Dynamic Motion Sensing System

Project Work by
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Bachelor of Engineering - ELECTRONICS

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25/08/2024

ACKNOWLEDGEMENTS

I would like to show my appreciation for all the persons who gave me a chance to complete my project work. I would specifically thank my examiner professor Hayek Ali who guided me in realizing my project work. He taught us subjects like hardware engineering and advanced embedded systems. These subjects helped me equip with the necessary skills for working with vivado and other softwares. Professor Ali Hayek also nurtured me in developing calculative approach when designing such projects. I would also like to that Hamm-Lippstadt University of applied Sciences for providing me with the necessary equipment to complete my project.

ABSTRACT

The rise of digital technology and firmware development has lead to development of complex hardware and software systems. These systems enable us to create real time systems that have higher sophistication. Thus it allows us to develop , maintain and upgrade electronic systems like multimedia and automobile applications.

This paper is documentation of a dynamic motion sensing system that was developed for the project work module in the Electronic Engineering course work. This document describes in brief about the motivation, problem space, methodology, system design and Xilinx Vivado- Vitis IDE implementations.

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Chapter 1

INTRODUCTION

This project documentation includes all aspects of the project that was realized. The Acknowledgement section describes the contributions of other persons or institutions towards this project. The Abstract gives an quick overview of this project. The Motivation section give the reason this project was carried out. The literature review chapter talks about various literature used to gain deeper understanding about the project concept. The methodology used in this project are described in the methods chapter. The System Design chapter tells about the way in which the system was realized for this project. The Hardware Synthesis Implementation and software implementation chapters talk about the further illustrations of this project. The result and evaluation chapter giver information about some critical metrics regarding the project and also some errors faced during the project realization.

1.1 Motivation

The developments in the field of automobile industry and drone manufacturing has led to a demand of smart real time systems that perform dynamic motion sensing. These systems use cutting edge hardware and embedded software technologies in form of sensors and actuators. These sensors nodes and computational nodes form a system that is responsible for detecting motion and location of an object in 3D space.

The motivation behind developing a dynamic motion sensing system is to explore the operational aspects of a Pmod ACL accelorometer, Oled rgb display. The complex integration of backend hardware system in Vivado IDE using microblaze embedded processor and the frontend software application in Vitis IDE.

Chapter 2

LITERATURE REVIEW

2.1 Vivado Design Suite

A research was carried out to understand some key features of the Vivado design suite. This paper [7] gives primary information about the vivado design suite needed for this project.

Hierarchical Design Flows

The Hierarchial Design Flow capability of the vivado design suite allows design reuse and partial reconfiguration. Each block can be designed , applied and tested independently. When all the block are successfully created then all of them can be brought together in the assembly run but maintaining individual results. Some blocks can be imported and are known as external IPs.

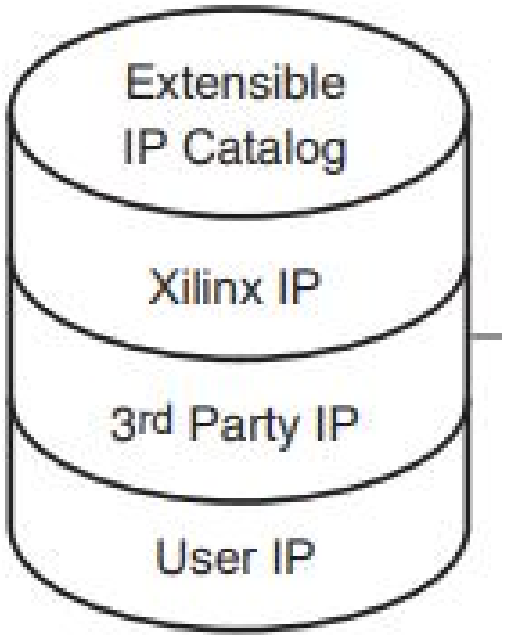

Figure 2.1: IP in Vivado [7]

High Level System Integration

The Vivado IP integrator is a advanced tool that can be used for integrating several IP blocks. The IP blocks are integrated in a hierarchical manner and can be developed locally or imported from third party. The integrator is a designed specially for easy use by graphically connecting the blocks. It has features like auto- connect that automatically connect the IP with each other when called upon. The design rule checking (DRC) checks whether the system is structurally integrated correctly.

