DEVELOPMENT OF A LOW COST INERTIAL MEASUREMENT UNIT SYSTEM WITH A HIGH SAMPLING FREQUENCY

A Project Proposal

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1.0 Introduction

Motion capture technology has evolved over the last century, from its early application in 19th century stop-motion animation to its application in developing big budget block-buster Hollywood movies such as Avatar and the Lord of the Rings Trilogy. But the origins of the science of motion capture and human motion analysis predates the 19th century as works by Aristotle, Leonardo Da Vinci, Gallileo, Euler etc. all laid the foundation for what E.J Marey applied scientifically to develop what is the modern day analytical concept of motion capture. Motion capture and analytical systems have been employed to capture and analyse the movement of the human body by multiple disciplines across the board. The need for motion analysis can be attributed to the fact that scientists and researchers alike seek to understand the complex mechanism used to interpret muscular movements about joints into visible functional activities. Activities such as walking, climbing, running etc. can be interpreted from muscular movements by motion capture systems. The working principle behind motion capture technology is in its ability to capture the movement of any subject (humans, animals or puppets) or static object existing in the real World and extracting relevant data for mapping of the movements into man-made synthetic creatures, into robots or into a data repository for executing commands or to study the behaviour of a part or the whole of any given subject. Motion capture technology has been applied in different disciplines. The most popular disciplines besides the Movie and Gaming industry, that motion capture technology has been used in are that of clinical research and sports sciences. In clinical research, medical scientists have used motion capture in gait analysis. The gait patterns of individuals who have been diagnosed with a disorder have been studied to deduce the rate at which the individual had been affected by the disorder and help plan a treatment protocol. In sports sciences, motion capture technology has been employed by sports scientists to improve the performance of athletes and develop better injury prevention strategies. This project proposal intends to introduce a model device that can be used in the motion capture and analysis of a human subject

1.1 The case for an efficient custom built wearable motion capture system

An effective wearable motion capture system would ensure that the data acquired from activities such as those (walking, running, cycling etc.) being performed in the sport sciences are as accurate as possible and is less affected by the environment in which its being carried out in. Designing an efficient wearable motion system is therefore tantamount to acquiring data that closely correlates with or describes the key aspects of any type of body motion in real life. The design of the wearable system is always the first step to ensuring the accuracy of the acquired data. The implementation of the said design, from building blocks of sub component parts into the complete or finished system is also a key step in maintaining the integrity of the end line data. Although, there are many commercial off-the-shelf wearable motion capture systems like the Xsens ® motion capture system, with a high degree of performance and proven durability in a controlled environment, the cost of acquiring such a system prevents easy access to them. A custom built wearable motion capture systems such as the one being put forward in this proposal, would ensure that there is an active bypass on the running costs of acquiring a commercially expensive off the-shelf efficient motion capture system and provide a platform that bridges the gap between low and high budgetary experimental environments. A low budget experiment will be subjected to factors such as a reduced sample size but this will be countered by a better controlled environment and a prompt efficient data analysis. The custom-built system will be cost effective and would be as efficient as its commercial counterparts. What the system makes up for in terms of cost would be paid for in terms of the man hours that would be used to design and build the system from the ground up. This in a nutshell, makes the case for the use of custom built systems over commercially available ones. The next step in the application of the system would be the methodology of its placement on the human anatomy.

1.2 The Significance of the Custom-Built System placement

Like the saying goes "if wishes where horses……". Any cost-effective system will be subjected to factors that will generally hamper its overall functionality. In this regard, the custom-built sensor will be bulky. The bulkiness of the system is because of its casing; this was necessary to ensure that the effect of external factors such as environmental vibrations are cushioned out as best as possible. To make up for the effects of the system size, the placement of the system was key to ensuring that the acquired data is accurate and describes the actual activity being carried out. This thesis aims to compare the data acquired from the chest and upper limbs, therefore the method of placement of the system would go a long way to ensuring that the result of the experiment is accurate and a valid conclusion is drawn. Although, there have been various works carried out in this field in regards to wearable system accuracy in detecting upper body motion, whereas current works in the field concentrated on addressing activity classification algorithms, this model device can be used to validate the effectiveness of a chest mounted data in acquiring accurate upper body motion data. This in the future will help answer the question of whether a single mounted wearable motion capture system is enough to accurately describe upper body movement. Power spectral density can be applied in analysing the signal data thus allowing for an easy efficient means of evaluating the signal data by comparing the energy and frequencies of the signal data across different activities. Although there are many complex analytical tools available for analysing sensor data the simplicity of the power spectral density function means a reduction in the overall processing time of the motion capture system.

