DESIGN OF AN ENGINEERING STEM TRAINING TOOLKIT

by

VAMSI PENMETSA

KARTHIKEYAN LINGASUBRAMANIAN, COMMITTEE CHAIR
MURAT M. TANIK
ELIZA SAZIA

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ELECTRICAL AND COMPUTER ENGINEERING

ABSTRACT

Recent reports proclaim that more students should engage in enrolling in STEM programs at an early stage of schooling. Due to insufficient number of students pursuing in STEM programs, lot of them missing out too early in their educational career. Nine out of every ten adults had at least a high school or general education diploma, but when it comes to a higher degree only one out of every three adults held a higher degree. To overcome this problem, we need to attract more students by implementing scientific STEM projects where they can actively work on and give them a hand on learning experience how STEM will be helpful in upgrading their career.

In this thesis, we have gone through several technological methodologies which were used as a case study in education and have chosen active or hands on learning methods which are suitable to design an engineering STEM training toolkit. In this training toolkit, we have used different sensors which are capable of reading real-time data. These sensors are connected to the Raspberry Pi and programmed with Wolfram Mathematica to design an interface which simplifies the learning curve and educate students with buttons or on click interface events on Wolfram Mathematica to read the sensor data in real-time. While developing this training toolkits on Raspberry Pi, we desired to comprehend the limitations of it in terms of execution and response time. It also to measure quantifying sensors data it can handle when connected parallel with I2C and to know if there is any memory, power or processing issue of Raspberry Pi while connecting these sensors. After determining the results of the experimental setup, we determined that the execution and response time increases whenever we add additional sensors to the Raspberry Pi. It is found that the 5 Voltage powers of Raspberry Pi is not distributing equal across all the sensors.

Keywords: STEM Education, Raspberry Pi, Wolfram Mathematica, Interface, Limitations

DEDICATION

I dedicate this thesis to my family, friends, and professors who has provided support throughout my life and always had faith in my success.

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LIST OF ABBREVIATIONS

ASC	Academic Self-Concept
CSI	Camera Serial Interface
DC	Direct Current
GLCD	Graphical Liquid Crystal Display
GPIO	General Purpose Input Output
GPS	Global Positioning System
GPU	Graphical Processing Unit
HDMI	High-Definition Multimedia Interface
HW/SW	Hardware/Software
I2C	Inter Integrated Circuit
IC	Integrated Circuit
LCD	Liquid Crystal Display
PC	Personal Computer
RTD	Resistance Temperature Detectors
SBC	Single-Board Computer
SD	Secure Digital
STEM	Science Technology Engineering Mathematics
USB	Universal Serial Bus
VNC	Virtual Network Computing

CHAPTER 1

INTRODUCTION

We have different and many kinds of STEM related educational training toolkits with single-board computer (SBC) [1], microcontroller, etc. in the market with a lot of sensors packed in single package in the form of an educational training kit, but none of them provide you with the basic implementation of an interface where you can understand and make the learning process easy for students. To make these learning process easier the code should be tremendously satisfying and educational, which involves tiny syntax possibly not even a line longer and you already see a lot of new and interesting things happening in front of you.

In this chapter, we will introduce the problem which is the subject of this research and explain the reasonability of the proposed interface solution. We will also provide the objectives and the main goal for this research with the general profile of overall interface solution.

This thesis document is categorized into five chapters as follows: Chapter 1 provides with the introduction and overall ideas for this thesis work. Chapter 2 provides a brief survey related to STEM and most available engineering toolkits in the market. Chapter 3 describes how the design process should be considered and what is needed to be on track. Chapter 4 describes the complete experimental setup to study the limitation and the development of the interface with the results which are obtained from the experimental setup, by the end of this chapter we will be knowing the limitation of experimental setup through the results, so in chapter 5 we can have a conclusion and provide suggestions for the future work in developing the toolkit and much more easy interface than the existing one.

1.1 Objectives and Goals

The main objective of this thesis is to design, assemble, and develop a toolkit for STEM related scientific projects to educate students in different fields. While developing, and assembling a new version of a toolkit we need to make sure it supports as many as peripheral sensor devices and perform as we expect. To succeed in developing the toolkit, we are using a Raspberry Pi microprocessor as a proof of concept and connecting as many as sensors to it and get the real-time information from the sensors.

While connecting all these sensors we need to check and measure the response time of each sensors individual and combined them to know the limitations and possibilities of Raspberry Pi. As we are collecting the sensor information in real time applications, timing and response is the most important factor when it comes to any real-time applications. All these real-time applications are based on timing such as response time, deadline, and etc.

These real-time applications are classified into hard real-time and soft real-time. Hard real time means the given task should be completed within the deadline of the time period if not the computation whatever it's done is no use and the damage caused by it is impossible to repair. Soft real time means the performance assurances which depends on the operating systems.

After knowing the response time of each sensor, we can analyze the results of the limitations and propose the needed changes for the Raspberry Pi to develop and design a new toolkit which can perform much better than the existing model.

CHAPTER 2

BACKGROUND RESEARCH

Nowadays the importance of science, technology, engineering, and mathematics (STEM) education is increasing rapidly around the world, but there is a concern of an insufficient number of students in the United States who are enrolled in STEM programs. So the demands of these academic programs should not dull the students' spirit and should not lose their self-confidence and also should not destroy their Academic Self-Concept (ASC). The overall courses in engineering use class, textbook materials, and laboratory, etc. to teach and let them practice in the curriculum studies. Although these type of teaching styles are generally accepted, most of them do not provide perfect methodologies in teaching. In this future section, we will discuss how the technological methods in education will be helpful in learning and developing a toolkit for educational propose.

2.1 Active or Hands on Learning

Active learning is an instructional method that captivates students to involve in the learning process. The faculty needs to inaugurate a way to formulate this learning in a traditional way. In addition, this learning advocates more alternatives ahead of traditional teaching methods with better acknowledgment. The following paragraphs provide an explanation of different proposed methodologies in active learning with their core elements.

Active learning [8] is defined in multitudinous ways, as there is no traditional universally accepted definition for this. One of those definitions is explicitly explained here. It is a process of engaging students in different activities such as reading, writing, discussion, or problem-based solving which nurture analysis, synthesis, and evaluation of class learning content. Student involvement in an activity and engagement in the learning process are the core elements of active learning along with reception of passive information by students from the instructor. Student activity can be introduced into the traditional lecture by pausing the lecture periodically and making the students to discuss and clarify their notes with their partner. “Understanding and Design” [10] emphasize all the quality activities needed to develop a deep understanding of prominent ideas. Student engagement can be promoted by encouraging the students to make an enhance thinking of what they are studying. These two core elements yield in the increase of force of learning, accelerated learning and understanding velocity for students after following traditional active learning.

Collaborative learning [9] is also an inherent instructional method in educational approach for teaching and learning, in which students work together in small groups to solve a problem or to complete a task. Generally, all group based approaches [11-14] are encompassed in collaborative learning. Emphasizing on student interactions is a core element in collaborative learning. Moreover, it improves academic achievement, quality of interpersonal interactions, self-esteem, perceptions of greater social support, student attitudes, and retention in academic programs. These many upstanding results effectively encourage faculty to promote collaborative learning in teaching.

Cooperative learning [16] is a structured form of successful teaching strategy which involves student’s group work to achieve common goals where individual assessment is evaluated. It accounts for individual accountability, interdependence, assessment in team work, proactive interaction among students. The core element in cooperative learning is more of cooperation among students for performing a task rather than competition among themselves. This learning helps students to educate on effective team functioning which in turn promotes interpersonal skills as well. It also promotes positive learning with enhanced academic achievements along with numerous attitudinal outcomes.

Problem-based learning can be defined as an instructional method where students get educated on the subject through the expertise in rectifying the problem found in the study material. It also promotes motivation of learning for students. Problem-based learning internally includes all other learning methods such as active learning, collaborative learning, and cooperative learning being itself as the beginning of the instructional cycle. Along with team effort, self-directed learning is also a part of it. Generally, problems encountered with some certain form of confusion in the working student is performing. This type of learning emphasizes the problems in depth providing a path for what is being studied. First, the problem must be assessed and should think of the ways to resolve the issues with group effort or individually based on the intensity of the problem. Quantifying the strength of problem can be measured by analysis methodologies incubated by Albanese [15], Cohen [17], and Colliver [19]. All these consolidated methods provide strength for active learning or hands on learning.

2.2 Blended Learning

Blended learning is an instructional method aggregates the technology based learning with traditional face-to-face teaching. Blended learning combines traditional classroom learning with technology based online learning. This type of learning can also be stated as hybrid learning. The following paragraphs explain in abstract about the traditional classroom based learning and online learning with their individual complications. In addition, it explains the proposed methodologies in blended learning which promote effective higher education.

Traditional classroom learning or face-to-face learning elevates the relationship between faculty and student. It promotes ease of learning basics, doubts clarification on suffering problems and real interaction. However, it lacks in providing abundant information about a certain topic and different options for solving that problem. Online learning is spreading prominently and compelling educators to opt this type of instruction method in teaching for higher education. Online-based learning is a transformation innovative for higher education in this century. Transformation of learning environments in higher education promotes the acknowledgment in the electronic world and the benefits of this can be easily realized [24]. However, this type of learning has some merits it lacks in providing interaction with the faculty, easy problem solving through faculty etc. These two types of learnings can be blended together to provide a better platform for learning of higher education. One famous personality admired the convergence of these two learnings as “the single greatest unrecognized trend in higher education today” [25].

Blended learning advocates blend of technology based internet learning with traditional face-to-face classroom learning. It is an effective and low pitfall strategy promoting technological developments for future. Blended learning is the concept of integrating the merits and strengths of face-to-face learning with text based internet learning, which is picturized in the figure below.

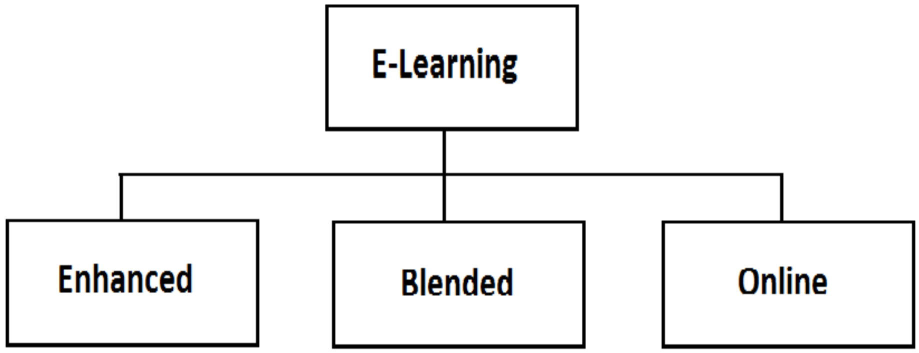

Figure 1. Blended learning block diagram

Blended learning is a form of e-based learning with includes enhancements of face-to-face approach along with asynchronous text based online technologies. The success of blended learning lies in the interactive capabilities of internet communication technology [26, 28]. Cognitive, social and teaching presence are the main three elements for both face-to-face learning and online learning. Even though, only these three are main elements for individuals there are elements such as social presence, supporting discourse, cognitive presence, selecting content, setting climate and teaching presence contribute to good educational experience in blended learning. Interpersonal skills, teamwork development, collaborative learning, flexibility, and motivation provides potentiality in meaningful educational experiences [27]. The affluence of blended learning always depends on factors such as proper administration and development, suitable policies, proper utilization planning, emphasizing required resources, proper scheduling and indeed support to students. By following all these core elements in a systematic manner leads to the transformative potential success of blended learning for higher education.

2.3 Gamification

Gamification learning is an instructional education method to create interest in learning for students using video games and game elements. The motto of using gamification learning is to maximize the enjoyment and inducing interest on learning. The primary aim is to include the elements which comprise games that brings fun to students and using the similar things to motivate the student towards non-game context. Serious games are always a better way to get learning experience as it leads to a serious story which is impressive in quality with thoughtful process.

