ArachnoBotics Research Inc.

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March 11th, 2010

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
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Re: ENSC 440 Capstone Project: *Design Specifications of the ArachnoBot™*

Dear Dr. Rawicz,

Please find the attached document titled *Design Specifications of the ArachnoBot™*, for our ENSC 440 Capstone Engineering Project. Our objective is to design a prototype spider robot, the ArachnoBot™, which is capable of traversing a pre-programmed trajectory. In its final stage of production, the ArachnoBot™ will be capable of scaling vertical obstacles and also transition between horizontal and vertical surfaces.

The enclosed design specifications build upon the framework created by our functional specifications. Each component of the ArachnoBot™ is discussed using specific technical details, and includes an outline of all previous work to reach the current state of the design. In order to ensure the success of the ArachnoBot™, the design process of the electrical, mechanical, control and user-interface components are explained in further detail, and include appropriate references.

ArachnoBotics Research Inc. consists of five highly motivated, innovative and talented fifth year engineering students experienced in a wide range of technical disciplines: Cristian Panaitiu, Daniel Naaykens, Pavel Bloch, Pranav Gupta and Stefan Strbac.

If you have any concerns or questions regarding this document, please feel free to contact me by phone (778.893.3303) or by email (pranav_gupta@sfu.ca).

Yours sincerely,

Pranav Gupta
Chief Executive Officer
ArachnoBotics Research Inc.

Enclosed: *Design Specifications of the ArachnoBot™*

ArachnoBotics
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Functional Specifications of the ArachnoBot™

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Executive Summary

"Engineers, scientists, and business people are increasingly turning toward nature for design inspiration" [1]

Through biomimetics, robotic implementations of natural organisms bring many benefits to society and technology. Scientists and Engineers are better able to understand the behavioral and functional mechanisms of organisms by designing them in electromechanical form. Furthermore, studying organisms in their natural surroundings allows researchers to identify possible advantages the creatures might have and apply these mechanisms to a scientific end. For example, Arachnids have excellent balance and are able to traverse the most difficult of terrain, often including perpendicular surfaces. This is an interesting physical property that can lend many positive benefits to exploration in outer space.

To this end, the European Space Agency has commissioned research for the development of robotic spiders that will be used for travel and construction in outer space. One of the requirements of these robots is to climb walls vertically, a functionality that will be extremely useful in unexplored terrain. To aid in this respect, the spider robot will come equipped with a chemical adhesive that allows the robot to attach to any surface.

ArachnoBotics Research Inc. plans to develop technologically advanced robotic spiders that contain much of the advantages of real spiders. The goal for these prototypes is to be autonomous, free moving, and intelligent creatures, much like real spiders. The first prototype, the ArachnoBot™, is designed to be a general proof of concept showcasing the control philosophy behind robotic hexapod walking platforms. Future generations of the ArachnoBot™ will incorporate wireless control from an external user as well as implementing basic intelligence to carry out tasks such as surveillance and construction.

The following specifications are a technical description of the systems that together make up the ArachnoBot™, including elements of design philosophy and the technical requirements that shaped the decisions made in designing the ArachnoBot™. Meeting these requirements will act as a first step towards designing a successful product and paving the way for future exploration.

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List of Acronyms

API - Application Programming Interface
ADC - Analog to Digital Converter
BRAM - Block Random Access Memory
BGA - Ball Grid Array
CAD - Computer Aided Design
CRTC - Canadian Radio-television Telecommunications Commission
DC - Direct Current
DOF - Degrees of Freedom
ESA - European Space Agency
FCC - Federal Communications Commission
FOS - Factor of Safety
FPGA - Field Programmable Gate Array
HDL - Hardware Description Language

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IC - Integrated Circuit
MTTF - Mean Time to Failure
MTBF - Mean Time Between Failures
PCB - Printed Circuit Board
PID Controller - Proportional-Integral-Derivative Controller
PLB - Processor Local Bus
PWM - Pulse Width Modulation
RoHS - Restriction of Hazardous Substances
SOC - System on Chip
SDRAM - Synchronous Dynamic Random Access Memory

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1. Introduction

The ArachnoBot™, a fully autonomous robotic hexapod walker, is based on a project commissioned by the European Space Agency (ESA). While the original project specifically targets space exploration, ArachnoBotics Research Inc. has furthered the project to design a small, lightweight robot capable of scaling complex terrains, and subsisting in extreme environments. Using Biomimetics, the study of Biological systems and methods and their implications toward robotic systems and engineering problems, the small, lightweight form of the Arachnid was chosen as the main design philosophy behind the ArachnoBot™.

1.1. Document Scope

This document is a technical description of the design of the prototype ArachnoBot™ system. The design presented here is meant to meet the functional requirements of the prototype system as stated in the document "*Functional Specifications of the ArachnoBot™* [2]. In addition to a description of the system and its constituent components, justification for the chosen design will be given throughout the document. Section 11 of the document will provide a system test plan that is intended to properly demonstrate that the system meets the required functional specifications.

This document is not meant to be a description of all the components, but rather how certain component characteristics were used to solve the functioning needs of the ArachnoBot™; technical details like voltage levels will thus be omitted in favor of more functional abstractions, but at the same time addressing the technical capabilities of the components.

1.2. Intended Audience

The design specifications here within enclosed are an explanation of the main design decisions of the ArachnoBotics Research Inc. management, and research and development teams. As such this document is only to be used by the members of ArachnoBotics Research Inc. Research and Development members are expected to adhere to the previously set functional specifications in their design processes to ensure all specifications are met in the final ArachnoBot™ production model. Members of the quality assurance and testing shall use this document's test plans to confirm the correct behaviour of the ArachnoBot™.

1.3. Future Uses

This document will lead to the creation of a detailed product description for potential investors and customers of the final ArachnoBot™ production model.

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2. System Specifications

The ArachnoBot™ system is designed to coordinate and carry out movement about complex surfaces. Functionally, the ArachnoBot™ system can be separated into a Control System and an Electromechanical System. Figure 1 below shows the different components of each of the ArachnoBot™ system. These systems are discussed in detail in the following sections, with further subsections for the internal components.