2.0 Project Overview

In this section, the proposal to complete the software/hardware development portion of the Inertial Motion Unit device, will be introduced. It will give a description of the purpose of the project and the objectives that are to be accomplished. It would also highlight the assumptions and constraints that underlie the project effort, the project deliverables, schedule and budget.

2.1 Purpose, Benefit and Scope

The purpose of this software project is to design a low cost inertial motion unit (LCIMU) device with an above average sampling rate of ±60Hz. Since most commercially available IMU devices are quite expensive and complex to integrate as a holistic system, this proposed inertial system will serve as a cost-effective alternative to the commercially available ones. Also, as the device would be manually developed and composed of various component parts, the performance of the inertial measurement unit can be improved by incorporating the most efficient and stable component parts available. The device would consist of three individual IMU's; a chest mounted IMU, a left limb mounted IMU and a right limb mounted IMU, which are all connected to a centrally mounted IMU. The data from the centrally mounted IMU will be collected on a base station (Laptop).

The software for the project will be written on the Arduino platform (that would aid the interaction between the sensors and the microcontroller), Intelli J (this would aid the transfer of data from the centrally mounted IMU to the base station) and on MATLAB (this would allow for the analysis of the captured data).

All activities related to the purpose of the project are in scope while others not related to the purpose of the project are out of scope. For example, customized user interfaces, activity classification and pattern recognition are not within the scope of this project.

2.2 Project goals and objectives

The goals and objectives of this project are:

- To design and develop a low cost inertial measurement unit device/system that can be used to capture human inertial data. The said inertial system would be developed within the next 15 weeks by myself, on campus, at The University of New England. The inertial system would be accompanied by all the specified deliverables as highlighted in section 2.4 project proposal. It would also be developed with the said constraints as highlighted in section 2.3. The software product would enable inertial data to be captured and sampled at a relatively above average sampling speed.
- To develop the inertial system within the given budget of $500 with relatively no cost of maintenance. This in effect means that the system will be able to capture inertial data over a long period without the device over heating or malfunctioning.
- To develop the software product with all stated deliverables as highlighted in section 2.4 of this project proposal, which would allow the implementation of the inertial system.

2.3 Assumptions and Constraints

This project will be planned with the following assumptions:

- The project will deliver both software and hardware components.
- Some parts of the overall software will be readily sourced from open source platforms.
- The software for the project will be implemented across three IDE platforms (Arduino, Intelli J and MATLAB).
- Licence to MATLAB will be provided by the University.

The project will be planned with the following constraints:

- Budget
    - \$500 (the cost of the laptop, for the base station, is not factored into the overall cost).
- Time
    - ±15 weeks.
- Project personnel
    - One
- Movability
    - the hardware device, consisting of the whole IMU system, will be connected by cables to the base station, thus restricting movement to the radius of the length of the cables.

2.4 Project deliverables

All the items listed in this subsection are the deliverables for this software project prior to the project completion.

- Software program and library binaries. The software program would execute such deliverables such as:
    - Captured motion data
    - Transfer motion data from each IMU device to the centrally mounted IMU
    - Transfer the data from the centrally mounted IMU to the base station.
    - Analyse the data (offline) on the base station
- Software documentation.
- User Application
- Hardware design and development.
- Installation of software program on target hardware

2.5 Time schedule and budget summary

The project has the following summary:

- Delivery of the hardware product on or before: June 13, 2017.
- Delivery of the software product on or before: June 13, 2017. This project has a budget summary of $500

2.6 Evolution of the LCIMU

This project proposal document is subject to modification. The assumptions, constraints, budget planning & timing of each phase of the project is subject to changes during the project. Any modification on this document will lead to a new modified version re-issued.