Gamification learning make an impressive effect on educational context influencing student to attend classes, learning and creative. There are so many elements of games that will influence the attention of students toward education. Progress mechanics, player control, immediate feedback, social connection, challenges and fun are some of the elements which creates a massive impact on learning for students. There are potential benefits in gamification for students in a classroom. It gives the power of ownership for students in learning. It provides great freedom that student can fail and try it again any number of times without negative effect. It also provides set of tasks in which the student should work on their sub-tasks as well. The important effect is it increases the chance of bringing more fun to classroom. Gamification has its influence in business, marketing, corporate management still it has huge influence on education.

Gamification learning has brought huge influence on instruction methods in education. It changed the word of study from education limiting to paper towards education by gaming. Gamification became a learning tool by extending towards ability to teach and reinforcing problem-solving, collaboration and communication skill set [29]. Gamification learning can be influenced by systematic mapping study design, inclusion, search, and screening. Gamification learning always depends on game elements, type of application, education level, academic subject, and its implementation.

2.4 Online Learning

Online learning methodologies for teachers and for students has been being trending and growing fast in the educational uses of technology. The National Center for Education Statistics (2008) has done an estimate stating that the number of K-12 public school who are enrolled in technology- based distance education [20] courses has been increased by 65 present over the years. We can say that online learning is an overlap of the broader category of distance learning, which has the roots of distance education over 100 years back of early correspondence courses. With the rapid increase of Internet and World Wide Web, the potential of any research learning courses has been available for learners around the world.

Today’s online learning has been offering a rich variety of resources in multiple media [18] and the major advantage of online learning is to provide asynchronous communication and real-time learning between learners and instructors as well as different instructors and learners within the group. Online learning has a potential for providing more content which can be accessed by anyone within the group at any time, from any place. The main reasons for involving online learning process is been listed below.

a. To increase the learning experience for learners who do not want to or couldn’t attend traditional face-to-face [21] classroom learning.

b. To allow instructors to handle more number of students with a larger diversity and maintaining the learning outcomes which are equivalent to face-to-face class room instruction.

c. Assembling and disseminating instructional material setup for each learner is cost-efficiently.

To support different models of online learning, different technology application is used such as asynchronous [22, 23] communication tools (for example e-mail, newsgroups, threaded discussion boards) to grant users to choose according to their convenience. Synchronous technologies (for example desktop video/audio technology, web casting, and chat room) are used to set face-to-face teaching in online learning format. In an earlier stage of online learning, programs instructor used to implement one model or the other. More recent online learning programs tend to have multiple forms of asynchronous and synchronous online interactions.

Table 1 Technology in Education

Online Learning	**Blended Learning**	**Gamification**	**Active or Hands on Learning**
1. Peterson et al. [2004]	1. Williams et al. [2002]	1. Deterding et al. [2011]	1. Bonwell et al [1991]
2.Hiltz et al. [2005]	2. Young et al. [2002]	2. O'Donovan et al. [2013]	2. Millis et al [1998]
3. Zhang et al. [2005]	3. Garrison et al. [2003]	3. Mitchell et al. [2013]	3. Wiggins et al [1998]
4. Zandberg et al. [2008]	4. Garrison et al [2003]	4. Anderson et al. [2014]	4. Ghislandi et al [2005]
			Our Research

The above Table 1 provides the case study and research's done by the authors who are involved in improving and implementing new practices in the technology of education. Our research held under Active or Hands on learning explaining traditional methods such as collaborative, cooperative and problem based instructions with their mutual benefits and their implementation.

2.5 Analyzing STEM related scientific programs

Analyzed the previous scientific STEM related teaching programs with in our department, where they used to educate the students using these scientific STEM experiments such as developing a weather station, parking space finder, surveillance camera, and etc. which includes only a few sensors connected to Raspberry Pi and code them in Wolfram Mathematica to get the results. These experiments work perfectly and illustrate STEM related education. But imagine if we want all the experiments combined in a single project which involves in combining all these sensors and get the real-time output through Wolfram Mathematica coding. For this purpose, there is a need to know the limitation of Raspberry Pi and the response time in order to have add-ons to the toolkit which are inexpensive and helps to reduce execution time.

2.6 Project Requirements

The current thesis involves in designing an interface in Wolfram Mathematica, manufacturing, and testing the limitations Raspberry Pi device. The completed project which could ease the learning process to students. There are some readily made toolkits available in the market but lacks some of the essential needs for students to learn. So, after reviewing the current devices, we decided to develop a device with the following minimum requirements.

1. Use a microprocessor or embedded processor.
2. Use reliable and affordable sensors.
3. Implement an User-Friendly Interface.
4. Finding the limitations of the microprocessor or embedded processor.
5. Implementing a remote access to the device for future upgrades (optional).

In addition to this, we might add the additional Liquid Crystal Display (LCD) if we don't have any external monitor. This LCD will work as an output display for the raspberry pi and at the same time this will also having a touchscreen input.

2.7 Market Research

Currently, for STEM there are many educational toolkits available from different manufactures like Texas Instruments, Raspberry Pi, Intel Galileo, Arduino etc., but they are still limited with their performance issues. So, there is an opportunity to explore all the possibilities and limitations of the Raspberry pi which is commonly used in STEM education and we are trying to unite all the different sensors attached to the single raspberry pi and emulating the performance and speed issues of the board.

2.8 Design Considerations

There are many design parameters we need to consider throughout the design process. Due to the limited research time and budget, there should be some précised design parameters by which we can gain the control over time and the design process. The three important parameters considered are:

2.8.1 Reliability

Overall the system reliability plays a vital role in this case because the users of this equipment will be students and assuming they are inexperienced towards the operating of the electrical and software devices. Therefore, for everyone operating and maintaining the device should be quite easy to understand.

2.8.2 Budget

The Budget is an important factor in every project. Due to the limited research budget, we used all the components which were already available for the STEM scientific programs with in our department. The quality and interface of the device shouldn't affect the learning process.

2.8.3 Upgrade

There should be some easy way to update the device functioning in future. So, we have implemented the wireless access to Raspberry Pi by plugin the USB Wi-Fi dongle to update the firmware and to update the code or to add any additional hardware components like sensors, motors etc. We can connect to Raspberry Pi by using Real Virtual Network

Computing (VNC) from your local machine (laptop or PC), But we need to have the same account logged in your machine and Raspberry Pi and then we can access Raspberry Pi from anywhere across the globe.

CHAPTER 3

DESIGN PROCESS

3.1 Introduction

This chapter will cover the design process and the major components that we used in this thesis work. The design process is started with the selection of the Raspberry Pi microprocessor that we wanted to implement with multiple sensors. Throughout the chapter, the detailed design criteria and implementation drawbacks for system components and their integration are discussed.

3.2 Sensor Overview

As we are working with few sensors in this thesis work, it will be good if we have a basic overview of sensors. In present day world, we can find sensors in everywhere from as big as a space shuttles rockets to phones in our pockets. These sensors play an essential part of each industry including agriculture, automobile, manufacturing, and, etc. Sensors are manufactured in different sizes, types and the design of these sensors are manufactured by considering different parameters like power consumption, cost, range, safety, response time, limitations, and, etc. Recently the sensor technology is mainly focusing for signal processing and efficiency on sensor [5]. Each sensor is different from each other and has its own specifications. These sensors can be called as detector and there are few other devices which are known as transducer converts a signal in one form of energy to a signal in another form. Now in the coming subsection, we can relate how sensor and transducer are related to each other.

3.2.1 Transducers

Transducer are the device which converts a non-electrical quantity to an electrical signal that means it is a signal to energy converter. This process of converting energy to another form is known as transduction [6].

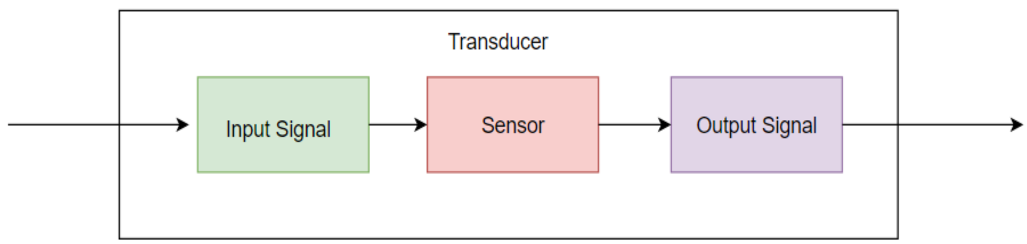

Figure 2. Transducer Structure

Types of transducer

1. Active: - This type of transducers doesn’t require any external source.
2. Actuators: - This device is responsible for moving or controlling a mechanism or system. In short, it is a mechanism by which a control system acts upon an environment.
3. Bidirectional: - This type of transducer converts physical phenomena to electrical signals and vice versa.
4. Passive: - This type generates electric signals in response to an external stimulus without an external source.
5. Sensors: - A sensor is a device that receives and responds to a signal.

3.2.2 Sensors

As we mentioned sensors are the devices which detect the changes of its surrounding and also provide the corresponding output, most of these outputs are electrical or optical signals and also provide different outputs.

Sensors are being used in different applications to detect temperature, light, motion, pressure, distance, and etc. For this thesis work, we use different types of sensors which connect through I2C or GPIO to the Raspberry Pi and get the outputs.

3.3 Implementation of Raspberry Pi with Sensors

3.3.1 Raspberry Pi 2 Model B

The Raspberry Pi 2 is a credit card sized, low-cost computer designed and developed by a British non-profit charity organization called “Raspberry Pi Foundation” which is founded in 2008 in England. Figure 3 shows a Raspberry Pi 2 board that we have used in our project. The Raspberry Pi is a very affordable single-board computer that is very broadly used for different STEM applications. We have used Raspberry Pi 2 which is a much-advanced version of initial designs and offers many new features.

The Raspberry Pi 2 Model B is being released in February 2015 with an upgrade of the ARMv7 multicore processor with 1GB of RAM shared with GPU, this credit card sized computer has been replaced with being a 'play computer' to a functional desktop PC.

One of the most import upgrades is removing the BCM2835 (single core ARMv6) and adding the BCM2836 (quad core ARMv7). The upgrade in processor types means we can see two times the performance increase on the processor-upgrade. The software in this processor can take advantage of multiple-core processors which increase four times the performance on average and for multi thread friendly code can be increased up to 7.5 times in speed.

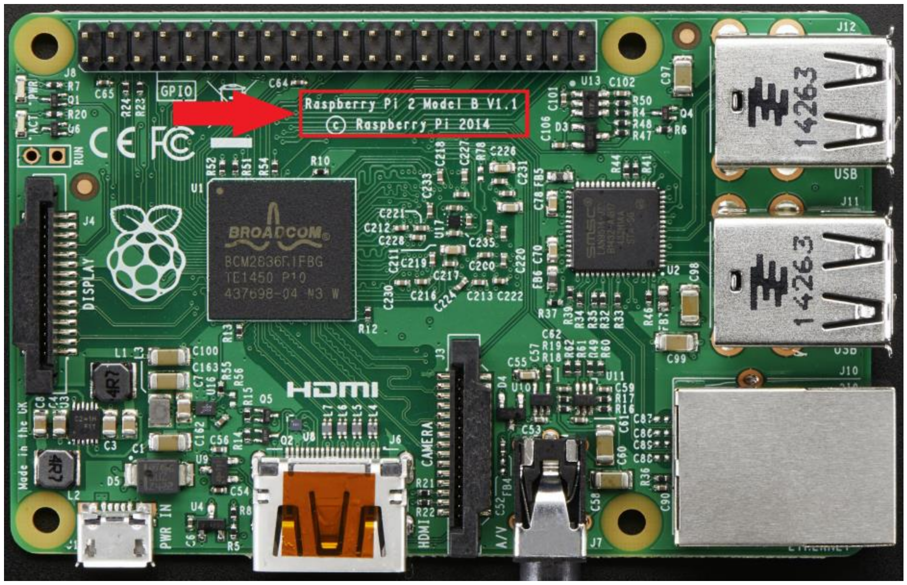

Figure 3. Raspberry Pi 2 Model B

The principle thought behind utilizing Raspberry Pi for STEM projects is the simple interfacing with the outside world, where students can understand implementing. It has a sufficient number of GPIO pins and with I2C bus conductor we can connect multiple sensor and use their interfacing. It is inexpensive and high-performance single board computer. Since it supports many open source software applications, it is very affordable to use Raspberry Pi to build inexpensive HW/SW applications.