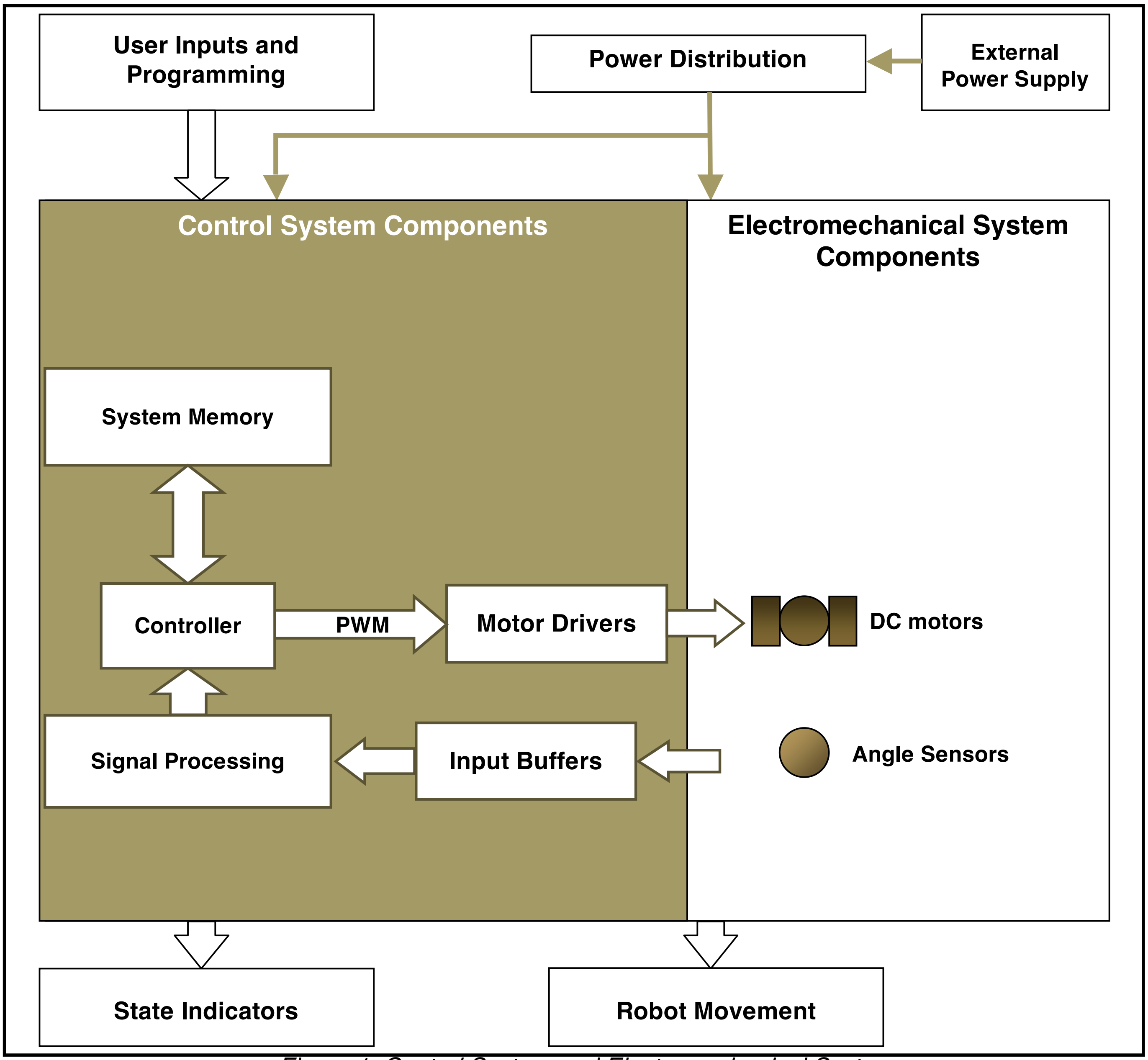

Figure 1: Control System and Electromechanical System

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3. Control System Overview

The systems driving the ArachnoBot™ are required to be able to control each leg, and each joint, independently of all the others. As outlined in the functional specifications, the controller must also be reprogrammable to suit a wide range of applications; new terrain recognition and different feedback processing algorithms should be user programmable into the control module. At the same time, however, the electromechanical components should be simple and have a fixed control interface that supports control flexibility. For these reasons, the ArachnoBot™ control system is divided into a processing module and a drive module.

3.1. Processing Module

As per the specifications, the control of the board should be able to convey signals to the legs according to an algorithm that is user customizable. This module should also be able to take in analog or digital signals from the feedback circuits, and be able to buffer and process them appropriately to output an appropriate response signal to control the motion of the ArachnoBot™.

The control module is further required to able to process feedback information that is optionally converted from analog to digital mode; and based on this to provide an appropriate control signal. The feedback processing is in the form of a digital PID process; a discrete function determines the speed output to the mechanical system.

The original design was to utilize multiple microcontrollers for control, as it would be difficult to power 18 motors in parallel with one microcontroller. There would be one microcontroller for each leg and a main microcontroller to coordinate the overall movement. This design solution is shown below in Figure 2. Using multiple microcontrollers posed a major challenge in designing the PCB given the area and power constraints of the robot. As a result, an FPGA was the ideal choice given its smaller footprint, greater number of inputs and outputs, as well as its ability to multitask in parallel (as opposed to pseudo-parallelism). However, most FPGAs come in a ball grid array (BGA) package making the PCB design and construction extremely complicated. The solution was to find a FPGA development board in the small form factor that we required. The FPGA Solution is described in greater detail in Section 5.

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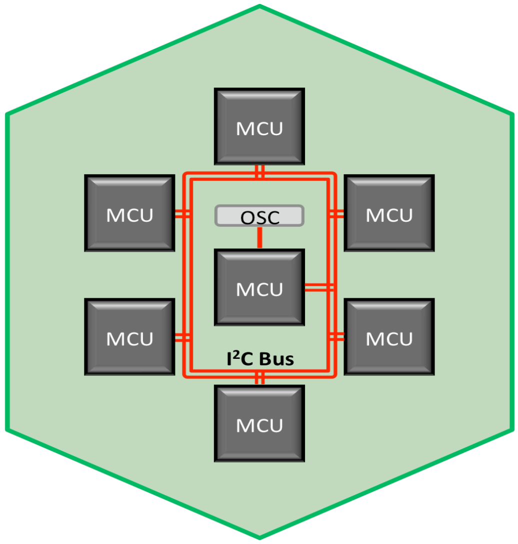

Figure 2: Alternative Processing Module Design

3.2. Drive Module

The drive module of the ArachnoBot™ is fairly simple, consisting of only a few types of major components. However, it is the most important component of the ArachnoBot™, as it interfaces the electromechanical system with the processing module of the control system. In order to drive each motor, an H-bridge is used to convert the PWM signal from the processing unit to a signal that will control the motor. The input to the processing module from the sensor uses buffering components in order to format the output of the sensor into a signal that the processing module can understand. The drive module also contains the power adapting circuitry for the ArachnoBot™, which is covered in Section 0.

Figure 3 shows a high-level block diagram of the ArachnoBot™ system, outlining the processing and drive modules, and their I/O connectors. One key feature to take note of is the modularity of this design **FS-39-III**. Separate sections of the system can be removed with ease. The FPGA module is fully disconnected from the rest of the circuitry and can be replaced by a higher performance module of a similar profile.