2.2 Microblaze soft core processor

This paper [8] gives information about the microblaze soft core processor. The microblaze soft core processor is a 32 bit RISC Harvard architecture processor. The microblaze processor can be clocked upto 150 MHz. The cache data can be from 2 to 62 Kbytetes. It requires peripherals like memory controller, UART and interuppt handler. The microblaze processor core can be connected with AXI Stream interfaces.

Chapter 3

METHODS

In order to realize this, a dynamic motion sensing a real time system was proposed that would measure acceleration in 3D space and display it on the OLED display.

The proposed system would consist of both hardware and embedded software parts that would make the entire system. This would give a global view of the entire system from bottom up approach.

3.1 Problem Space

Many dynamic motion sensing systems exist in the current world of technology. After conducting a review of various such systems it was discovered that there are limited number of such FPGA based systems.

Chapter 4

SYSTEM DESIGN

This section defines proposed system specifications and an overview of the system.

4.1 Hardware Requirements

The hardware components used in this project are as follows

Xilinx Nexys A7 100T Board

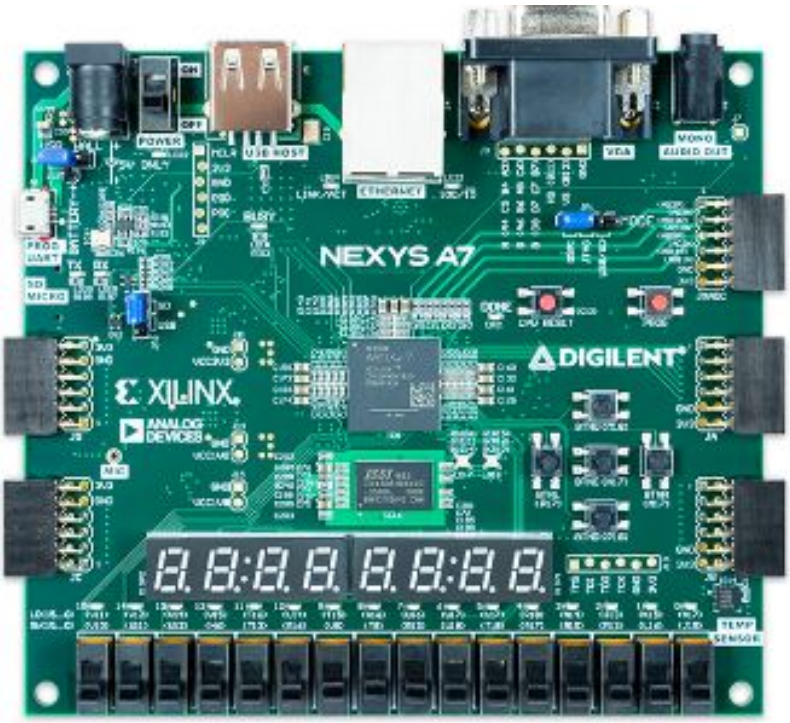

Figure 4.1: Digilent Xilinx Nexys A7 100T[7]

Figure 4.1 shows the Xilinx Nexys A7 100T board that is used for this project. This board is responsible for the required digital processing of the entire system. This particular board is chosen beacuse it has significant number of Pmod Ports which would be needed for sensor integration.

Pmod ACL 3 Axis Accelerometer

Pmod ACL 3 Axis Accelerometer shown in figure 4.2 is used in this system for measurement of acceleration and motion of an object in 3 dimensional space. This

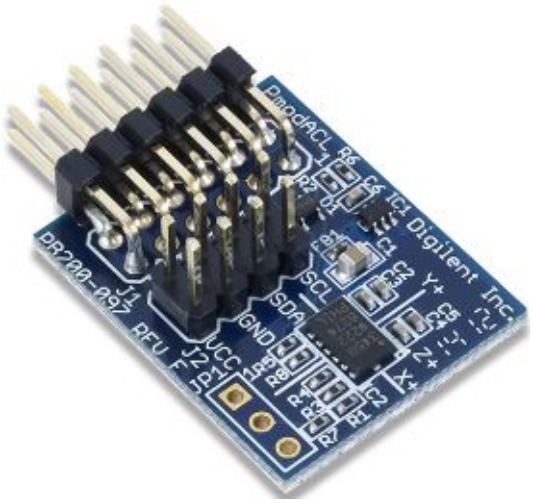

Figure 4.2: Pmod ACL 3 Axis Accelerometer[1]

particular device is chosen because of it high resolution. It uses SPI communication protocol over Pmod interface.