The Raspberry Pi also supports Secure Digital (SD) cards with memory range from 4GB to 128GB. We have used 8GB SD cards for various open source software installations and data storage on Raspberry Pi board. We have installed the Wolfram Mathematica [4] computational program, sometimes termed as a computer algebra system or program, which used in many scientific, engineering, mathematical and computational fields.

3.3.2 Raspberry Pi with Camera Connection

In this section, we will discuss regarding the camera interfacing to the Raspberry Pi microprocessor. The camera module come with 15-way ribbon cable, which should have inserted in a right way in between the Ethernet port and the HDMI port of Raspberry Pi or else the camera does not work. The main purpose is to start a task in Wolfram Mathematica and execute it for multiple time and then check the response time of Raspberry Pi processor after connecting the camera. Once we get the response time, we can analyze the Raspberry Pi processor limitation of multiple images for a single task. Figure 4 shows the model of the Raspberry Pi camera which we used in this work.

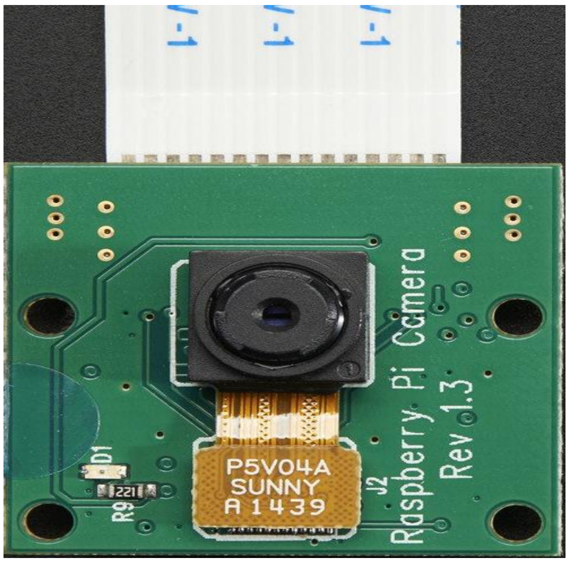

Figure 4. Raspberry Pi Camera Module

Figure 5 provides the basic block diagram of connection between Raspberry Pi and Raspberry Pi camera.

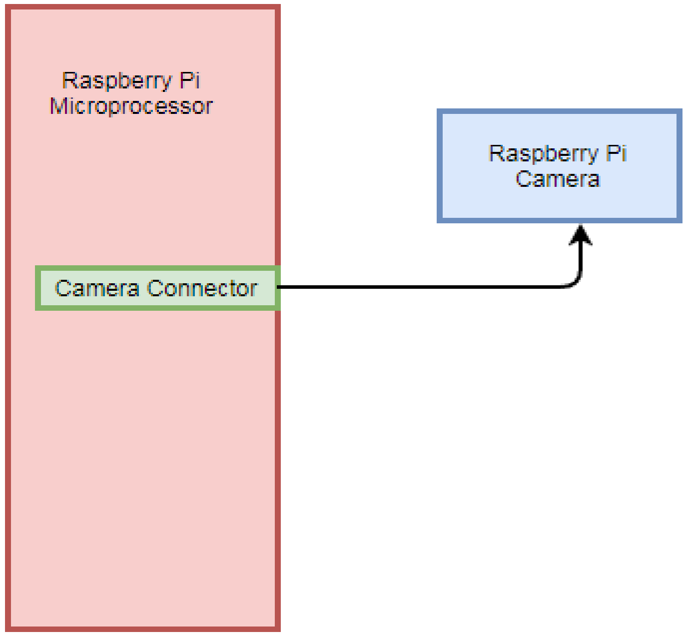

Figure 5. Raspberry Pi Connection with Camera Module

3.3.3 Raspberry Pi with Temperature and Humidity Sensor Connection

Temperature and Humidity sensor [3] is used to measure the outer environment temperature and humidity. This sensor can sense, measure, and report the real-time humidity and temperature of the air. Therefore, we can get moisture content and air temperature. Relative humidity is the ratio of actual moisture in the air to the highest amount of moisture that can be held at that air temperature. The warmer the air temperature is; the more moisture it can hold. Humidity/dew sensors use capacitive measurement, which relies on electrical capacitance. Electrical capacity is the ability of two nearby electrical conductors to create an electrical field between them. The sensor is composed of two metal plates and contains a non-conductive polymer film between them. This film collects moisture from the air, which causes the voltage between the two plates to change. These voltage changes are converted into digital readings showing the level of moisture in the air.

Temperature is the most often-measured environmental quantity. This might be expected since most physical, electronic, chemical, mechanical, and biological systems are affected by temperature. Certain chemical reactions, biological processes, and even electronic circuits perform best within limited temperature ranges. Temperature is one of the most commonly measured variables and it is therefore not surprising that there are many ways of sensing it. Temperature sensing can be done either through direct contact with the heating source or remotely, without direct contact with the source using radiated energy instead. There are a wide variety of temperature sensors on the market today, including Thermocouples, Resistance Temperature Detectors (RTDs), Thermistors, Infrared, and Semiconductor Sensors. Figure 6 shows the HTU21D-F temperature and humidity sensors along with the five pins.

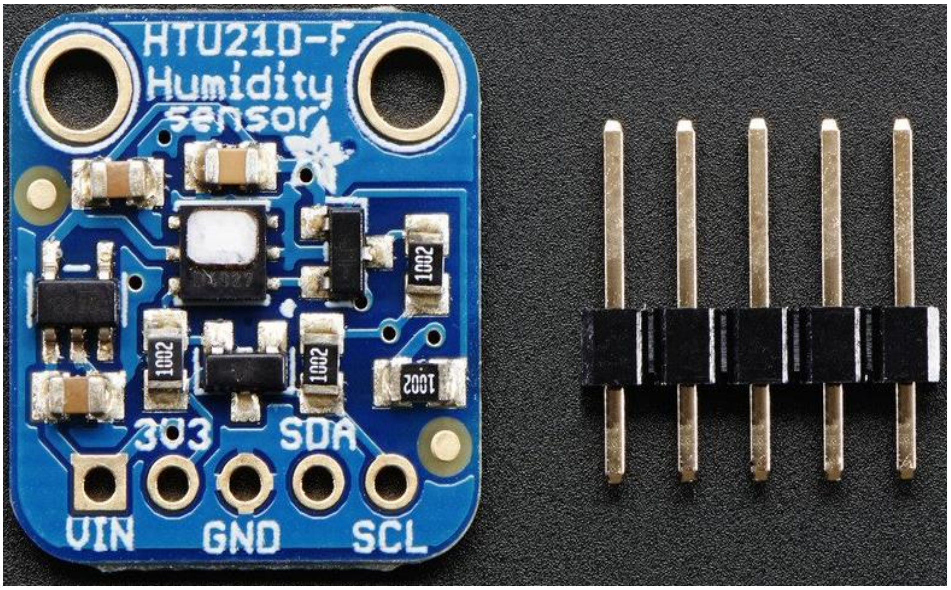

Figure 6. HTU21D-F Temperature & Humidity Sensor

Figure 7 provides the basic block diagram connections of Raspberry Pi I2C pins to the HTU21D-F sensor.

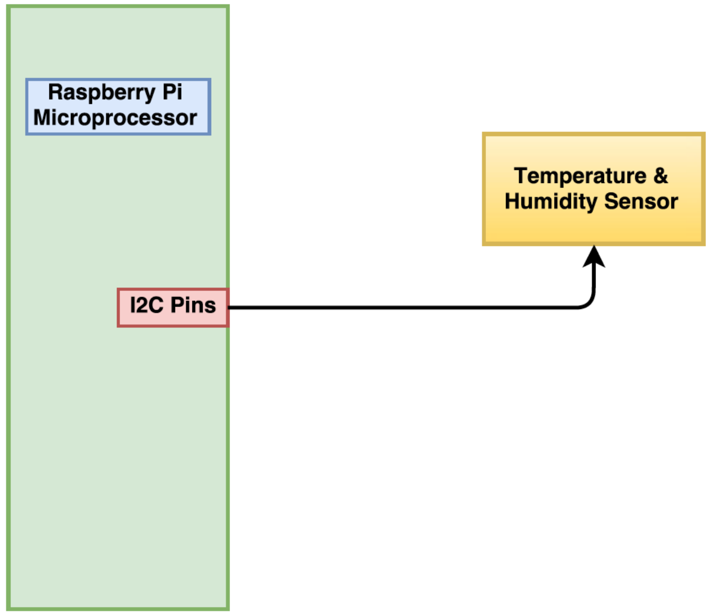

Figure 7. Raspberry Pi Connection with Temperature & Humidity Sensor

3.3.4 Raspberry Pi with Ultrasonic Sensor Connection

In this section, we will discuss regarding the ultrasonic sensor interfacing to the Raspberry Pi microprocessor. We have used HC-SR04 ultrasonic sensors to measure the obstacle distances. The ultrasonic sensors are the low-cost and versatile solution for many robotic applications. It is used to measure the distance of the object by sending and receiving pulsed sound waves. Figure 8 shows a sample sensor board that is used in the model autonomous vehicle. The ideal range of HC-SR04 is specified by the manufacturer (MULTICOMP/China) as from 2cm to 400cm and the beam angle of 15^{o}. The HC-SR04 board has a 40 KHz transmitter and a receiver that is tuned also to 40 KHz. A small electronic circuit produces all timing signals that are required for a reliable measurement. The small PCB board has four pins: $+V_{cc}$, Trigger, Echo, and Ground. The operating voltage of the ultrasonic sensor is 5VDC. Figure 8 shows the Ultrasonic sensors which we have used in our thesis work and Figure 9 provides the basic block diagram connecting the Raspberry Pi and Ultrasonic sensor.

` Figure 8. Ultrasonic Sensor HC-SR04

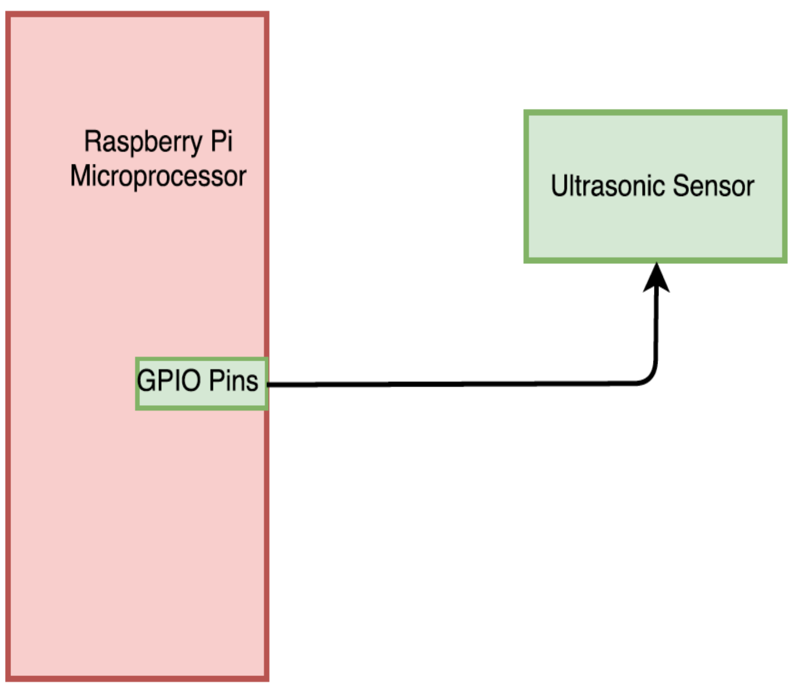

Figure 9. Raspberry Pi Connection with Ultrasonic Sensor HC-SR04

3.3.5 Raspberry Pi with Motion Sensor Connection

PIR sensors are used to detect motion from pets/humanoids from about 20 feet away (possibly works on zombies, not guaranteed). This one has an adjustable delay before firing (approx. 2-4 seconds), adjustable sensitivity and we include a 1 foot (30 cm) cable with a socket so you can easily reposition the sensor or mount it using the two drills on either side. Figure 10 shows the Motion sensor image and Figure 11 provides the basic block diagram connection of motion sensor to Raspberry Pi.