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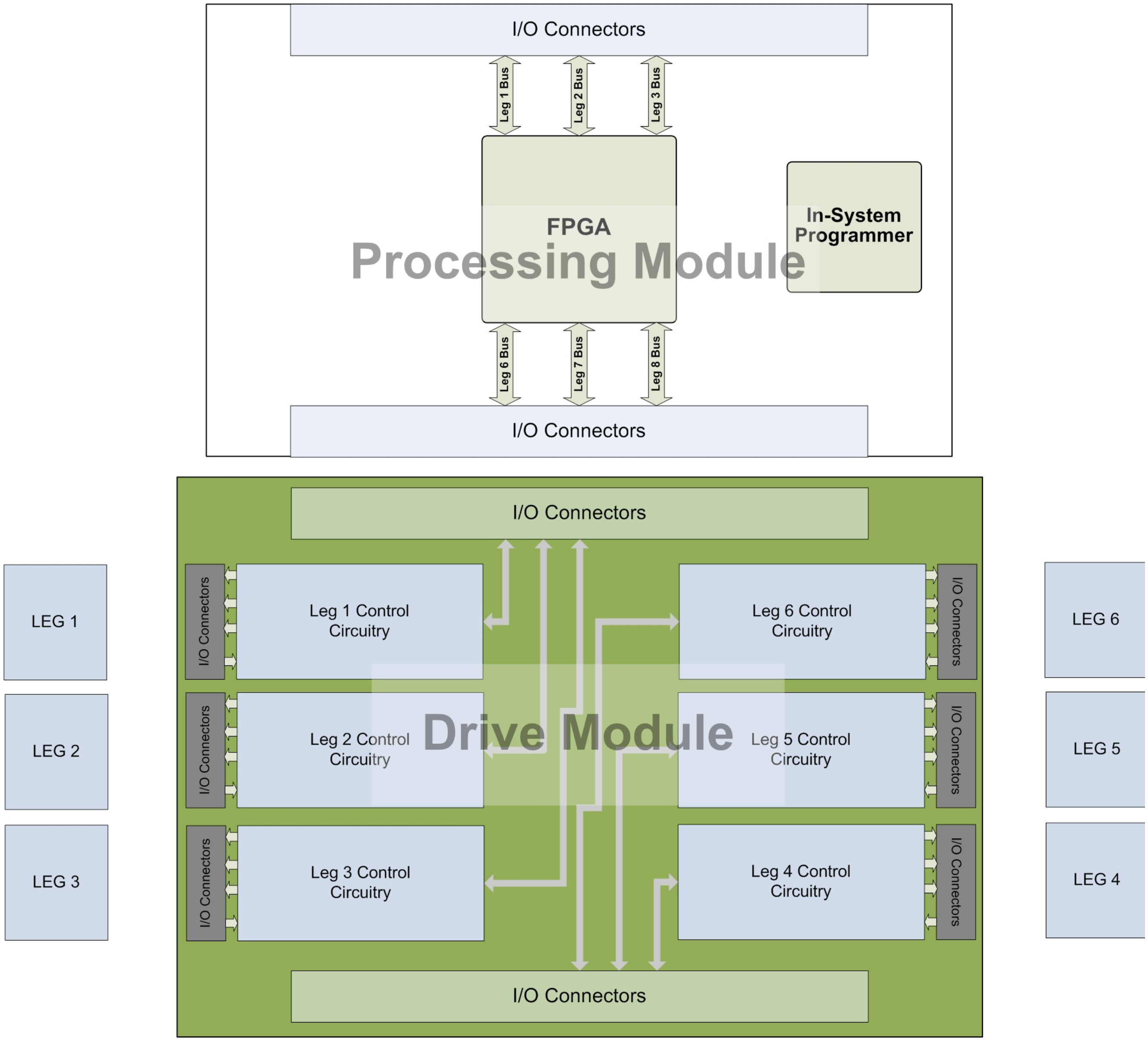

Figure 3: Simplified ArachnoBot™ Control System Block Diagram

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4. Electromechanical System Overview

4.1. Mechanical System

The ArachnoBot™ is designed as a hexapod, in order to make use of the many papers on hexapod gait, and reduce the complexity of walking algorithms. It has 6 legs, each with 3 joints, for 3 Degrees of Freedom (DOF) per leg. Each joint consists of an actuator, and a position sensor. These legs are mounted on a hexagonal frame that attaches to the control system circuitry. The 3D model of the ArachnoBot™ prototype can be seen in Figure 4, and will be used to create the first ArachnoBot™ model through rapid prototyping.

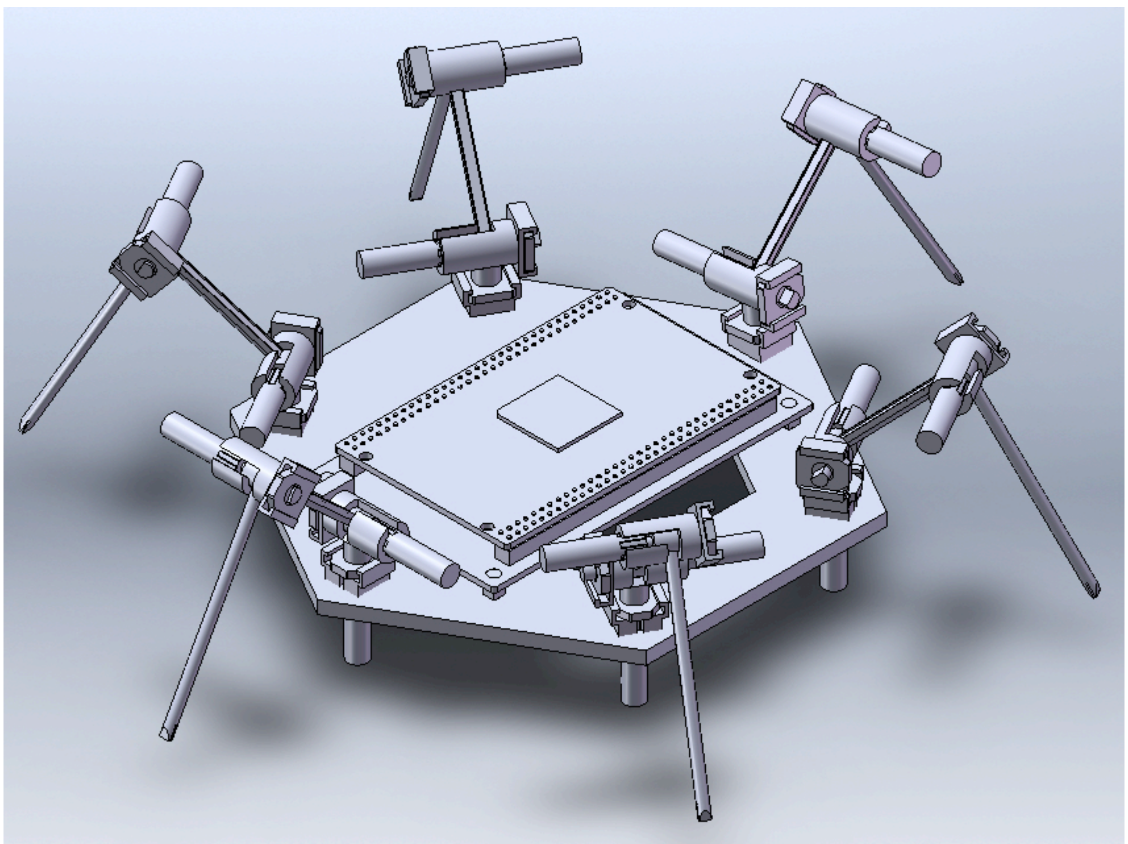

Figure 4: ArachnoBot™ Prototype 3D Model

The main hexagonal frame is designed to hold the control circuitry and support the legs, thereby creating less stress on the PCB's. The frame also affords battery containment, and future expansion from the prototype ArachnoBot™ system, to the final ArachnoBot™ system. Each mechanical component is designed to be replaceable, **FS-32-II**, allowing quick repair of the ArachnoBot™ without affecting critical electronic components. As we will be using 3D printing ABS plastic to construct the ArachnoBot™ prototype, the legs of the prototype system may be fragile, thus enhancing the need for this design specification.