- To develop the software product within the said time frame of 15 weeks and of a high quality as this would ensure timely application of the device to a human host.

2.7 Feasibility Study Overview

A feasibility study was carried out on the possibility of executing this project within the said time frame and with all its accompanying project deliverables. The feasibility study revolved around the acquisition of the individual component parts of the device, the device build, the software development and implementation in regards to the overall project time frame.

The binary libraries for some parts of the project software can readily be obtainable from open source sites such as GitHub and on online forums. The component parts required to develop the project hardware can be acquired from multiple online hardware stores with relative faster shipping time frames (two to three weeks' maximum, for component parts to be bought online and received). The device build and set-up could be carried out also within a two-week time frame (with a week's lee-way for unforeseen circumstances). The software development could also be undertaken within a 6 weeks' time frame (assuming licenses for access to MATLAB is provided by the University). User tests, documentation and presentation could finally be carried out in a three-week time frame, thus aligning with the overall time frame for the project.

Therefore, the project would be deemed feasible considering the factors briefly explained above that would determine the project commencement, development and completion.

3.0 Software Development Process

The development process for the software for this proposal will be carried out using the incremental approach. The software would be incorporated into the device development incrementally in stages. As mentioned in section 2.3, the platforms for the software development would be the Arduino IDE, Intelli J IDE and MATLAB.

On the Arduino IDE, which will be ran on the base station (laptop), the Arduino programming language (which is a variant of C/C++ functions) will be used to program the accelerometer/gyroscope (MPU6050) device.

The IntelliJ IDE will also be running on the base station (laptop), the java programming language will be used to write the program that receives the data being transmitted by the master IMU. The java program will be used to receive data from the master IMU after some modification and displaying the data in real time on a graph. The data stored on the IntelliJ IDE will be retrieved later (offline).

On the MATLAB application ran on the base station (laptop), the MATLAB programming language will be used to pre-process and analyse the offline data. The program will simply allow the IMU data to be pre-processed by interpolating the data and running an analysis of the data using the power spectral density function on MATLAB.

3.1 Incremental Delivery Plan and Implementation

The software delivery plan would be carried out in three stages.

- Stage One

In this stage the software would be developed after the development of the individual motion capture units. The Arduino IDE would provide a platform for the motion capture units to be programmed individually. This would allow the data to be captured in packets from each developed motion capture unit.

- Stage Two

  In the second stage, the Intelli J IDE will serve as a software platform that would allow for the cohesive collection of all the data captured in stage one. A real-time graph will be generated to highlight some of the characteristics of the data being captured. The captured data will essentially be stored on the Intelli J IDE to be used offline for further analysis in the next stage.

- Stage Three

  In this final stage the MATLAB software will be introduced to serve as a means of analysing the data being captured. A program written using the MATLAB language will enable the offline captured data to be analysed using the power spectral density tool for analysis.

4.0 Activity Planning

4.1 Project Deliverables

As highlighted in section 2.4, the deliverables for this project are as follows:

- Software program and library binaries. The software program would execute such deliverables such as:
    - Capture motion data
    - Transfer motion data from each IMU device to the centrally mounted IMU
    - Transfer the data from the centrally mounted IMU to the base station.
    - Analyse the data (offline) on the base station
- Software documentation.
    - User Manual
- User Application
    - A simple User Interface for implementing the system
- Hardware design and development.
    - Developed device hardware.
    - Design documentation
- Installation of software program on target hardware

4.2 Project Breakdown Structure

The project deliverables highlighted in section 4.1 is broken down and the project breakdown structure is shown in figure 4.1 below.