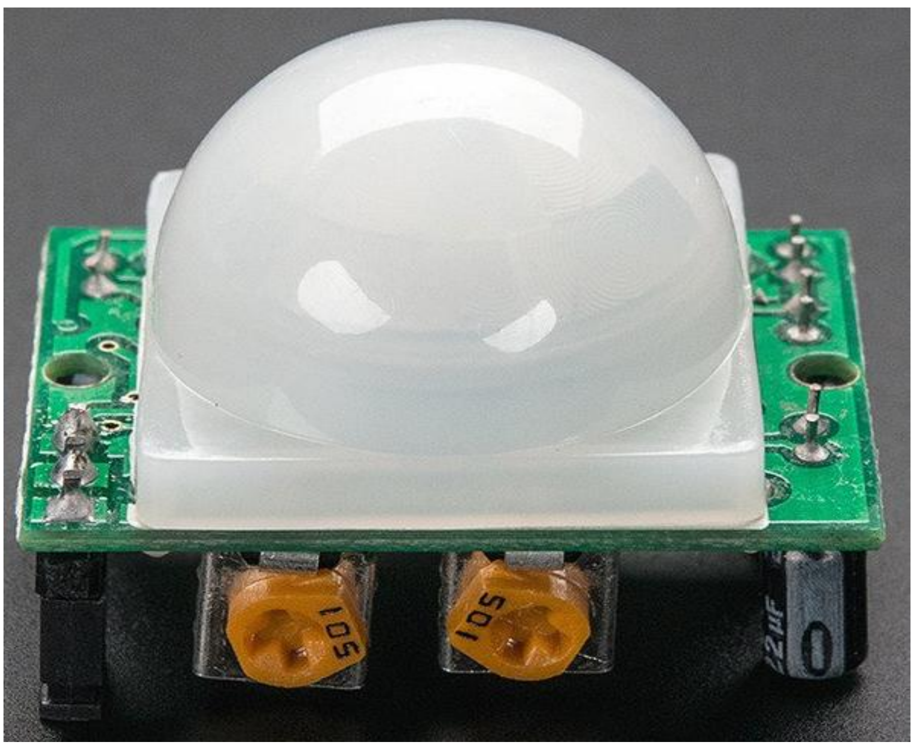

Figure 10. Motion Sensor

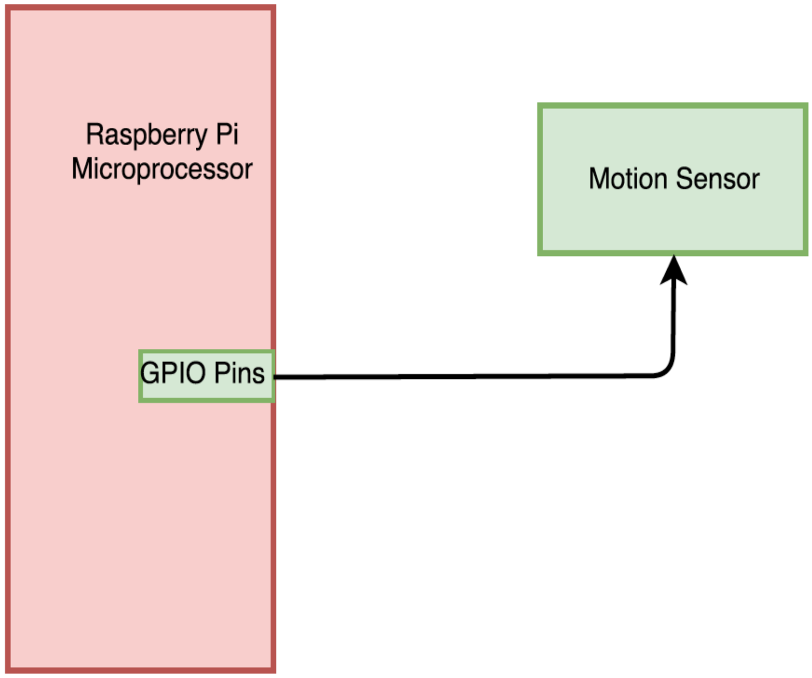

Figure 11. Raspberry Pi Connection with Motion Sensor

3.3.6 Raspberry Pi Connection with Barometric Pressure Sensor

This precision sensor from Bosch is one of the available low costing sensing device which can measure barometric pressure and temperature. As we know that pressure changes with altitude thus we can also use it as an altimeter with this sensor. This sensor is soldered onto a PCB with a 3.3V regulator, I2C level shifter and pull-up resistors on the I2C pins.

The BMP180 is one of the upgraded sensors from Bosch which replaces the BMP085. The good part of this sensor is that it is completely identical to the BMP085 in terms of framework and software. In BMP180 sensor the XCLR pin is not physically present, so if we want to know the data then we need to query the I2C bus. This board is 5V compliant - a 3.3V regulator and a i2c level shifter circuit are included so you can use this sensor safely with 5V logic and power. Figure 12 shows the image of BMP180 Pressure sensor.

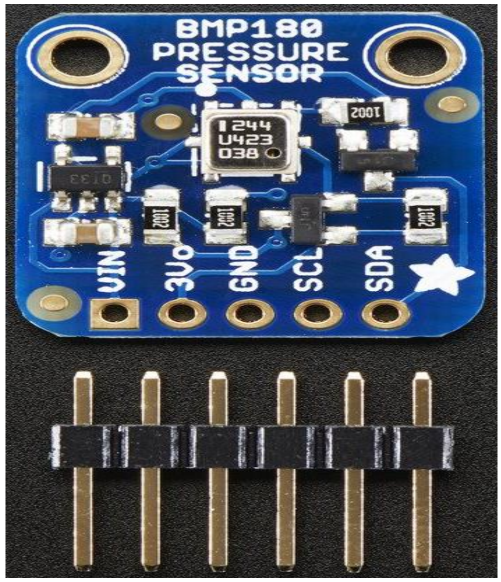

Figure 12. BMP180 Sensor

The BMP180 is a basic sensor that is designed specifically for measuring barometric pressure (it also does temperature measurement on the side to help). It's one of the few sensors that do this measurement, and it's fairly low cost so you'll see it used a lot. You may be wondering why someone would want to measure atmospheric pressure, but it’s actually really useful for two things.

One is to measure altitude. As we travel from below sea level to a high mountain, the air pressure decreases. That means that if we measure the pressure we can determine our altitude - handy when we don't want the expense or size of a GPS unit. Secondly, atmospheric pressure can be used as a predictor of weather which is why weather-casters often talk about "pressure systems". Figure 13 provides the basic block diagram connection of BMP180 sensor.

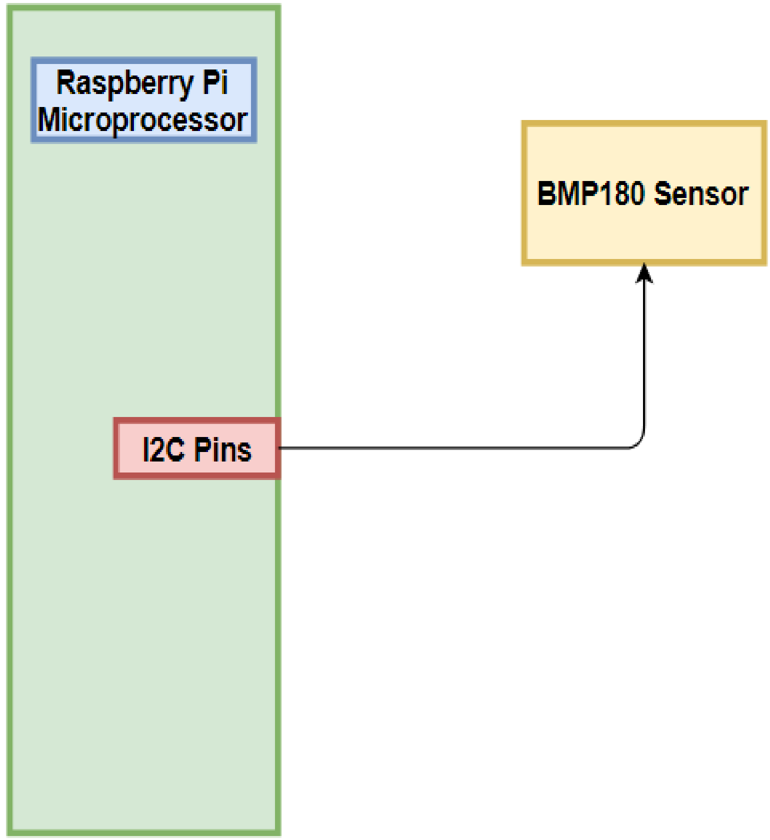

Figure 13. Raspberry Pi Connection with BMP180 Sensor

3.3.7 Raspberry Pi Connection with Stepper Motor

In this section, we will learn how to control a stepper motor using the Raspberry Pi and the L293D motor control chip. Stepper motors fall somewhere in between a regular DC motor and a servo motor. They have the advantage that they can be positioned accurately, moved forward or backward one 'step' at a time, but they can also rotate continuously.

A stepper motor or step motor or stepping motor is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed. Switched reluctance motors are very large stepping motors with a reduced pole count and generally, are closed-loop commuted.