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As the whole mechanical system is designed to fit into a 15 cm x 15 cm x 15 cm cube, **FS-3-I**, the size of the main frame was chosen to be the maximum of 15 cm x 15 cm, allowing the control system to use as much area as necessary for the prototype. With the legs of the ArachnoBot™ being 13 cm long when fully extended, the ability of the ArachnoBot™ to fit into a 15cm cube is displayed in Figure 5.

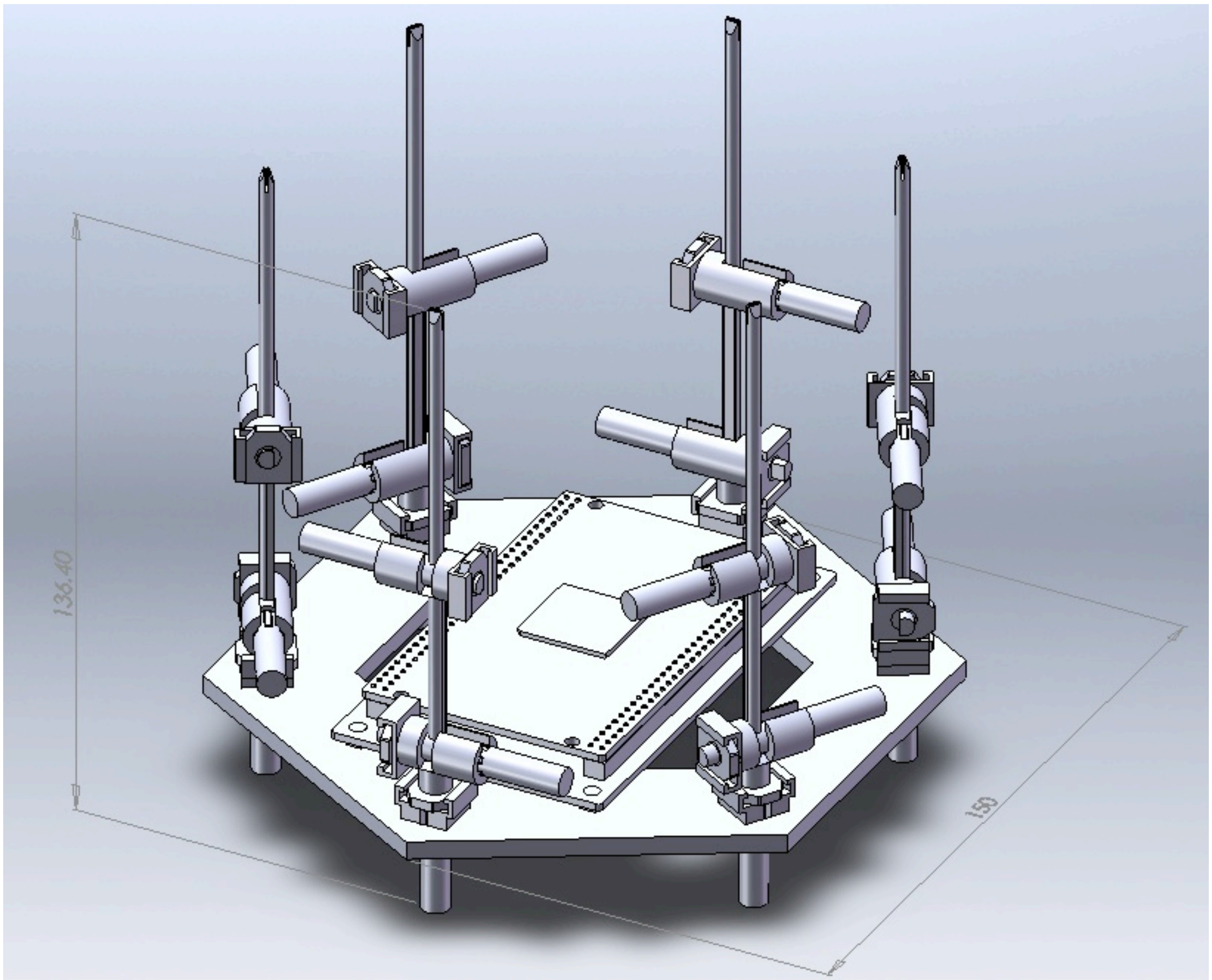

Figure 5: Size Specification of ArachnoBot™

4.2. Leg Specifications

The typical Cartesian co-ordinate system is applied to the point where the rotational axes of the first and second joints meet. This reference system is carried through to the control system of the ArachnoBot™. This co-ordinate system and the associated joint label is shown in Figure 6, and Figure 7. Joint 1, is colloquially called the shoulder joint, joint 2 the elbow joint, and joint 3 the arm joint.

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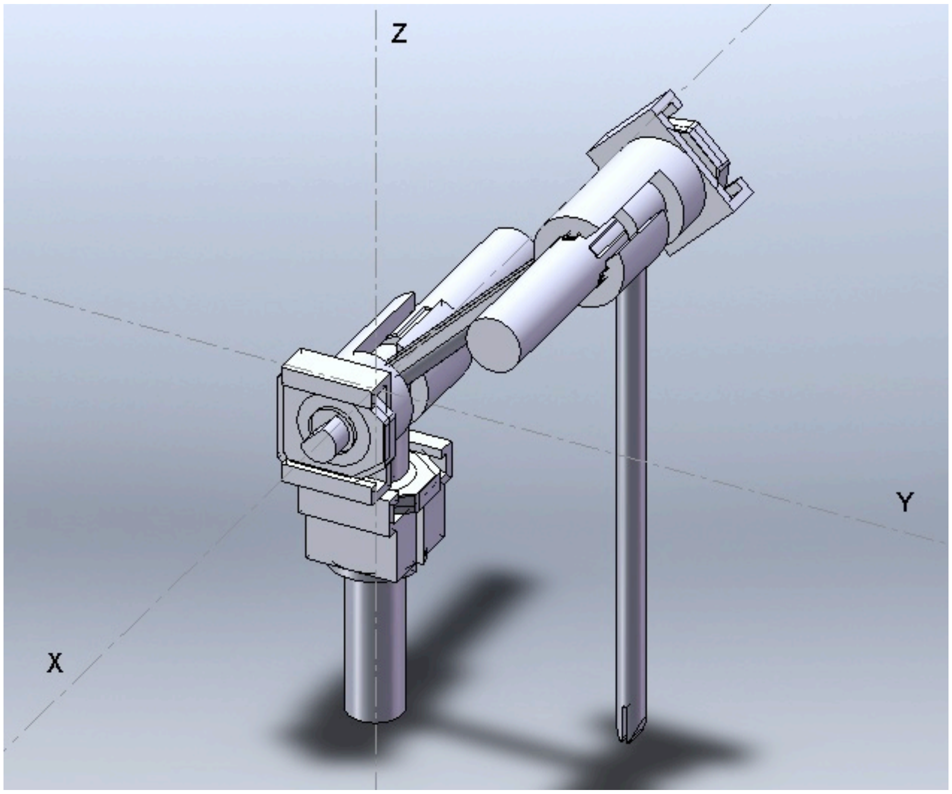