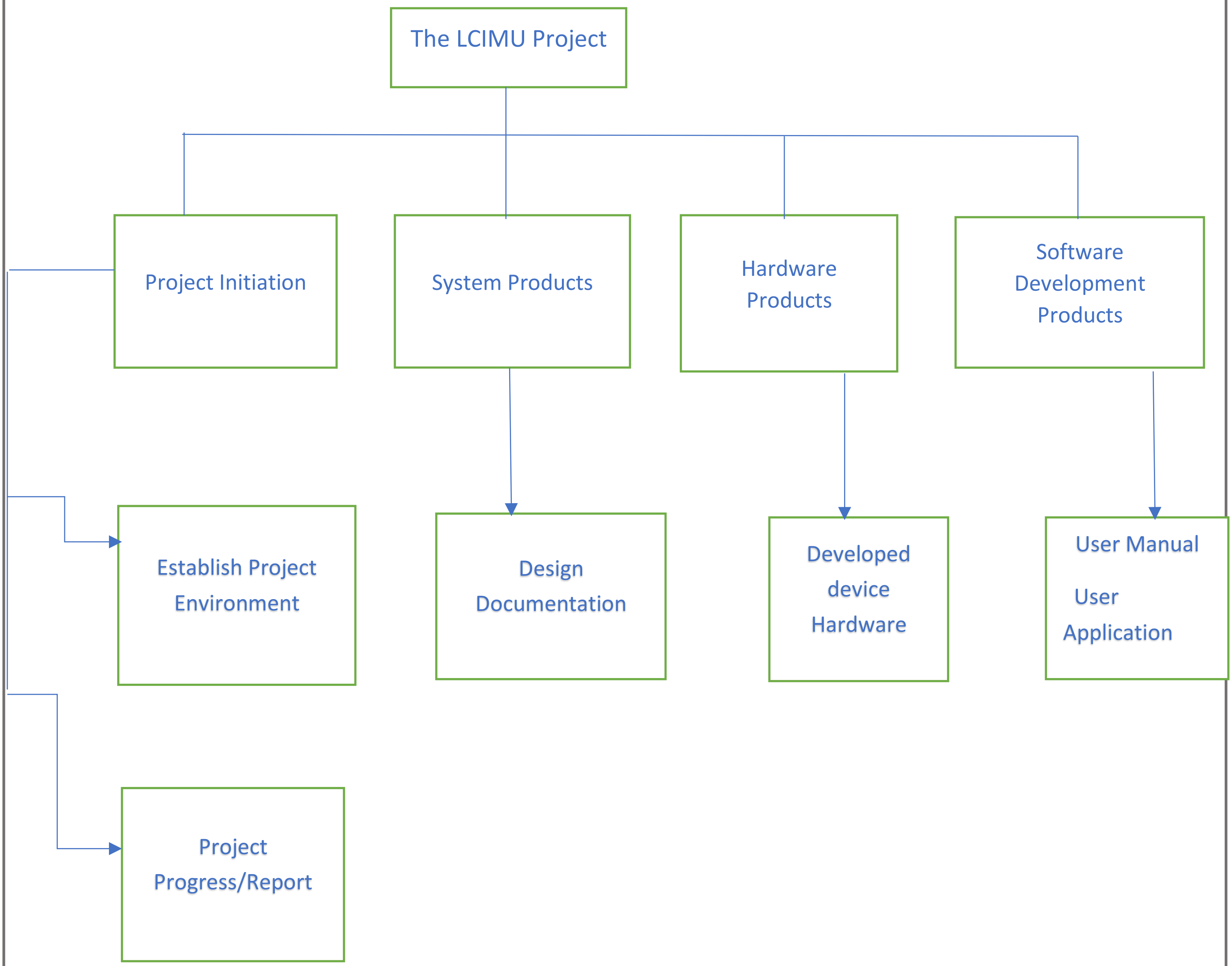


Figure 4.1. The LCIMU Project Breakdown Structure

4.3 Product Flow Diagram

Based on the product breakdown structure in section 4.2 a product flow diagram can then be developed as shown in figure 4.2 below