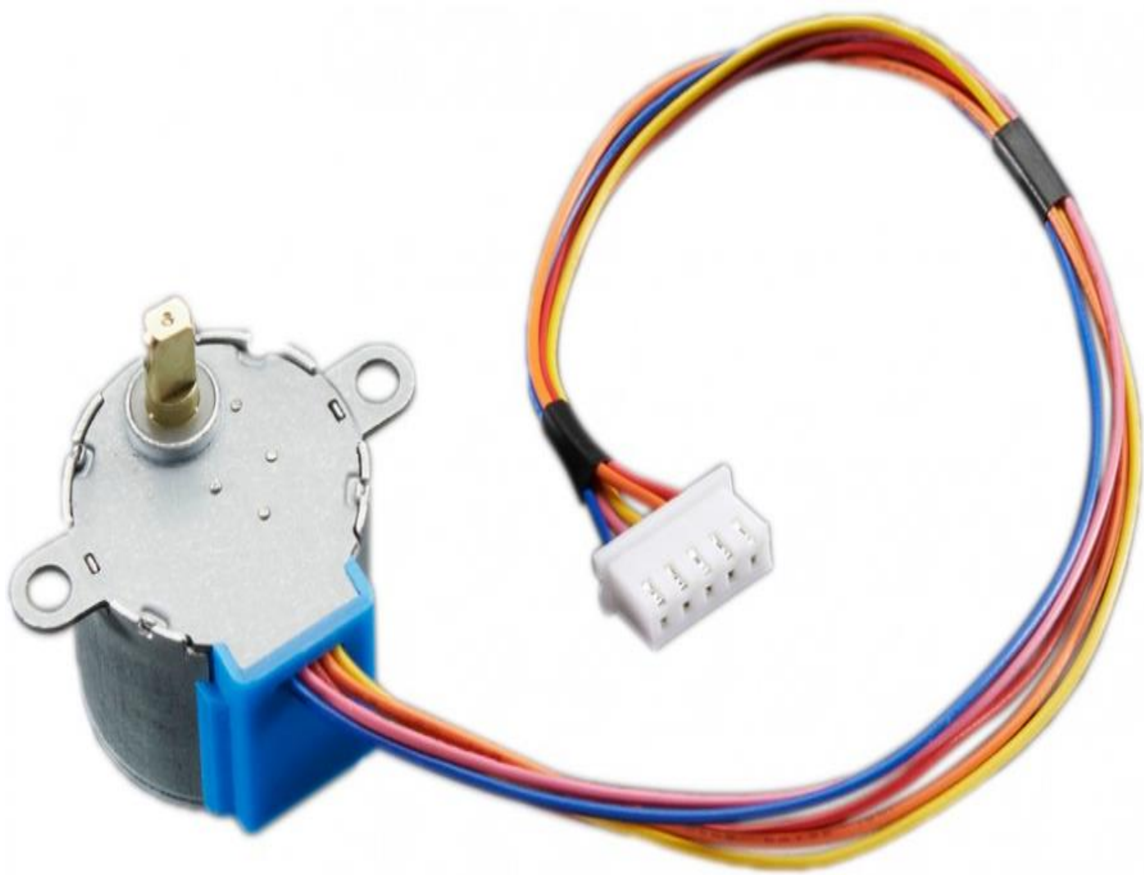

Figure 14. Stepper Motor

We used L293D motor control chip to control the stepper motor. L293D is a dual H-bridge motor driver integrated circuit (IC). Motor drivers act as current amplifiers since they take a low-current control signal and provide a higher-current signal. This higher current signal is used to drive the motors.

L293D contains two in-built H-bridge driver circuits. In its common mode of operation, two DC motors can be driven simultaneously, both in forward and reverse direction. The motor operations of two motors can be controlled by input logic at pins 2 & 7 and 10 & 15. Input logic 00 or 11 will stop the corresponding motor. Logic 01 and 10 will rotate it in clockwise and anticlockwise directions, respectively.

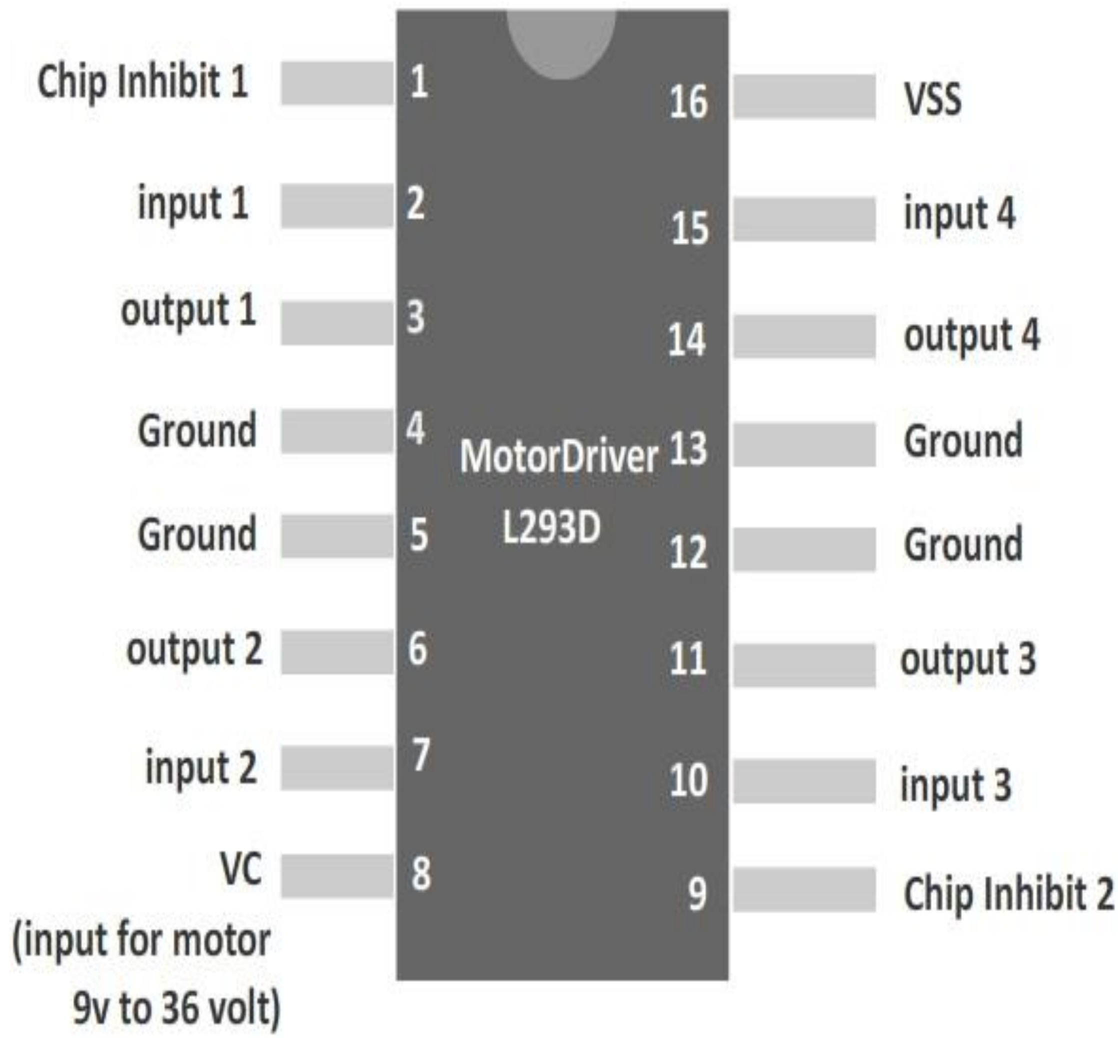

Figure 15. L293D Stepper Motor Driver

Enable pins 1 and 9 (corresponding to the two motors) must be high for motors to start operating. When an enable input is high, the associated driver gets enabled. As a result, the outputs become active and work in phase with their inputs. Similarly, when the enable input is low, that driver is disabled, and their outputs are off and in the high-impedance state. Figure 15 provides with a basic block diagram of connecting the Stepper motor to L293D Motor Driver and then to Raspberry Pi.

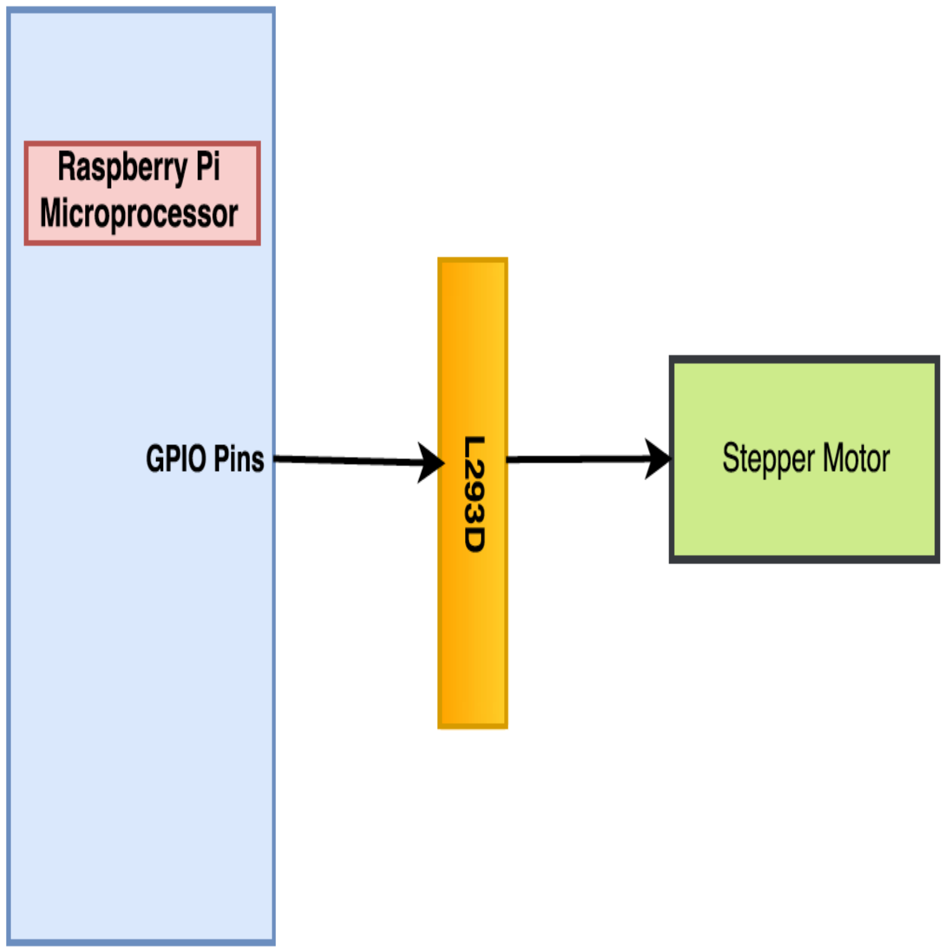

Figure 16. Raspberry Pi Connection with L293D Stepper Motor Driver

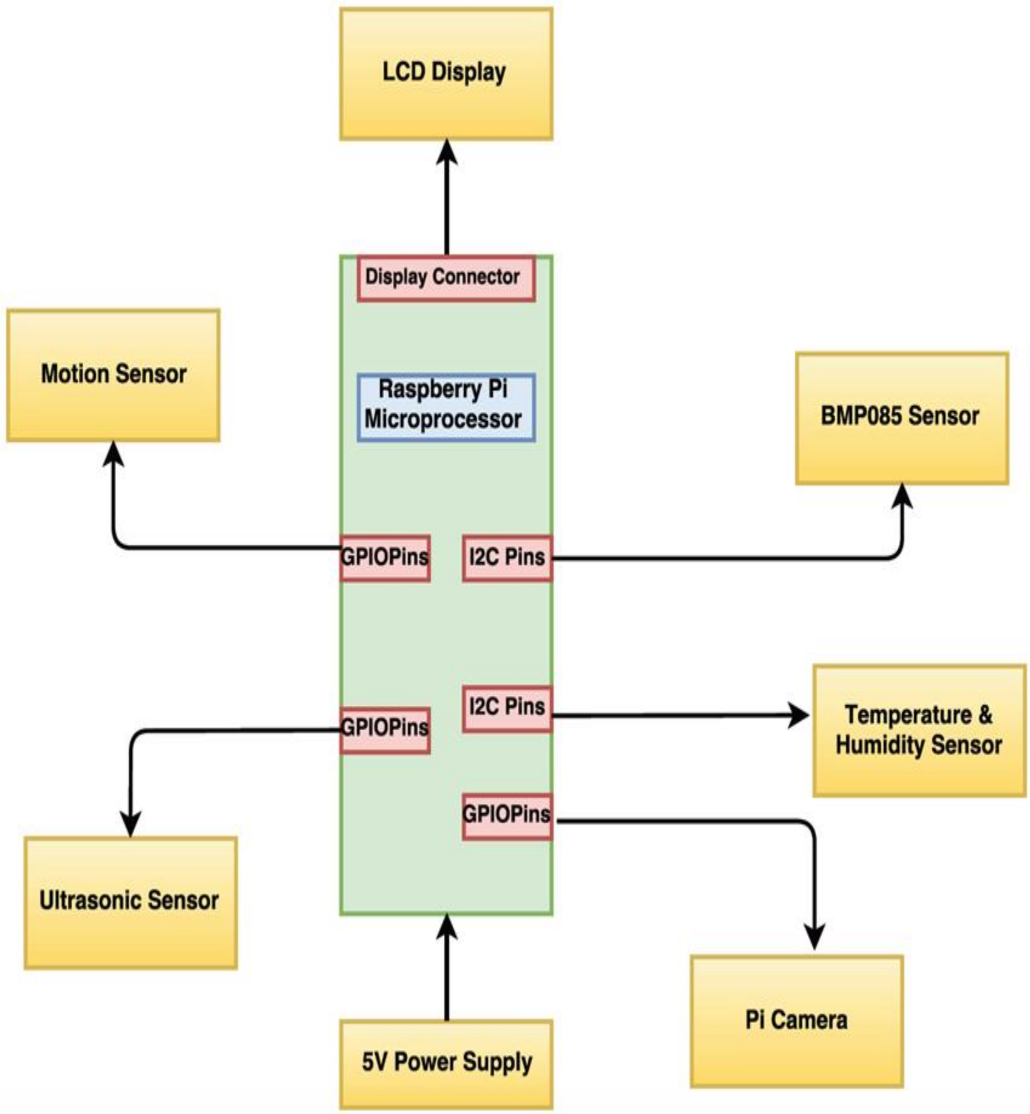

Figure 17 Raspberry Pi Connection with All Sensor

Figure 17 provides with a basic block diagram with over all connections of all sensors of the initial experiment setup to know the performance time of each sensor separately and also know the limitations of these sensors when connected all together.