Pmod OLED rgb display

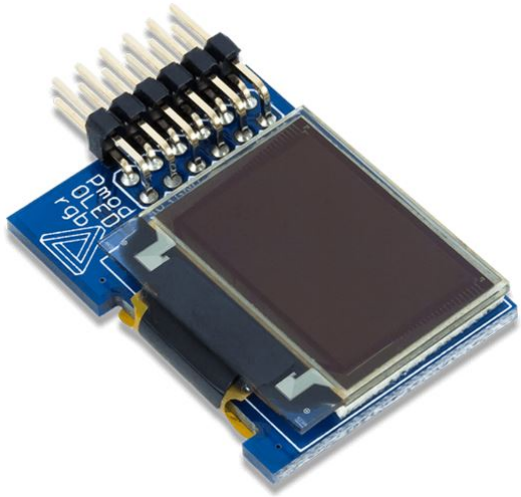

Figure 4.3: Pmod OLED rgb display[3]

The Pmod OLED rgb display shown in figure 4.3 is chosen for displaying pourposes needed in this project. This device has been chosen as it has 16 bit color resolution. It uses SPI communication protocol over Pmod interface for communication purposes.

Figure 4.4: Pmod BLE Bluetooth Module[2]

Pmod BLE Bluetooth Module

The Pmod BLE bluetooth module shown in figure 4.4 is used for data transfer process with other devices. It has UART communication protocol over pmod interface.

USB A to micro USB cable

Figure 4.5: USB A to micro USB cable[4]

The USB A to micro USB cable shown in figure 4.5 is used for communication between the Windows PC applications to the Xilinx Nexys A7 board. The cable is used to connect the USB- UART Bridge communication interface. The USB A end of the cable is attached to a Windows PC while the micro USB end of the cable is attached to the UART Bridge PORT on the Nexys A7 board.

4.2 Software Requirements

The software components used in this project are as follows

Vivado Design Suite 2023.1

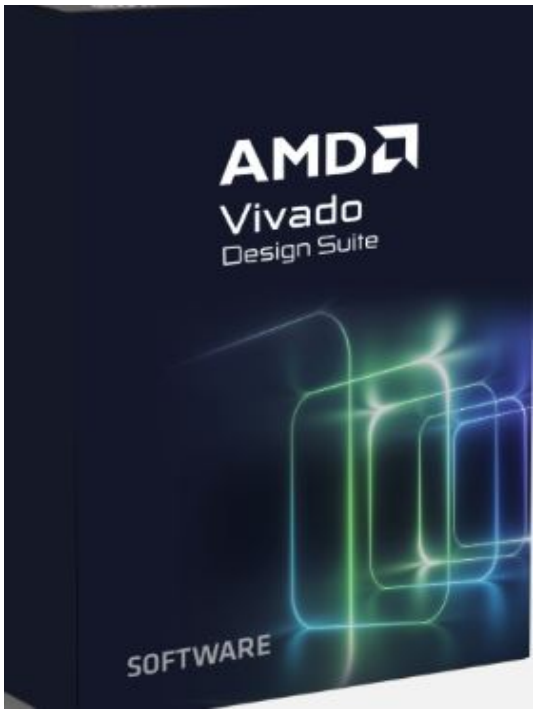

Figure 4.6: Vivado Design Suite 2023.1[6]

The Vivado Design Suite version 2023.1 shown in figure 4.6 is an Integrated Development Platform (IDE) used for hardware synthesis and hardware discription language (HDL) based designs. This IDE is used for the hardware synthesis of hardware block designs in this project. This IDE is choosen as it is best suited IDE for the hardware development when working with the Nexys A7 board as it has all required feature integrated. For example it has block design feature which allows to use IP block and repositories, it can run synthesis and generate bitstream which will be used to create a HDL wrapper for the project.

Vitis Unified Software Development Platform

The Vitis Unified development platform shown in figure 4.7 is an IDE that is used for software development in this project. The vitis IDE has a crtitical feature like compatability with integrating backend hardware wrapper file. This allows for developing the complete project including hardware synthesis integration.

Figure 4.7: Vitis Unified Software Development Platform[5]

C programming language

The C programming langugae as been choosen for the software development. This is because C programming language has features of embedded C and is closely related to low level languages like assembly language.