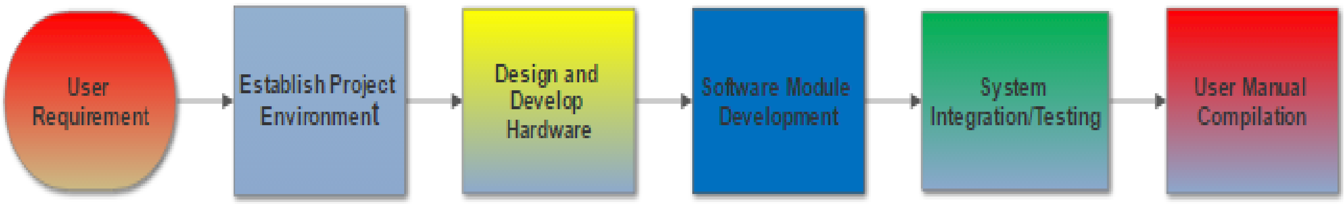


Figure 4.2. A Product Flow Diagram of the LCIMU Project

4.4 Activity Network Diagram

The LCIMU project has a series of activities which facilitates the creation of the products shown in figure 4.2. These activities were identified and the activity network diagram is given in figure 4.3 below.

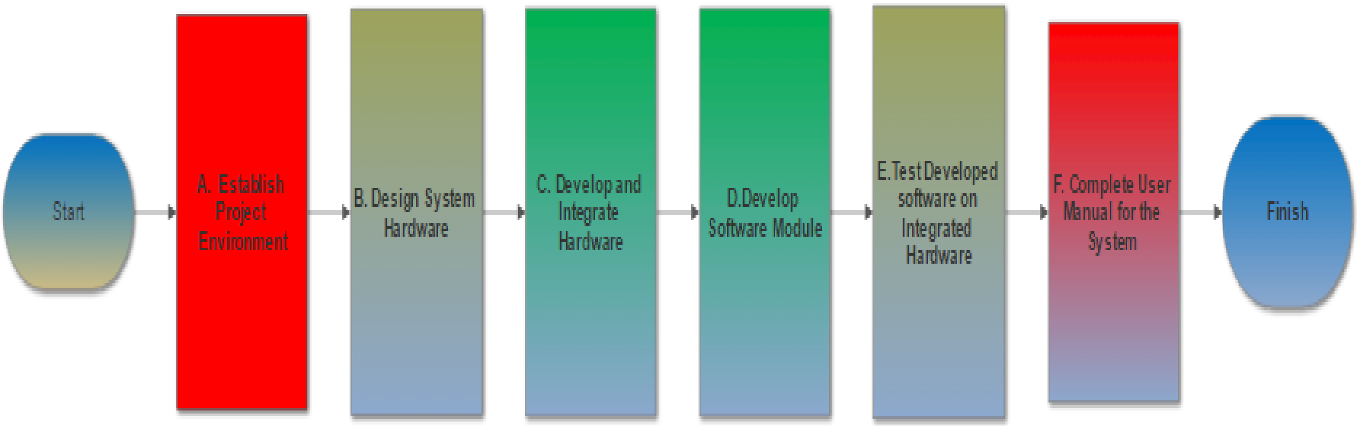


Figure 4.3. Activity Network Diagram

4.5 Activity effort estimation

In other to ensure the timely roll out of this project, the analogical effort estimation technique was used to gauge the varying levels of effort, in days, that will be utilized to complete this project. This technique validation was based on existing time frames of similar projects that have been executed in recent times and they can be sourced from the general web.

	Activities	Duration(days)	Predecessor
A	Establish Project Environment	14	
B	Design System Hardware	7	A
C	Develop and Integrate Hardware	35	B
D	Develop Software Module	21	C
E	Test Developed Software on Integrated Hardware	14	D
F	Compile User Manual for the System	14	E

Table 4.1. High Level Effort Estimation for the LCIMU Project

4.6 Enhanced Activity Network Diagram

Based on the effort estimation calculated and the dependency of each activity described in table 4.1, the enhanced Activity Network Diagram is shown in figure 4.4 below and the critical path is marked with the blue arrows.