CHAPTER 4

EXPERIMENTAL WORKING

In this chapter, we will describe the overall experimental working setup of each sensor with Raspberry Pi using Wolfram Mathematica interface and providing the outputs of each sensor with their response times.

4.1 Interface Framework Using Wolfram Mathematica

Using Wolfram Mathematica coding we have tried building a button click interface for repeating the task to get multiple data until the task has been stopped manually by the user with stop task button. This interface can be explained with a simple flowchart, where a scheduled task is being created to provide a set of evaluation for arbitrary expressions in the future. These tasks can be scheduled for one time execution or to make repeated executions at regular intervals of time. Create scheduled task [7] in Wolfram Mathematica just creates a local scheduled task which will repeatedly evaluate the expression within the task for every second. After initiating the whole expression in the create scheduled task, we need to start the scheduled task which we have created before to execute the expression within the task to generate outputs until someone stops the task. Figure 19 shows you the interface buttons in Wolfram Mathematica.

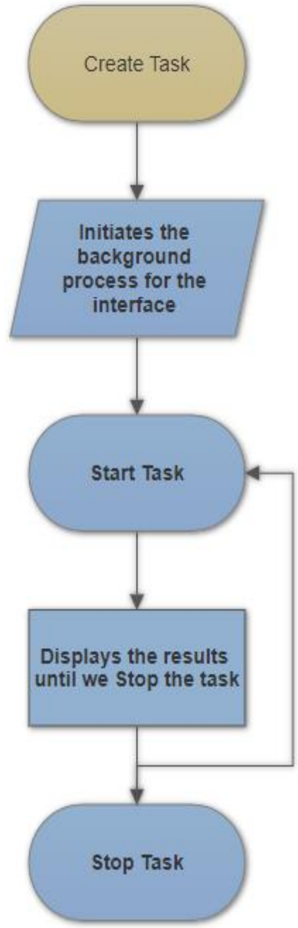

Figure 18. Flowchart of Interface Framework

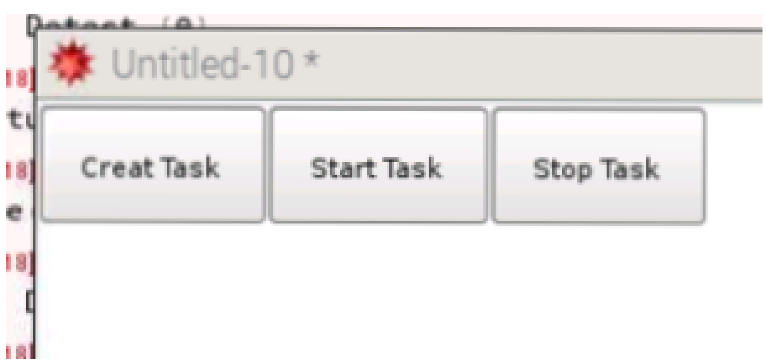

Figure 19. Buttons Interface in Wolfram Mathematica

4.2 Explaining the Case Study with Results

In this section, we will explain the case study of this thesis work along with the results which we have recorded while conducting the experiments. For this case study, we have used 11.0 version of Wolfram Mathematica on Raspberry Pi and connected the sensors through GPIO pins and I2C pi cobbler. With the help of Wolfram Mathematica coding, we can see whether the connections of GPIO pins or I2C pi cobbler sensors are established or not. Figure 20 shows that the Wolfram Mathematica is identifying the GPIO and I2C but it’s not ready to read the data from the sensors. To open the connection for reading the data, we need to write a code to open the device objects which will show it is “Connected” with a green circle beside the status column when its ready to use.

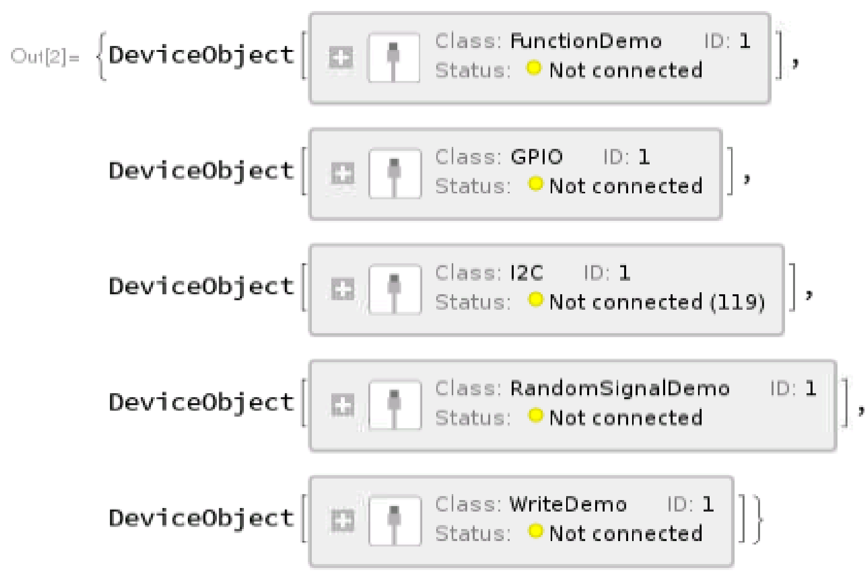

Figure 20. GPIO & I2C Object

4.2.1 Capturing the Images from Raspberry Pi Camera

Each sensor in Wolfram Mathematica is considered as a device where we need to open and read these devices for the output. This camera module is a custom designed and connected through dedicated CSI bus connector of Raspberry Pi. As we mentioned in the interface framework section, we have written scheduled task to repeat the process of collecting the images and see the limitation of Raspberry Pi camera through Wolfram Mathematica. Initial task is we have set up to capture the image for every 5.00 seconds and the response time or the execution time for the first image was 0.57 second. However, when we change the image capturing time for every 1.00 second and run the scheduled task, then the Wolfram Mathematica notebook has stopped working without executing the code. So, we needed to kill the local kernel to make it work on the notebook. While capturing the images for every 5.00 seconds, we have come across an error in Wolfram Mathematica stating that the memory has been full. These were the two limitation which we came across while we are working with Raspberry Pi camera.

4.2.2 Collecting the Humidity and Pressure sensors data.

Initially, for these Humidity and Pressure sensors, we connect Arduino UNO micro controller with Raspberry Pi to read the data of these sensors. For this experimental setup, we have hard-coded in Wolfram Mathematica to find and record the physical address of these sensors for future use. Figure 21 shows the physical address of Humidity and Pressure sensors. Using sudo i2cdetect -y 1 command, we find the physical address and store these addresses in a Wolfram Mathematica variable. After storing the address into the variable, we execute the code get the output in a scheduled task. But here we came across a limitation in Wolfram Mathematica where it is only detecting one I2C sensor at a time. So, we are unable to read the Pressure sensor data through Wolfram Mathematica.

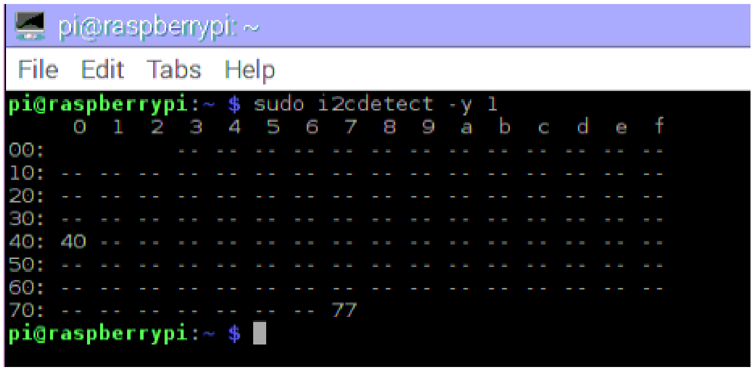

Figure 21. I2C Sensors Address

Figure 22 shows the graphed data of Temperature and Humidity along with execution time of single I2C sensor.

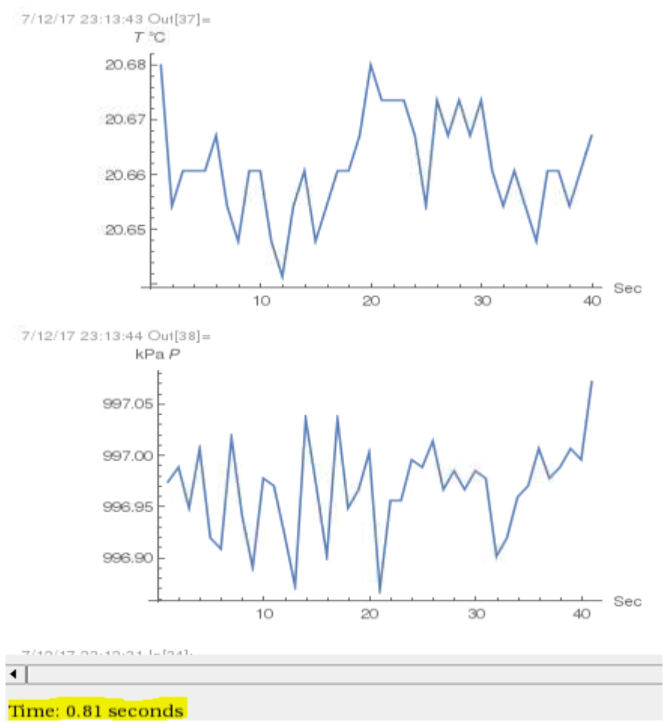

Figure 22. Humidity Sensor Data

4.2.3 Integrating Ultrasonic Sensor with the System

For the Ultrasonic sensors, we coded using Python to get the outputs to check how efficiently Raspberry Pi can execute multiprogramming, while running Wolfram Mathematica and Python at the same time. Here is the delay of the execution time of the both programs showing less than 0.29 seconds because we have connected only two Ultrasonic sensors to Raspberry Pi through GPIO pins. Whenever we add an extra sensor to Raspberry Pi, the execution time got increased. Figure 23 shows the output distance data of the Ultrasonic sensors.

```
Measured Distance = 14.4 cm
Measured Distance = 14.5 cm
Measured Distance = 14.5 cm
Measured Distance = 14.5 cm
Measured Distance = 9.3 cm
Measured Distance = 6.5 cm
Measured Distance = 12.1 cm
Measured Distance = 6.2 cm
Measured Distance = 14.4 cm
Measured Distance = 14.4 cm
Measured Distance = 14.4 cm
Measured Distance = 14.5 cm
Measured Distance = 14.5 cm
```

Figure 23. Ultrasonic Sensor Distance Output

4.2.4 Detection with Motion Sensor

Here in this experimental setup, we have connected two Motion detecting sensors. We recorded the execution time of each sensor separately and combined. When executing the single motion sensor, we got 0.22 seconds as the execution time and when we added second sensor, we got 0.26 seconds as the execution time.