System Overview and Block Diagram

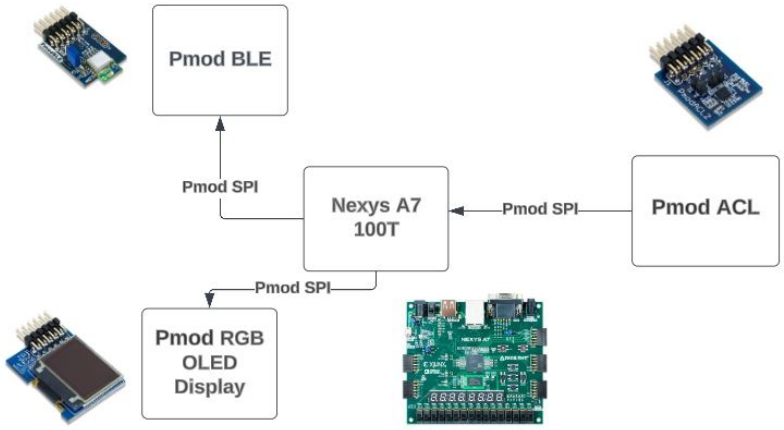

Figure 4.8: Block Diagram

The block diagram shown in figure 4.8 give an overview of the entire system. It shows that the pmod ACL module is the input sensor node, the Nexys A7 100T board module is the central processing node while the pmod OLED diaplay and bluetooth module are the actuators in the system. The communication protocols used are Serial peripheral interface SPI.

Chapter 5

HARDWARE SYNTHESIS AND IMPLEMENTATION

This section focuses on the hardware implementation in the Vivado IDE.

Microblaze Processor

Figure 5.1: Microblaze Processor

The microblaze processor as shown in Figure 5.1 is a soft processor developed by AMD Xilinx. It has 32 bit processor core and has RISC Harvard architecture. This processor is used in vivado Block design as the main microcontroller to perform all the necessary computations of the system. The processor has AXI peripheral interface and other feature like memory and DDR register.

System Clock

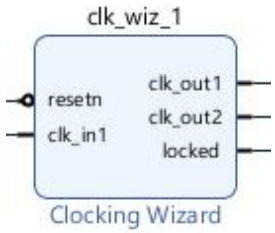

Figure 5.2: System Clock

The Clocking Wizard LogiCORE ™ IP is used for providing clocking requirements for the system. The clock wizard has the ability to provide multiple clock frequency

to various IP blocks. The mircoblaze IP processor, Mig 7 serires memory and the Pmod IP block modules have been provided a clock speed of 100 MHz.

AXI Uartlite communication interface

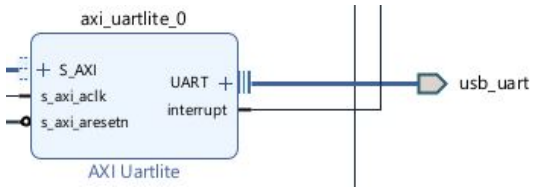

Figure 5.3: AXI Uartlite communication interface

The AXI Uartlite interface shown in figure 5.3 is designed to provide asynchronous serial data transfer using the Advanced eXtensible Interface (AXI) that the UART communication protocol. This IP block creates a communication channel between the Mircoblaze central processor and the Vivado IDE on Windows PC using the USB- UART Bridge communication interface on the NEXYS A7 board.

Pmod IP Blocks

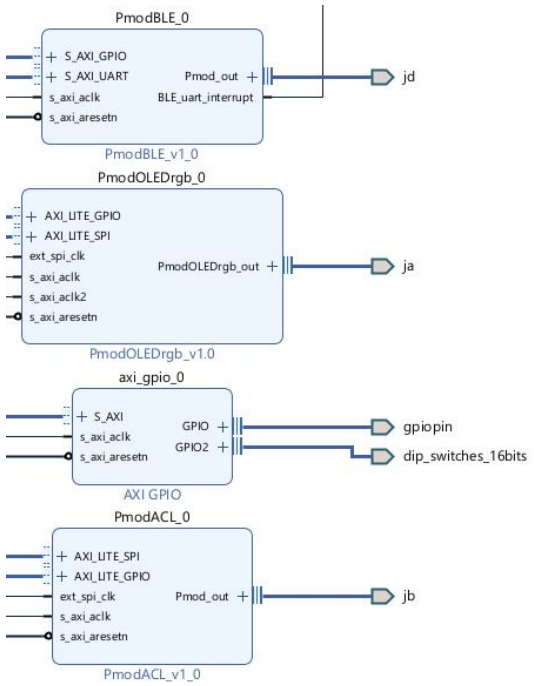

Figure 5.4: Pmod IP Blocks

The pmod IP blocks shown in figure 5.4 are IP blocks of Bluetooth module OLED display module and Pmod ACL accelerometer sensor. The Pmod IPs are the official

IPs for pmod sensors provided by Digilent.