Figure 6: Co-ordinate System

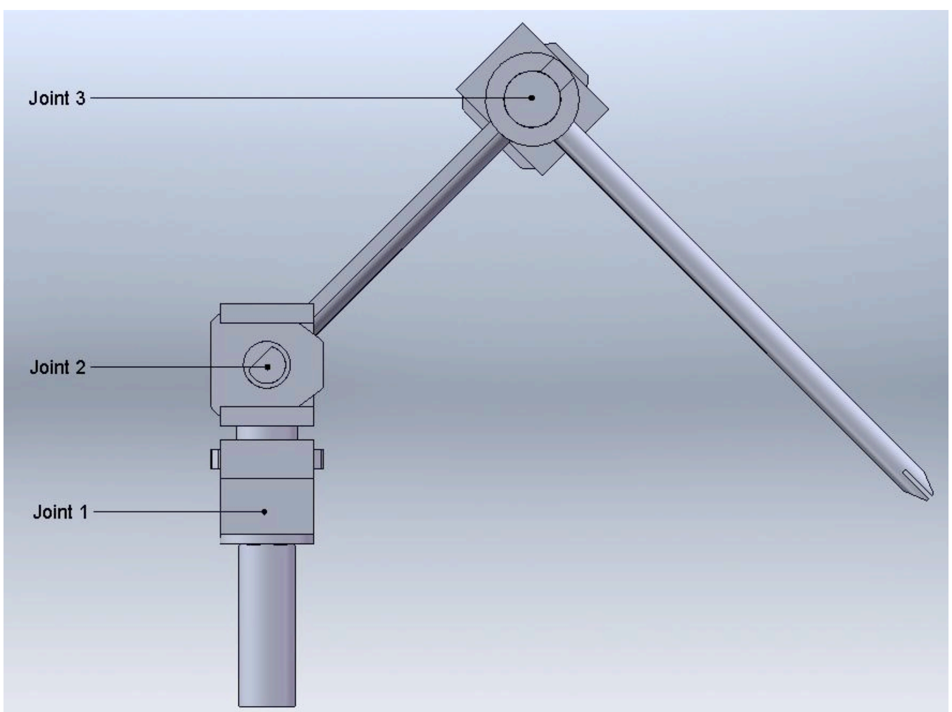

Figure 7: Joint Labels

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The length of the active section of each leg comes to 10 cm, and thus the ArachnoBot™ is able to reach almost any point in a 10 cm radius from the zero position of the leg's co-ordinate system. Joints two and three have a rotational allowance of 120˚, and are able to lift the ArachnoBot™ to a height of 4 cm from the ground. These details are shown here in Figure 8, Figure 9, and Figure 10.

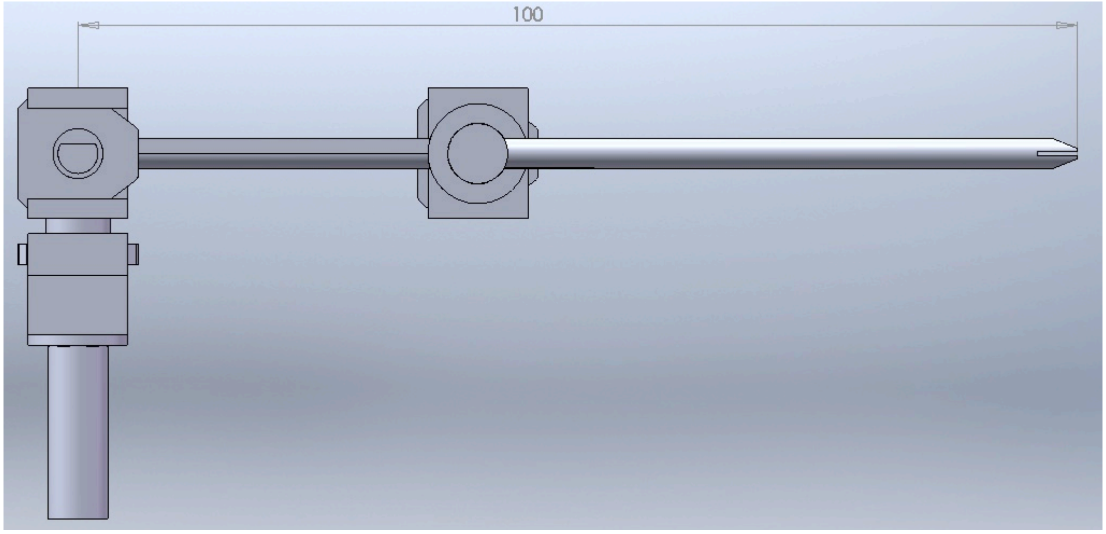

Figure 8: Leg Length

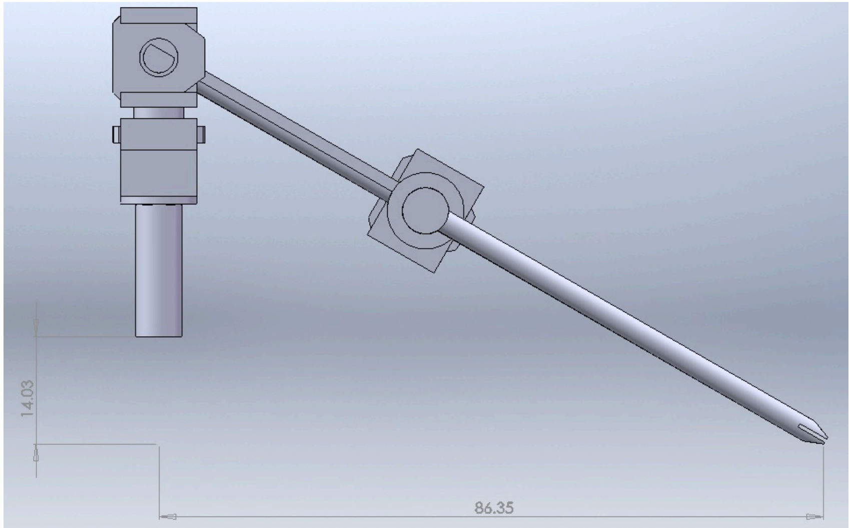

Figure 9: Joint 2 Fully Lowered

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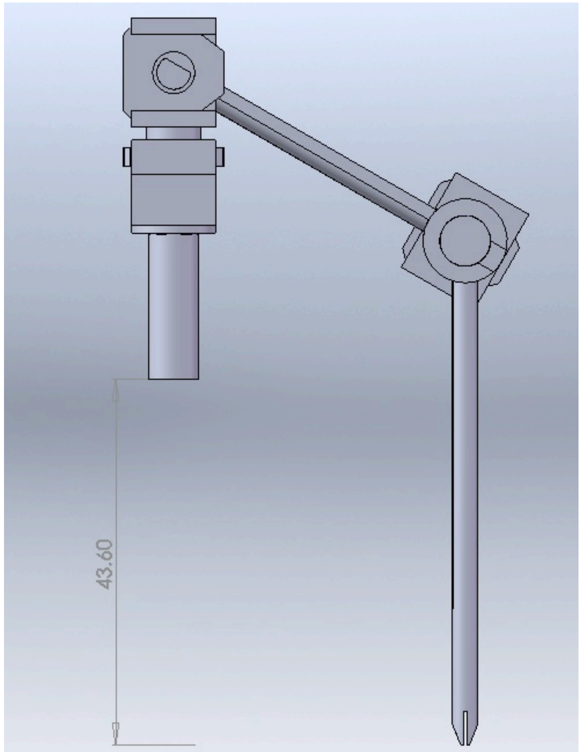