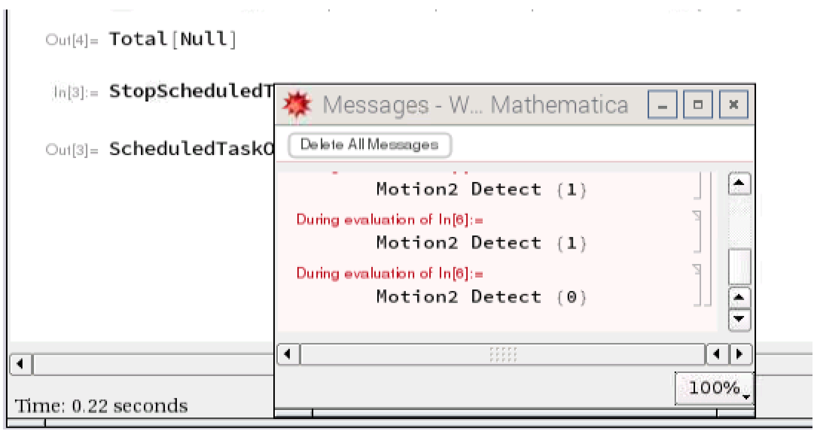

Figure 24. Single Motion Sensor Data

The execution time is increasing whenever we add the sensors. If this is the situation, then it will be drawback when we want to get the data from these sensors in real-time.

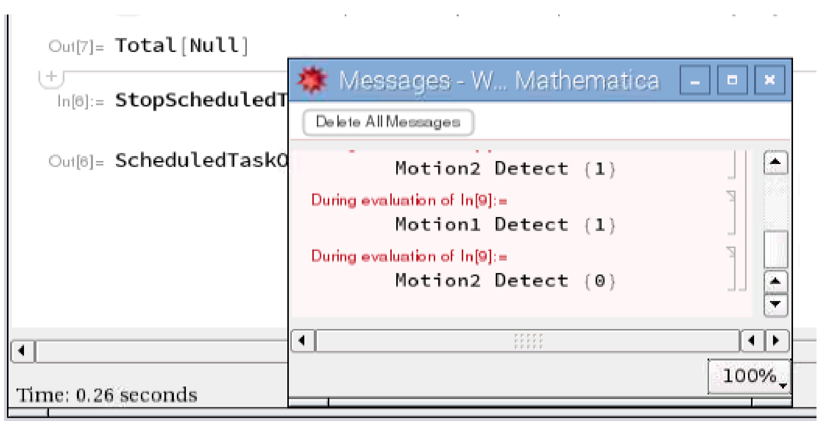

Figure 25. Double Motion Sensor Data

4.2.5 System Output with all Sensors

This is our final experimental setup, where we added all the seven sensors and connected to Raspberry Pi. If we execute all of them together, we have got 28.35 seconds as the execution time which we can see in Figure 27.

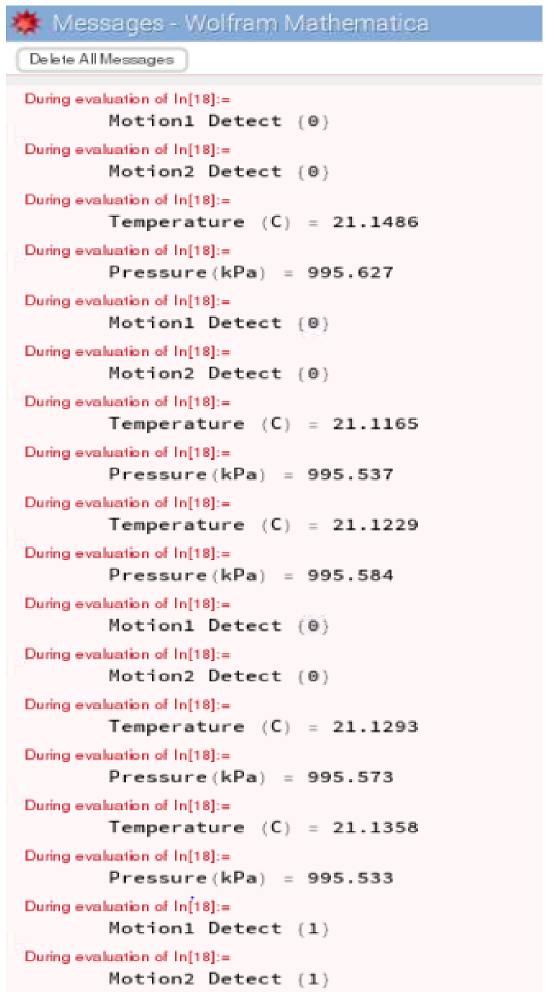

Figure 26. Output Data of all Sensors

As per I2C protocols, we can connect 100 to 110 sensors in parallel to get the data out of these sensors. But the major problem will be the execution time, by all these experimental setups we can say that execution time is one of the limitations of Raspberry Pi.

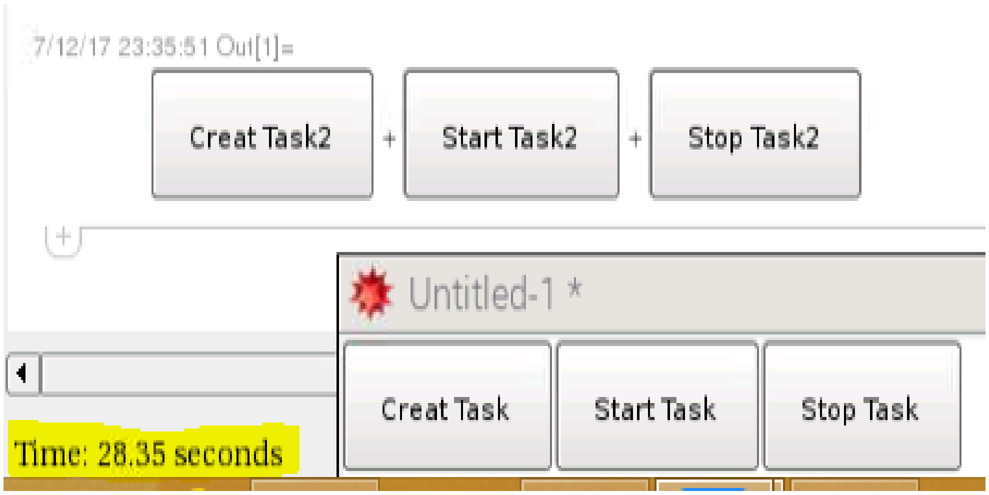

Figure 27. Execution Time of all the Sensors

CHAPTER 5

CONCLUSION AND FUTURE RESEARCH

5.1 Conclusion and Summary

We have designed a complete device with the initial interface for different sensors like Temperature & Humidity Sensor, Ultrasonic sensors, Motion Sensor etc., using Wolfram Mathematica. We developed an effective visual interface by which we can plot the sensors data in real-time with the help of graphs of better understanding. This is much helpful for the training of basic Engineering courses for high school students in the STEM program. Our goal is to find out the capability and limitations of the raspberry pi which is commonly used in the STEM.

5.2 Limitations & Future Work

Due to the limited time for the thesis work, our project has some limitations with Wolfram Mathematica. This device is programmed with Mathematica to do limited tasks. But for some of the sensors, the I2C is not working for multiple devices like BMP180 due to the device address issue and there is some delay in the output for each loop execution. In addition to that, we encountered another problem with the voltage levels while driving the Stepper Motor. The voltage required to drive the stepper motor is used by the other sensors too which is making impossible to drive the stepper motor but we can still drive the motor if we only use the stepper motor.

Due to the limited time for thesis work, our project has some limitations. The device is preprogrammed to do only particular tasks. For creating more enthusiastic for the students we will create a custom design kit with 7”-10” Inch GLCD (Graphical Liquid Crystal Display) with possible touch screen which will make the learning process more attractive for the students. Another thing is to consider that we need to supply additional power supplies for the different components like stepper motor for now and if we use any additional sensor which may require in future. We also considering the upgrading of the interface to make it much more easily than the present one and to reduce the execution time of the interface.

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APPENDIX A

SETTING UP RASPBERRY PI

A.1 Installing Rasbian operating system for RPi 2

- Download the Raspbian operating system with Jessie to your machine (laptop or PC) which is based on Debian. Then use a 7zip extractor to extract the image file which we can download free from their websites and have been tested to unzip the image correctly.
- Raspbian comes preinstalled with a lot of softwares for education, programming, and general use. It has Mathematica, Python, Scratch, Sonic Pi, java, and more.
- Copy that extracted file to micro secure digital(SD) card which should be more than 4Giga bytes(GB)
- Then plug in the SD card, power supply, and necessary hardware components to your raspberry pi and start the raspberry pi. Which should usually take around 30 min to install the operating system. Then from the next time, it will take less than five seconds to boot up the device and RPi will boot in Jessie mode.

A.2 Updating Raspberry Pi to the lastest software

Even if we install the latest Rasbian Jessie with the pixel, we need to update the firmware and other if any. It’s good if we update and upgrade every time before installing something.

- $sudo apt-get update
- $sudo apt-get upgrade

A.3 Installing GPIO libraries

We need to install some additional libraries if we want to access to General Purpose Input and Output (GPIO) pins from python code. This will help you to send commands to external hardware modules and to take data from outside through GPIO pins.

- $sudo apt-get update
- $sudo apt-get upgrade
- $sudo apt-get -y install python-rpi.gpio

A.4 Installing I2C-Tools

We need to enable I2C communication by installing some of the libraries.

- $sudo apt-get install i2c-tools
- $sudo apt-get install python-smbus.

Then check whether the sensors are to Rpi or not by using

- $sudo i2cdetect -y 1

Then we will recognize the different I2C address for each component as assigned by the manufactures of the sensors. This address is different for different sensors to communication with the raspberry pi.

A.5 Installing libraries for Real VNC

We can only install one of the remote desktop software in raspberry, either xrdp or real VNC for remote desktop connections. Real VNC is far better xrdp in many aspects.

Installing Libraries for Virtual Network Connections:

If we want to connect to RPi from anywhere then we need to install some additional libraries:

- $sudo apt-get update
- $sudo apt-get upgrade realvnc-vnc-server realvnc-vnc-viewer

If we booted Rpi in pixel mode, we need to go to Menu > Preferences > Raspberry Pi Configuration > Interfaces and check that VNC is set to Enabled. Go to Real VNC Website and create an account with an email address and password and the open Real VNC in Rpi and select Licensing from the VNC server menu and sign into your VNC account with the email address and password provided. Then you will find your Raspberry pi under the name of your team.

A.6 Installing Mathematica

Mathematica is a computational programming tool used in science, maths, computing and engineering, first released in 1988. It is proprietary software that you can use for free on the Raspberry Pi and has been bundled with Raspbian and NOOBS since late 2013. Mathematica is already preinstalled in Raspbian Jessie if in any cases it wont present the below are the steps to install Mathematica.

Mathematica and The Wolfram Language are now available from ours and the Raspberry Pi foundation's software repositories for the default Raspbian Linux distribution for the Pi. If you're running a Raspbian image provided by the Raspberry Pi foundation, you can now install the software with the following steps.

1. Ensure that you have at least **600** megabytes of free storage on your Raspberry Pi's SD card. The package itself will take up 429 megabytes of disk space when installed.
2. $ sudo apt-get update && sudo apt-get install wolfram-engine
3. Agree to the licensing terms displayed (Use tab to move between fields in the license window. You will only need to do this once).
4. Wait for the installation to complete.

You should now find Mathematica and the Wolfram Language installed on the LXDE desktop under the Education menu and the Wolfram Language under the programming menu.