Pmod BLE Bluetooth IP

The Pmod bluetooth module is responsible for providing the bluetooth connectivity for the system. It has an interrupt pin that is connected to the interrupt handler of the microblaze processor system. The pmod BLE IP is connected to pmod port D on the NEXYS A7 board.

Pmod OLED rgb IP

The pmod oled ip is used to form a hardware connection for the pmod oled display module on the pmod port A of the NEXYS A7 board. The module is connected to the microblaze AXI peipheral ip to form connection with the microblaze processor.

Pmod ACL accelerometer IP

The pmod ACL ip is used to form hardware connection with the pmod port B on the NEXYS A7 board and the pmod ACL module.

A hardware wrapper file is formed after successfully generating the bitstream of the whole block design integration. The HDL wrapper is acts as an underlaying file with hardware informations for further development of the software top layer. The HDL wrapper is exported to the Vitis IDE.

Chapter 6

SOFTWARE IMPLEMENTATION

This section focuses on the software implementation.

C code Libraries

```
#include "PmodBLE.h"          //pmod bluetooth library
#include "bitmap.h"
#include "PmodOLEDrgb.h"   // pmod oled library
#include "sleep.h"         // c code delay library
#include "xil_cache.h"
#include "xparameters.h"    // vitis primary library
#include "xil_types.h"
#include "xil_io.h"
#include "PmodACL.h"       // pmod acl library
#include <stdio.h>
#include <stdlib.h>
```

Figure 6.1: C code Libraries

The libraries used for the software c programme development are shown in figure 6.1. The pmod bluetooth, ACL and OLED display libraries are offcical libraries provided by digilent for the respective pmod modules. The sleep.h and xparameters.h libraries are Vitis IDE specific libraries used for delay functions and board specifications respectively.

Initialization and Setup

The figure 6.2 shows initialization for microblaze cache data, bluetooth module, ACL module and OLED display. The initialization functions are provides by the libraries, for example the BLE_Begin() function is from the PmodBLE.h library. The module base addresses for example XPAR_PMODACL_0_AXI_LITE_GPIO_BASEADDR is the base address for the pmod acl module and is automatically generated by the HDL wrapper and can be found in the xparameters library.

```
void Initialize()
{
    EnableCaches();          //enable cache data from microblaze
    SysUartInit();           // initialize uart for bluetooth
    BLE_Begin (              // blue tooth initialization
        &bluetooth,
        XPAR_PMODBLE_0_S_AXI_GPIO_BASEADDR,
        XPAR_PMODBLE_0_S_AXI_UART_BASEADDR,
        BLE_UART_AXI_CLOCK_FREQ,
        115200
    );
    OLEDrgb_begin(&oledrgb, XPAR_PMODOLEDRGB_0_AXI_LITE_GPIO_BASEADDR,  // initialize oled display
            XPAR_PMODOLEDRGB_0_AXI_LITE_SPI_BASEADDR);

       ACL_begin(&ACL, XPAR_PMODACL_0_AXI_LITE_GPIO_BASEADDR,XPAR_PMODACL_0_AXI_LITE_SPI_BASEADDR);
        SetMeasure(&ACL, FALSE);                    // initialize ACL module
        SetGRange(&ACL, PAR_GRANGE_PM4G);
        SetMeasure(&ACL, TRUE);
        CalibrateOneAxisGravitational(&ACL, PAR_AXIS_ZP);
}
```