Figure 10: Clearance of Leg

Figure 11 shows the fully raised ArachnoBot™ with each leg moved to the position shown in Figure 10. The clearance of 4 cm affords the ArachnoBot™ the ability to climb highly complex surfaces in its final production model.

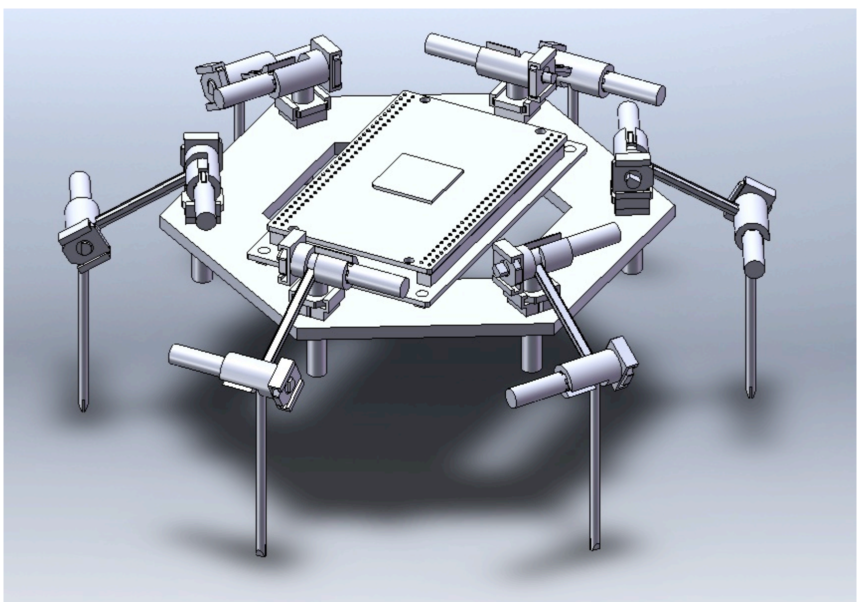

Figure 11: Fully Raised ArachnoBot™

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4.3. Electrical System

The actuator on each joint is a small, geared rotary motor [3], which provides the high torque necessary for movement, as well as a thoroughly slowed rotational speed in order to simplify the control of the robot. The choice of the position sensor is between a Hall Effect Sensor [4] (HES) or a rotary potentiometer [5]. Both design choices have their pros and cons. The Hall Effect sensor is small, frictionless, and provides digital output. However, it needs a voltage translator, a magnet of a sufficient strength which tends to cause interference to other sensors, and creates design constraints on the third joint of the leg. The potentiometer has a pass through shaft, and highly simplifies the PCB circuitry. The negatives of the potentiometers include analog output, and increased friction at each joint. The robot joints have motors placed on opposite sides. This is so that the stress on joint 1 is reduced. The current version of the ArachnoBot™ makes use of potentiometers for the feedback sensors, maintaining simplicity in design. This document refers to the potentiometer implementation for all discussions related to the feedback sensors.

4.4. ArachnoBot™ Movement

As each joint of the ArachnoBot™ operates independently, they must be controlled to move in a synchronous motion. In order to simplify the computations for the FPGA, the walk cycle of the ArachnoBot™ prototype will be pre-calculated and loaded on to the processing module in the form of a look-up table. In order to provide movement of the ArachnoBot™ as a whole, each leg is sequentially lifted up, moved forward, and touched down. Then, using the friction of the leg against the ground, the leg is pulled back and pushed down, lifting the ArachnoBot™, and propelling it forward. In order for this operation to be successful, all of the joints must be acting simultaneously, with multiple legs moving forwards and backwards. Figure 12 shows an example of a single leg's walk cycle.

Figure 12: Example Walk Cycle

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5. FPGA Processing Module

As specified above, the ArachnoBot™ will have 6 legs to help it move. Each leg has 3 DC motors for movement allowing 3 degrees of freedom. Hence a total of 18 DC motors will be required, where each motor will require its own control mechanism. The Controller is a multi-processor system on chip (SOC) implemented on an FPGA, allowing it to be reconfigurable **FS-52-II**. The use of multiple processors allows simultaneous movement of each leg. There are 6 soft-core processors, one per leg, that control all 3 joints on each leg. The use of processors instead of custom logic allows tuning of PID control without any knowledge of HDL. New code can be written through a C language API and downloaded to BRAM during FPGA configuration. Debugging, which is also a functional specification of the prototype, **FS-51-II**, is realized by the Xilinx MicroBlaze Debug Module soft IP [6].

The internal FPGA system is shown below in Figure 13. Like the mechanical structure of the robot, the Controller system has a fair share of symmetry. One main processor is surrounded by six subsystems each connecting to dedicated external leg control circuitry. The main arbiter is the MicroBlaze 0, which sends commands to each leg control subsystem. Trajectory data is stored in the data BRAM connected to MicroBlaze 0.