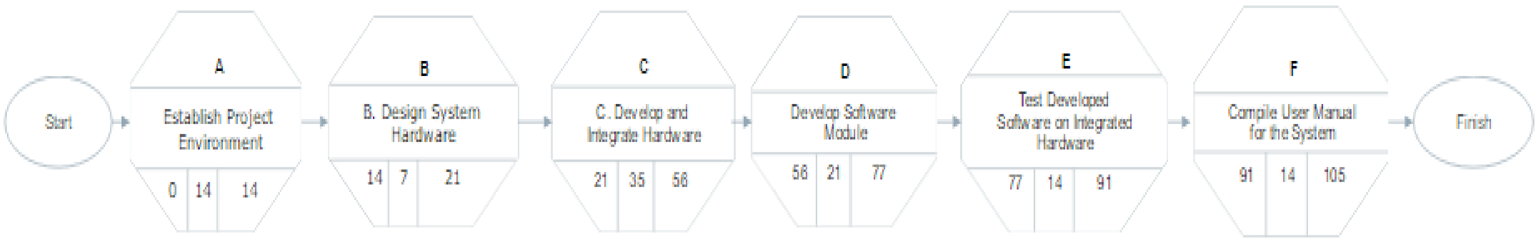


Figure 4.4. The Enhanced Activity Diagram of the LCIMU Project

4.7 Activity Schedule

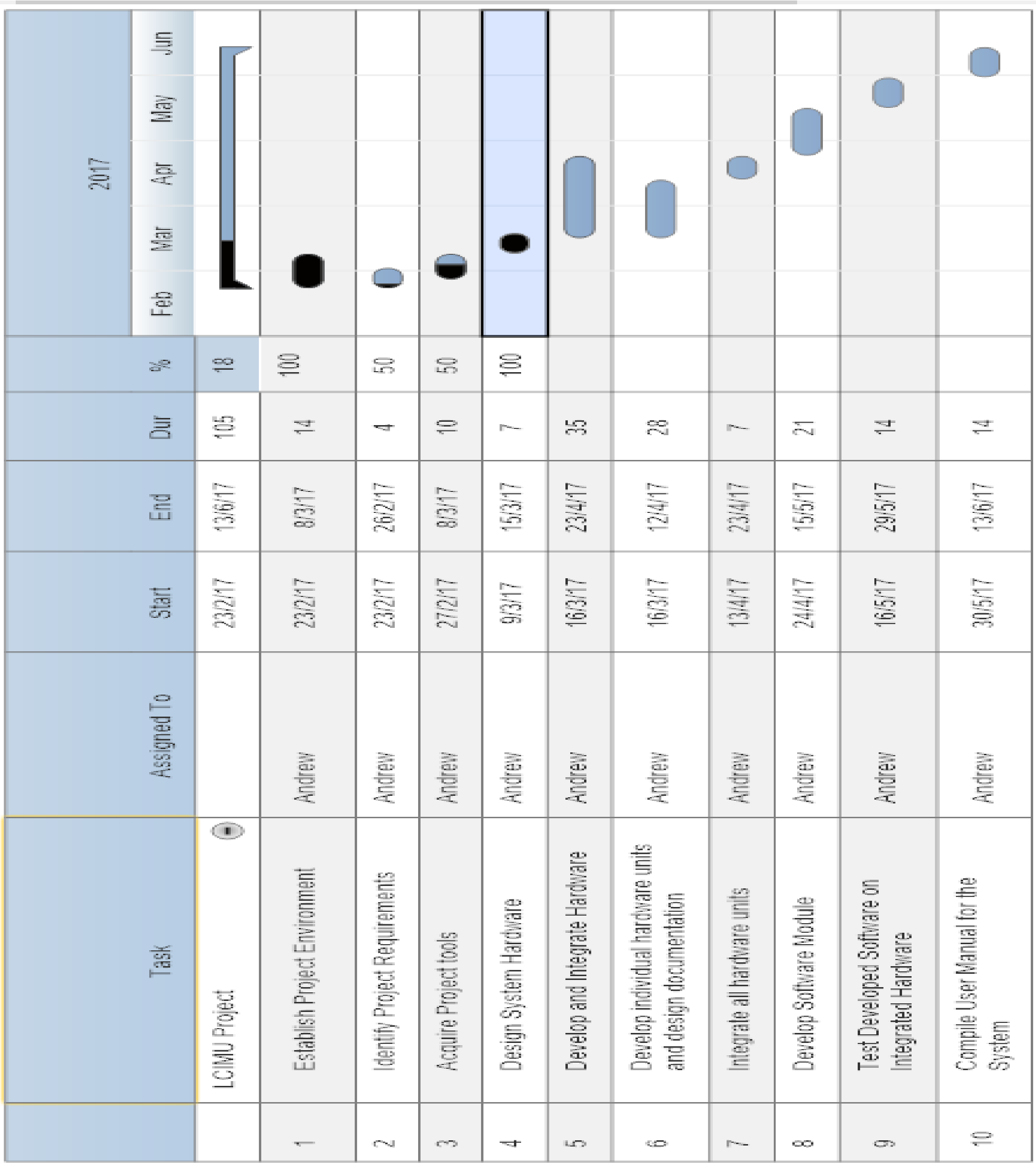
The activity schedule for the proposed project is displayed in Table 4.2 below.