Figure 6.2: Initialization

```
 float x;     // variable for x axis location
 float y;       // variable for y axis location
 float z;      // variable for z axis location
 int i = 0;
char stringConvertX[12];        // convert float x value to a string
   char stringConvertY[12];
   char stringConvertZ[12];

while(1) {
    ReadAccelG(&ACL, &x, &y, &z);     // read x, y, z values from pmod acl
           sprintf(stringConvertX ,"%f", x);   // conversion of float x to string
           sprintf(stringConvertY ,"%f", y);
           sprintf(stringConvertZ ,"%f", z);

           usleep(10000);
       OLEDrgb_SetCursor(&oledrgb, 0, 0);         // setting the location for the cursor on first line, first alphabet
       OLEDrgb_SetFontColor(&oledrgb, OLEDrgb_BuildRGB(0,255, 0));  // choose color, red
       OLEDrgb_PutString(&oledrgb, "X=");
       OLEDrgb_PutString(&oledrgb, stringConvertX);           // print the x component value on the oled display

       usleep(1000);

       OLEDrgb_SetCursor(&oledrgb, 0, 2);         //setting the cursor on the second line, first alphabet position
       OLEDrgb_SetFontColor(&oledrgb, OLEDrgb_BuildRGB(0, 0, 255)); // green color
       OLEDrgb_PutString(&oledrgb, "Y=");
       OLEDrgb_PutString(&oledrgb, stringConvertY);
```

Figure 6.3: Main logic

Main function logic

The main function of the program is shown in figure 6.3. The x , y , z variables are created to store the values of the 3D motion. stringconvertX variable stores the value of 3D motion in a string data type. The ReadAccelG(&ACL, &x, &y, &z) function reads value of the respective x,y,z components of the 3D motion using the pmod ACL sensor. sprintf() function then converts the float data type memory in x,y,z varibale to string data type and stores it in stringconvertX, stringconvertY and stringconvertZ respectively. The OLEDrgb_SetCursor function sets the cursor on the oled display. The OLEDrgb_SetFontColor() function sets the color of the font to be displayed on that specific line. The OLEDrgb_PutString(&oledrgb, stringConvertX) function

displays the charachters of the string variable stringConvertX on the oled display.

```
BLE_SendData(&bluetooth, "X= ", 3);
usleep(1000);
BLE_SendData(&bluetooth, stringConvertX, 8);       // send x component value over bluetooth
usleep(1000);
BLE_SendData(&bluetooth, "    ", 3);
usleep(1000);

BLE_SendData(&bluetooth, "Y= ", 3);
usleep(1000);
BLE_SendData(&bluetooth, stringConvertY, 8);      // send y component value over bluetooth
usleep(1000);
BLE_SendData(&bluetooth, "    ", 3);
usleep(1000);

BLE_SendData(&bluetooth, "Z= ", 3);
usleep(1000);
BLE_SendData(&bluetooth, stringConvertZ, 8);       // send z component value over bluetooth
usleep(1000);
BLE_SendData(&bluetooth, "    ", 3);
```

Figure 6.4: Bluetooth Transmission

The figure 6.4 shows the code for transmitting data via the Bluetooth module. The BLE_SendData() function sends data of the stringConvertX variable of string type over the bluetooth.

Chapter 7

RESULTS AND EVALUATION

This chapter will discuss the results of the project implementation. The vivado design suite has various features that help us in analyzing various metrics of the hardware system. Critical metrics of the hardware implementation are shown here.

7.1 Resource Utilization

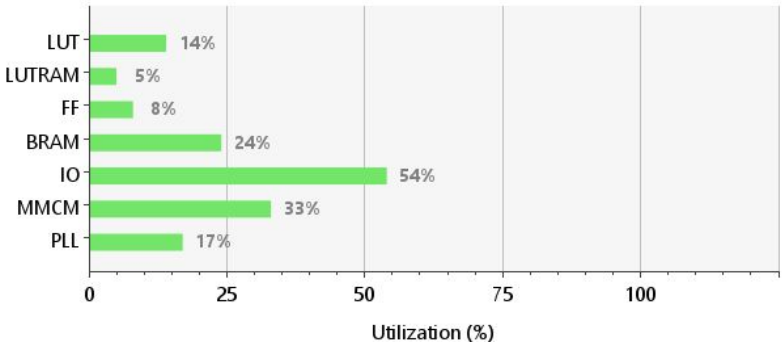

Figure 7.1: Resource utilization

The results shown in figure 7.1 tells that only 14 percent Look Up Tables are used. And 24 percent of BRAM is utilized, this points toward possible future extension of the project.

7.2 Power analysis

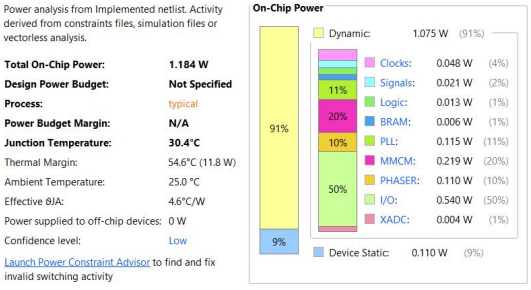

Figure 7.2: Power consumption

The power usage shown in figure 7.2 indicates that 91 percent of power is used by dynamic components of the system like I/O pins, clocks , BRAM , Logic , etc. This indicates that usage of memory components actively.