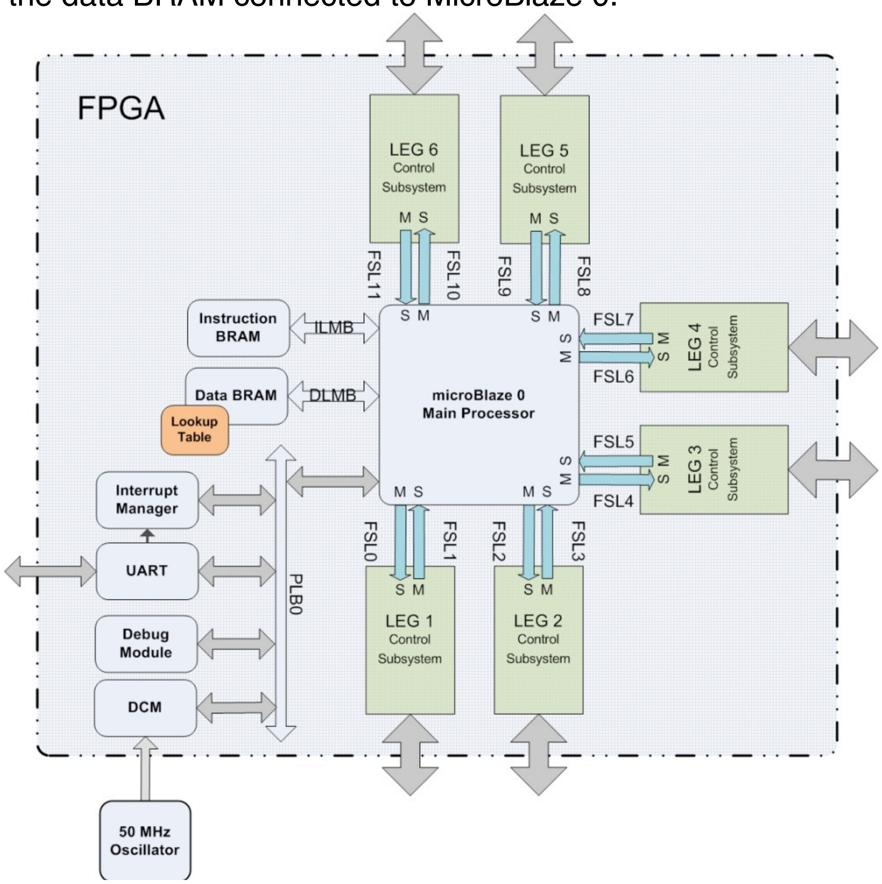

Figure 13: Internal FPGA System

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There are six leg control subsystems, as show in Figure 14 consisting of a local dedicated MicroBlaze, a PLB bus, and separate PWM and ADC modules for each joint. PLB addressing allows each local MicroBlaze to select which module it wants to command. By doing this at a reasonable clock speed it can quasi-simultaneously control all three joints at the same time. PWM generation and the ADC module will be described in more detail in the proceeding sections.

This internal FPGA design of the Controller meets the Controller functional specifications **FS-42-II** to **FS-45-II**, **FS-49-II**, **FS 51-II**, **FS-52-II**

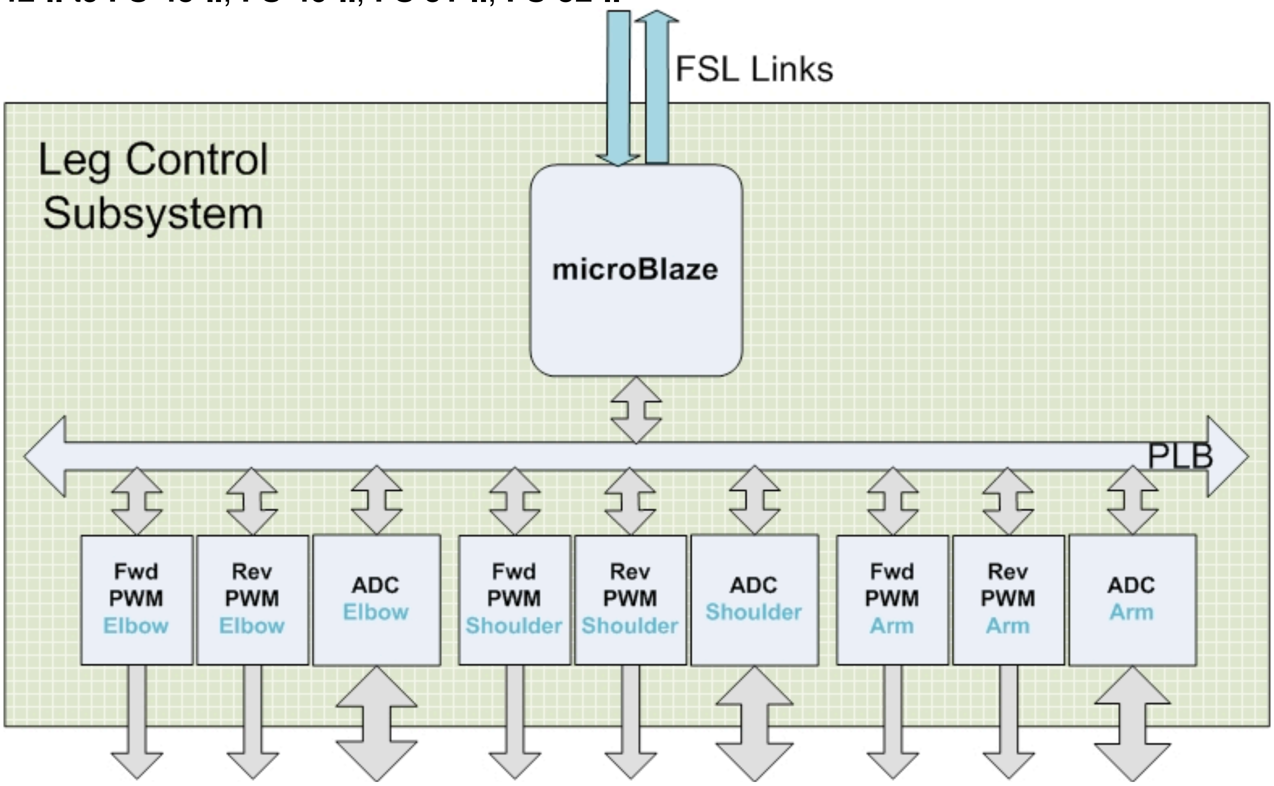

Figure 14: Leg Control Subsystem

Given the physical constraints of the robot, the XCM-016 FPGA development board [7] from Humandata Ltd. was found to be ideal for this application, primarily due to its small form factor (86 x 54 mm). The board provides us with 100 I/O connectors (the CNA and CNB connectors) to interface with the motors and other modules. It will connect to a custom daughter board which will supply it with power and interface the FPGA module with external circuitry. This makes the task of designing the PCB less challenging.

The board comes with a Xilinx Spartan 3A DSP XC3SD3400A FPGA. The XC3SD3400A has 53,712 logic cells and 2268Kb of BRAM which serves the synthesizable logic and memory requirements for this project. The FPGA will essentially implement the multiple microcontroller design shown above using the MicroBlaze™ soft processor IP core. During preliminary

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testing, the resource usage for controlling a leg comes to about 3,500 logic cells. Each processor requires at least 64 Kb of BRAM for storing the program. Hence about 24,500 logic cells and 448 Kb of BRAM will be required for synthesizing the system on the FPGA. In case more memory is required, there is an additional 256 Mb of SDRAM available on the board. Figure 15 shows the features of the FPGA module.