ID	WBS	Task Name	Duration (days)	Start	Finish	Predecessor	Cost
		LCIMU Project	105	23/02/17	13/06/17		$500
1	1	**Start**	0	23/02/17	23/02/17	-	-
2	2	**Establish Project Environment**	14	23/02/17	08/03/17	1	$500
3	2.1	Identify Project Requirements	4	23/02/17	26/02/17	1	$0
4	2.2	Acquire Project tools	10	27/02/17	08/03/17	3	$500
5	3	**Design System Hardware**	7	09/03/17	15/03/17	4	$0
6	4	**Develop and Integrate Hardware**	35	16/03/17	23/04/17	5	$0
7	4.1	Develop individual hardware units and design documentation	28	16/03/17	12/04/17	6	$0
8	4.2	Integrate all hardware units	7	13/04/17	23/04/17	7	$0
9	5	**Develop Software Module**	21	24/04/17	15/05/17	8	$0
10	6	**Test Developed Software on Integrated Hardware**	14	16/05/17	29/05/17	9	$0
11	7	**Compile User Manual for the System**	14	30/05/17	13/06/17	10	$0

Table 4.2. The Activity Schedule for the proposed LCIMU Project

5.0 Resource Planning

In allocating resources to activities, consideration was given to activity float, activity duration, and resource availability. On successful completion of resource allocation, a GAnt chart was produced as shown below.



	Task	Assigned To	Start	End	Dur	%
	LCIMU Project		23/2/17	13/6/17	105	18
1	Establish Project Environment	Andrew	23/2/17	8/3/17	14	100
2	Identify Project Requirements	Andrew	23/2/17	26/2/17	4	50
3	Acquire Project tools	Andrew	27/2/17	8/3/17	10	50
4	Design System Hardware	Andrew	9/3/17	15/3/17	7	100
5	Develop and Integrate Hardware	Andrew	16/3/17	23/4/17	35	
6	Develop individual hardware units and design documentation	Andrew	16/3/17	12/4/17	28	
7	Integrate all hardware units	Andrew	13/4/17	23/4/17	7	
8	Develop Software Module	Andrew	24/4/17	15/5/17	21	
9	Test Developed Software on Integrated Hardware	Andrew	16/5/17	29/5/17	14	
10	Compile User Manual for the System	Andrew	30/5/17	13/6/17	14	

Figure 5.1 A Gant chart of the LCIMU Project

6.0 Risk Management Plan

The risks attributed to this project is inherent in the design and in the testing phase.

6.1 Identified Risks in the design and testing phase

- The possibility of the onset of fires while the component bits are being soldered because of bad soldering leads, poor working environment, improper soldering technique and component damage.
- The possibility of electrocution during the development of the hardware components due to wire breakage and poorly earthed power outlets.
- Sustaining Injuries during device demonstration in the testing phase.
- System malfunction due to a poorly suited base station (laptop).

6.2 Risk Mitigating procedures

- High quality materials to be purchased for the project and the implementation of an efficient soldering technique, the utilization of a well ventilated working environment, a functional fire alarm and the use of safety precautionary tools (E.g. soldering gels, damped pads, fire extinguishers etc.)
- The power outlets to be used for powering all work tools should be assessed for current leakages, active fuses, switch breakers and proper earthing functionality in accordance with the standard power regulations for building appliances.
- A professional or well-trained individual would be required to mount and test the completed device hardware.
- An efficient base station with a high capacity processing speed should be utilized in carrying out the running of the program platform and data analysis.