7.3 Timing analysis

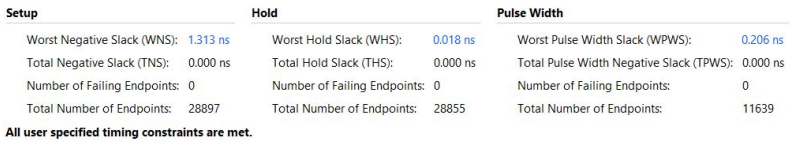

Figure 7.3: Timing analysis

The timing analysis in figure 7.3 show us that the worst negative slack and the total negative have appropriate timings. This tells us that the designed system can function effectively and efficiently.

Implementations

The Serial Bluetooth Terminal application shown in figure 7.4, from Google Play was used for reading messages transmitted on Bluetooth.

The image shown in figure 7.5 indicates the results of the pmod accelerator shown on Pmod OLED display with high resolution and RGB colors.

7.4 Errors and issues solved

- While implementing the project various errors and issues were encountered at different stages. The Nexys A7 board was shown not compatible with the use of pmod IPs. This issue has can be solved by simply ignoring this error and connecting microblaze block design

- Another issue face was not able to fully achieve the functionality of the IP blocks in the wrapper file. This issue was tackled by including a mig 7 series memory in the integrated block design.

- Some other error that was encountered was the Pmod IP Board support files were either not created or not included when the project was to be realized in vitis. This issue was solved by changing some critical contents of the Make File of the pmod IPs an instructed by the digilent official engineer in an online forum. This change allowed vitis SDK to fully create and utilize the BSP files.

- Some clock requirements and interrupt requirements of some Pmod IPs were met using the clocking wizard and the interrupt handler.

