of the operator performing the task, Order Number, box number of the brick in the pick-by-light setup. Beside these. there are images to display the quantity to be picked (for clear visibility), image of the brick and an image of an additional operation to perform.

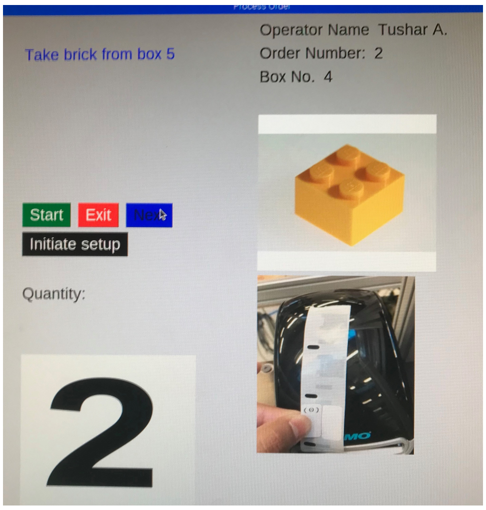

Figure C.1: Pick Brick for Customised Order

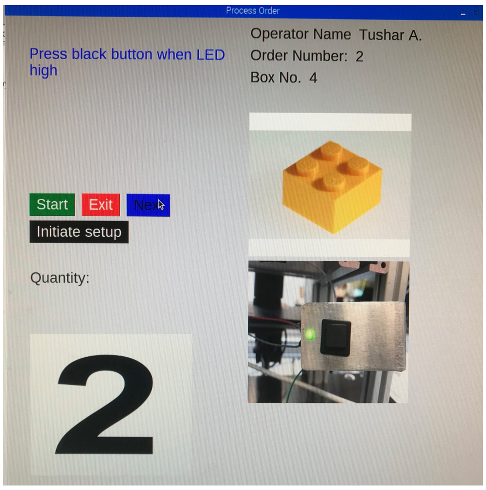

Figure C.2: Press Button When LED Glow

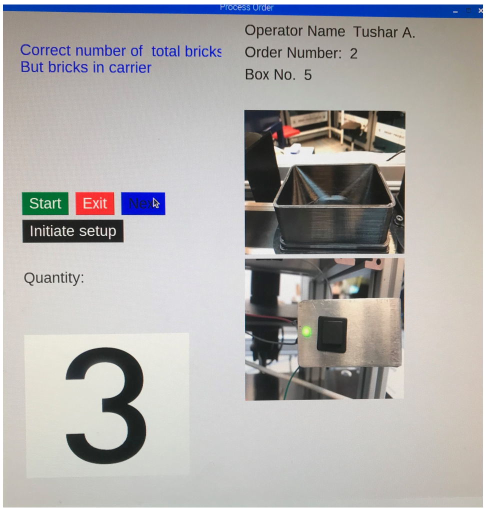

Figure C.3: Correct Number of Total Bricks Collected. Put them in the Carrier

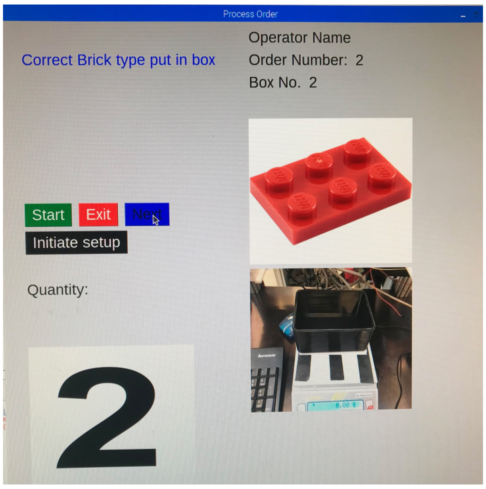

Figure C.4: Correct Brick type Collected. Place it in Box