In order to start the application from the Linux command line, type:

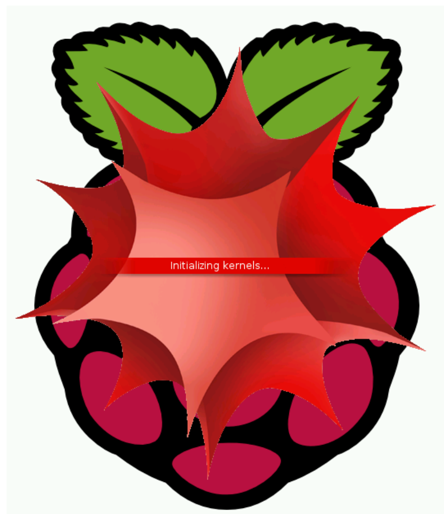
$ wolfram

To start Mathematica, type:

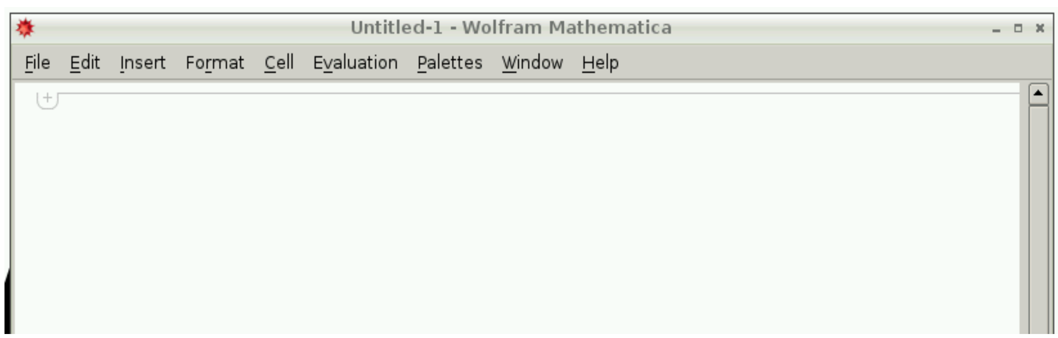
$ mathematica

To Start Mathematica:

Double-click the Mathematica icon on the Desktop or open it from the applications menu to start. You'll see a splash screen with the red Mathematica logo while the program loads:



Once loaded, you'll see two windows. These are the Wolfram information dialogue: and the Mathematica notebook.

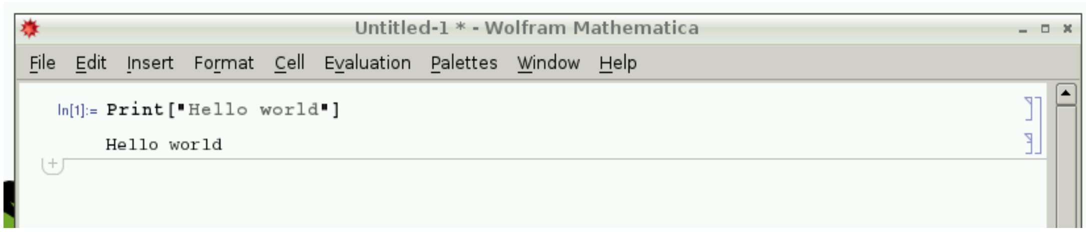


To Program in Mathematica:

Click inside the notebook window and enter:

```
Print["Hello world"]
```

Press Shift + Enter; it will run the command and print "Hello world" to the screen like so:



A.7 Python Programming Language

Python programming language is developed in the late 1980s at the National Research Institute by Guido van Rossum. Python has grown in popularity, and it is widely used commercially. (Upton, E. & Halfacree, G. 2012, 152.). Python is a flexible and powerful programming language but still it is easy to learn and follow. The clear syntax of Python makes it a valuable tool for users who wants to learn programming. This is one of the reasons why it is recommended by the Raspberry Pi Foundation. Python is published under an open-source license and it is available for different operating systems. Python runs on Linux, OS X and Windows computer systems. (Upton, E. & Halfacree, G. 2012, 152.) Cross-platform support guarantees that the programs which are written in Python are also compatible in other platforms. There are few exceptions where the programs are not compatible. For instance, when the Python is addressed to use the specific hardware such like Raspberry Pi's GPIO. (Upton, E. & Halfacree, G. 2012,152).

APPENDIX B

WOLFRAM MATHEMATICA SKETCH

This chapter of appendix includes all the code related to the interface and to the sensors coding used in Wolfram Mathematica.

```
Total[CreatePalette[{
temp = {};
pr = {};
delay = 0.5;
rGet[reg_] :=
StringTrim[
RunProcess[{"i2cget", "-y", "1", chipAdr, reg},
"StandardOutput"]];
rPut[reg_, value_] :=
StringTrim[
RunProcess[{"i2cset", "-y", "1", chipAdr, reg, value},
"StandardOutput"]];
usGet[reg1_, reg2_] := (V = Flatten[{rGet[reg1], rGet[reg2]}];
V1 = Map[FromDigits[#, 16] &, StringReplace[V, "0x" -> ""]];
BitShiftLeft[V1[[1]], 8] + V1[[2]]);
ssGet[reg1_, reg2_] := (r = Flatten[{rGet[reg1], rGet[reg2]}];
V1 = Map[FromDigits[#, 16] &, StringReplace[r, "0x" -> ""]];
V2 = BitShiftLeft[V1[[1]], 8] + V1[[2]];
If[V2 > 32767, -32768 + (V2 - 32768), V2]);

Button["Creat Task",
readTP = CreateScheduledTask[ (*read temperature*)
chipAdr = "0x77";
ac1 = ssGet["0xaa", "0xab"];
ac2 = ssGet["0xac", "0xad"];
ac3 = ssGet["0xae", "0xaf"];
ac4 = usGet["0xb0", "0xb1"];
ac5 = usGet["0xb2", "0xb3"];
ac6 = usGet["0xb4", "0xb5"];
```

```
b1 = ssGet["0xb6", "0xb7"];
b2 = ssGet["0xb8", "0xb9"];
mb = ssGet["0xba", "0xbb"];
mc = ssGet["0xbc", "0xbd"];
md = ssGet["0xbe", "0xbf"];
rPut["0xf4", "0x2e"]; Pause[0.05];
ut = usGet["0xf6", "0xf7"];
V3 = (ut - ac6)*ac5/2.^15;
V4 = mc*2.^11/(V3 + md);
V5 = V3 + V4;
t = (V5 + 8.)/2.^4/10.;
Print["Temperature (C) = ", t];
AppendTo[temp, t];

        (*Read Pressure*)
rPut["0xf4", "0x34"]; Pause[0.05];
up = usGet["0xf6", "0xf7"];
V6 = V5 - 4000.;
x1 = (b2*(V6*V6/2^12))/2^11;
x2 = ac2*V6/2^11;
x3 = x1 + x2;
b3 = ((ac1*4 + x3) + 2)/4.;
x1 = ac3*V6/2^13;
x2 = (b1*(V6*V6/2^12))/2^16;
x3 = ((x1 + x2) + 2)/2^2;
b4 = ac4*(x3 + 32768)/2^15;
b7 = (up - b3)*50000;
If[b7 < FromDigits["80000000", 16], p = b7*2/b4, p = b7/b4*2];
x1 = p/2^8*p/2^8;
x1 = x1*3038/2^16;
x2 = (-7357*p)/2^16;
p = p + (x1 + x2 + 3791)/2^4;
p = p*0.01;
```

```
Print["Pressure(kPa) = ", p];
AppendTo[pr, p], delay], FrameMargins -> 15]

Button["Start Task", StartScheduledTask[readTP]
Dynamic[
ListLinePlot[temp, Joined -> True, PlotRange -> Automatic,
AxesLabel -> {"Sec", T (\[Degree]C)}]];
Dynamic[
ListLinePlot[pr, Joined -> True, PlotRange -> Automatic,
AxesLabel -> {"Sec", P (kPa)}]];
, FrameMargins -> 15]

Button["Stop Task", StopScheduledTask[readTP] , FrameMargins -> 15]
},
WindowSize -> {800, 800}, WindowMargins -> Automatic];
DeviceOpen["GPIO"]

{Enable, coilA1, coilA2, coilB1, coilB2} = {18, 4, 17, 23, 24};

timestep = 0.005;
step = 68;


    DeviceConfigure[
    "GPIO", {Enable -> "Output", coilA1 -> "Output",
    coilA2 -> "Output", coilB1 -> "Output", coilB2 -> "Output" }];

    DeviceWrite["GPIO", Enable -> 1];


    motor = CreateScheduledTask[
    DeviceWrite[
    "GPIO", {coilA1 -> 1, coilA2 -> 0, coilB1 -> 1, coilB2 -> 0}];
```

```
Pause[timestep];
DeviceWrite[
"GPIO", {coilA1 -> 0, coilA2 -> 1, coilB1 -> 1, coilB2 -> 0}];
Pause[timestep];
DeviceWrite[
"GPIO", {coilA1 -> 0, coilA2 -> 1, coilB1 -> 0, coilB2 -> 1}];
Pause[timestep];
DeviceWrite[
"GPIO", {coilA1 -> 1, coilA2 -> 0, coilB1 -> 0, coilB2 -> 1}];
Pause[timestep], {0.1, step}];

reversemotor = CreateScheduledTask[
DeviceWrite[
"GPIO", {coilA1 -> 1, coilA2 -> 0, coilB1 -> 0, coilB2 -> 1}]
Pause[timestep]
DeviceWrite[
"GPIO", {coilA1 -> 0, coilA2 -> 1, coilB1 -> 0, coilB2 -> 1}]
Pause[timestep]

ClearAll;

DeviceOpen["GPIO"];

{sense1, sense2} = {22, 27} ;(*GPIO read/write pins: 25*)

DeviceConfigure["GPIO", {sense1 -> "Input", sense2 -> "Input"}];
Do[

DeviceWrite["GPIO", pins[[1]]->1];

Pause[.2];
```

```
DeviceWrite["GPIO", pins[[1]]->0];

Pause[.2];

,{15}]

runPython@"

Libraries

import RPi.GPIO as GPIO

import time

(*GPIO Mode (BOARD BCM) *)

GPIO.setmode(GPIO.BCM)

(*set GPIO Pins *)

GPIO_TRIGGER = 24

GPIO_ECHO = 23

(*set GPIO direction for IN & OUT *)

GPIO.setup(GPIO_TRIGGER, GPIO.OUT)

GPIO.setup(GPIO_ECHO, GPIO.IN)

def distance():

(* set Trigger to High *)

GPIO.output(GPIO_TRIGGER, True)

(* set Trigger after 0.01ms to Low *)
```

```
time.sleep(0.0001)

GPIO.output(GPIO_TRIGGER, False)

StartTime = time.time()

StopTime = time.time()

(* save the StartTime *)

while GPIO.input(GPIO_ECHO) == 0:

StartTime = time.time()

(* saves the time of the arrival*)

while GPIO.input(GPIO_ECHO) == 1:

StopTime = time.time()



(*time difference between start $ arrival*)

TimeElapsed = StopTime - StartTime

(* multiply with the sonic speed by (34300 cm/s) *)

(* and divide by 2 *)

distance = (TimeElapsed * 34300) / 2

return distance

if name == 'main':

try:
```

```
while True:

dist = distance()

print (" Measured Distance  of Sensors = % .1 f cm " % \

dist)

time.sleep(1)

except KeyboardInterrupt:

print(" Measurement stopped ")

print(" Task has been Killed ")

GPIO.cleanup()

"
```

```
Button["Creat Task2", read = CreateScheduledTask[

Print["Motion1 Detect ",
motion1 = Values[DeviceRead["GPIO", sense1]]];
Print["Motion2 Detect ",
motion2 = Values[DeviceRead["GPIO", sense2]]], 5],
FrameMargins -> 15]

Button["Start Task2", StartScheduledTask[read], FrameMargins -> 15]

Button["Stop Task2", StopScheduledTask[read], FrameMargins -> 15]]
```