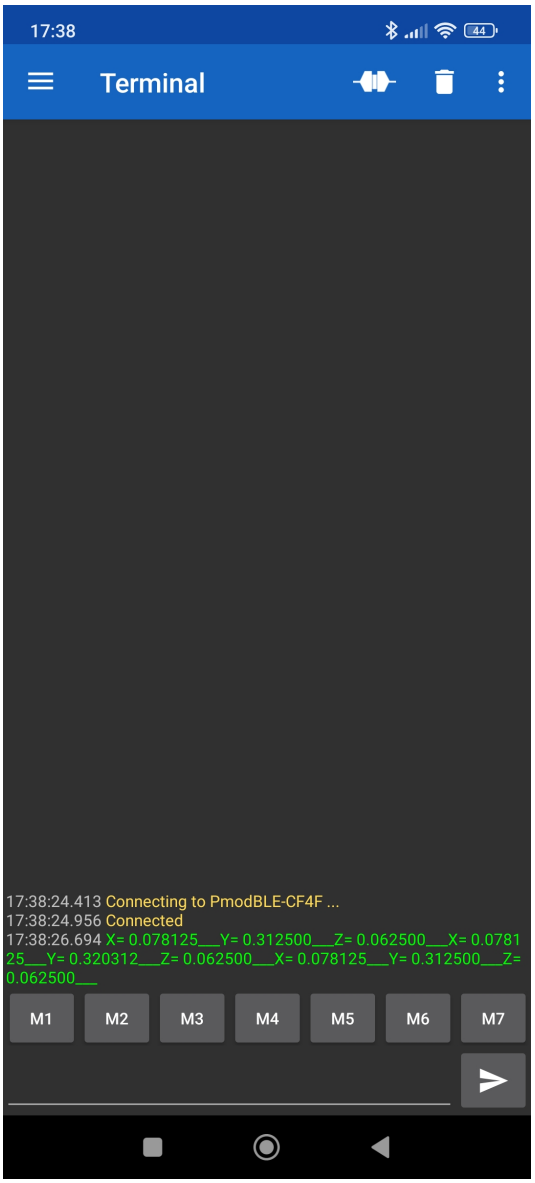

Figure 7.4: Bluetooth terminal data transfer

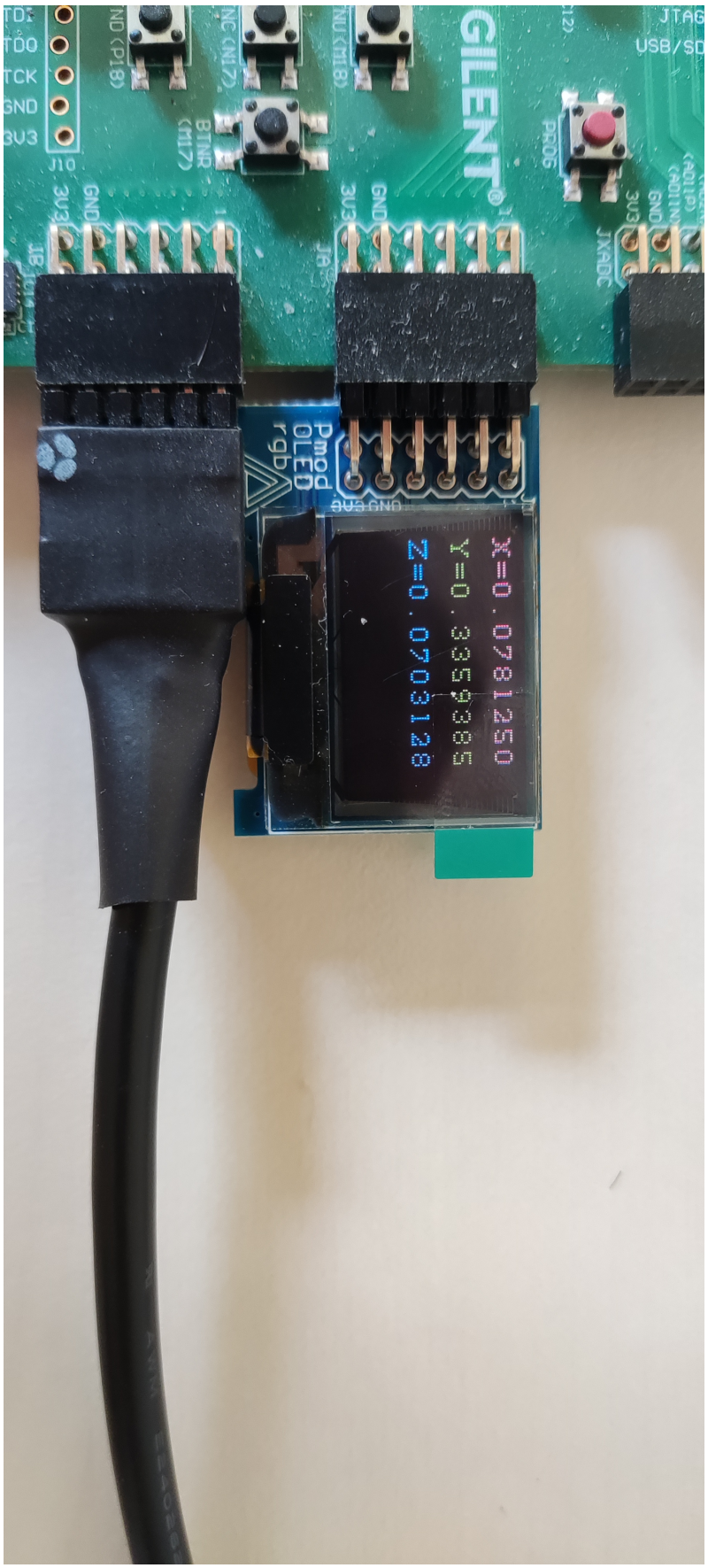

Figure 7.5: Results displayed on Oled display

Chapter 8

CONCLUSION

To conclude, every single aspect of the project has been documented in this report. I have explored and learnt various things from this project. The project deepens my understanding about concepts of hardware and software integration, use of Vivado/Vitis design suite and the operation of pmod modules. The project also helped me develop a global view of working with embedded system and can prove to be crucial for my further career.

Chapter 9

DECLARATION OF ORIGINALITY

I, Yashodhan Vishvesh Deshpande, herewith declare that I have composed the present paper and work by myself and without the use of any other than the cited sources and aids. Sentences or parts of sentences quoted literally are marked as such; other references with regard to the statement and scope are indicated by full details of the publications concerned. The paper and work in the same or similar form have not been submitted to any examination body and have not been published. This paper was not yet, even in part, used in another examination or as a course performance. I agree that my work may be checked by a plagiarism checker.

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[2] Pmod BLE - digilent reference.

[3] Pmod OLEDrgb - digilent reference.

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