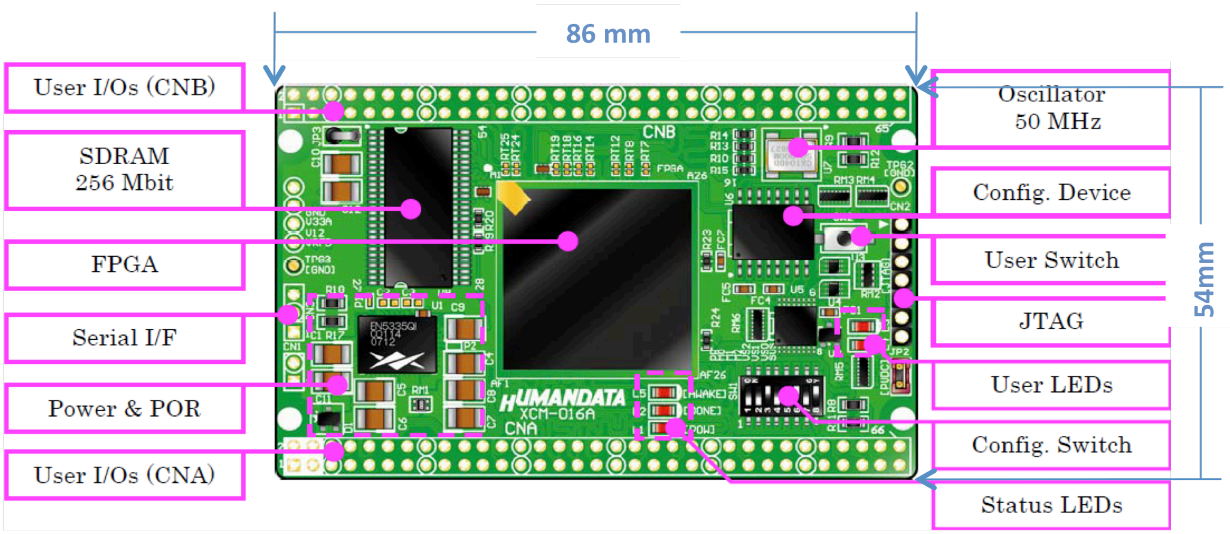

Figure 15: XCM-016 HUMANDATA FPGA Module

The FPGA and soft processors are clocked via the on board 50 MHz oscillator. If required, this frequency may be boosted internally using one of the available DCMs inside the FPGA. The synthesized hardware bitstream and will be downloaded on the board via the JTAG connector using the Xilinx Platform USB II JTAG programmer.

6. Motor Control

Each leg of the ArachnoBot™ will consist of three independently controlled DC motors. From theory, the speed of a DC motor varies linearly with voltage and its torque varies linearly with current. As a result, there is a need for a controllable variable-voltage supply input to speed up or slow down the motors. In addition, a specialized circuit is needed to handle the higher currents traveling through this inductive load. To accomplish this task, a Quad H-Bridge Motor Driver IC (MPC17550 from Freescale Semiconductor [8]) is used. It comes with four ports for driving DC motors, each with an internal H-bridge that accepts PWM input signals for both forward and reverse directions. Figure 16 below gives the system overview for one leg. Note that all components to the right of the I/O connectors will be found on the drive module PCB, and the I/O connectors connect both the motors and motor driver to the FPGA processing module.

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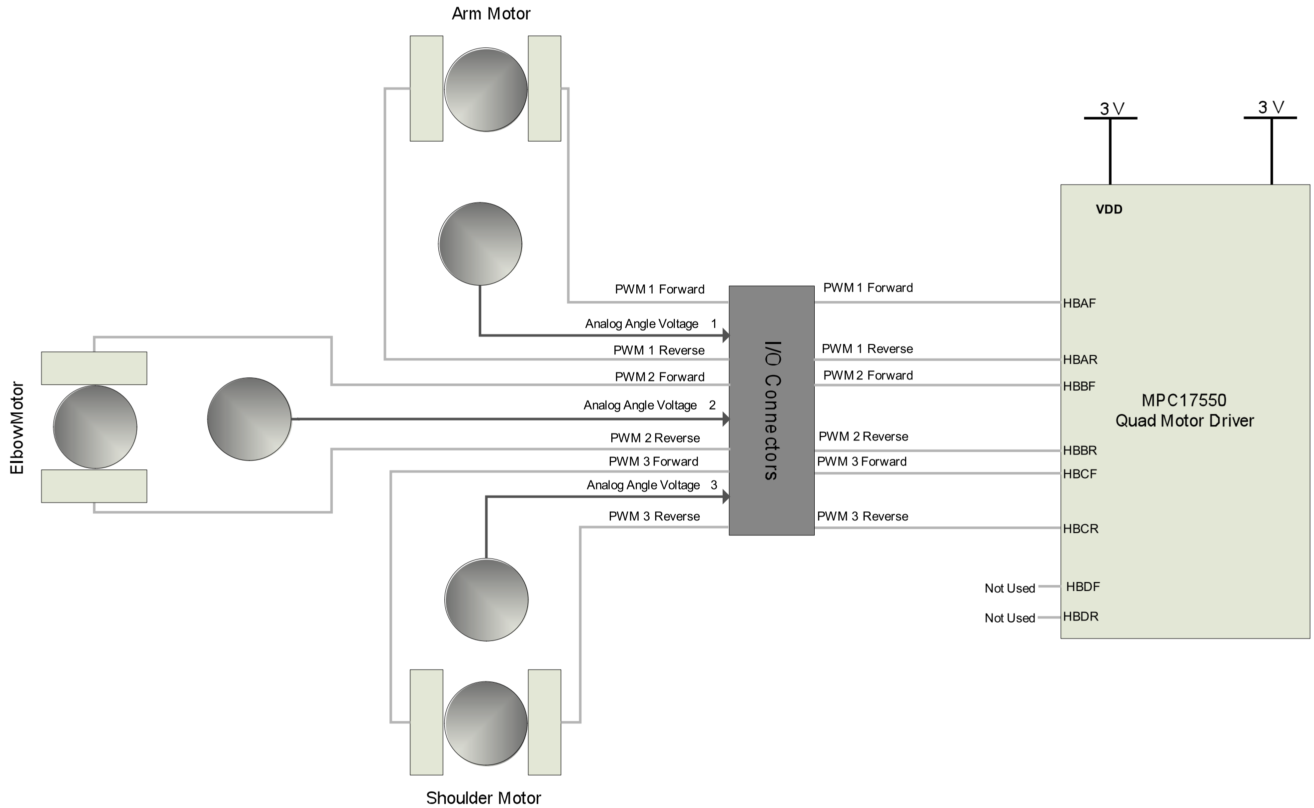

Figure 16: Motion Generating System Overview

The second component of the PWM control is PWM generation. The PWM is generated using the Xilinx XPS Timer/Counter soft IP. Based on the datasheet, the counters for PWM period and duty cycle are calculated using the following equations:

Period_Counter = ((Period_in_seconds * Clock_Frequency) - 0x2) (Equation 3.1)
Duty_Cycle_Counter = (((Duty_Cycle * (Period_Counter + 0x2)) - 0x2)/100 (Equation 3.2)

As shown earlier in Figure 14 two timers are required for each motor, one for the forward direction (Fwd_PWM) and the other for the reverse (Rev_PWM). The timer modules manipulate both the frequency and duty cycle of the input square wave and feed this signal into the H-bridge.

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7. Angle Sensing and PID Feedback

In addition to PWM generation, there is a negative feedback system that corrects the output angle of each leg joint. This feedback system consists of rotary position sensors and Analog to Digital Converters (ADC). The sensors are rotary potentiometers and the ADC blocks are further broken down into comparators and soft-IP Xilinx XPS Delta-Sigma ADC modules on the FPGA. Figure 17 below shows the basic structure of the feedback system.

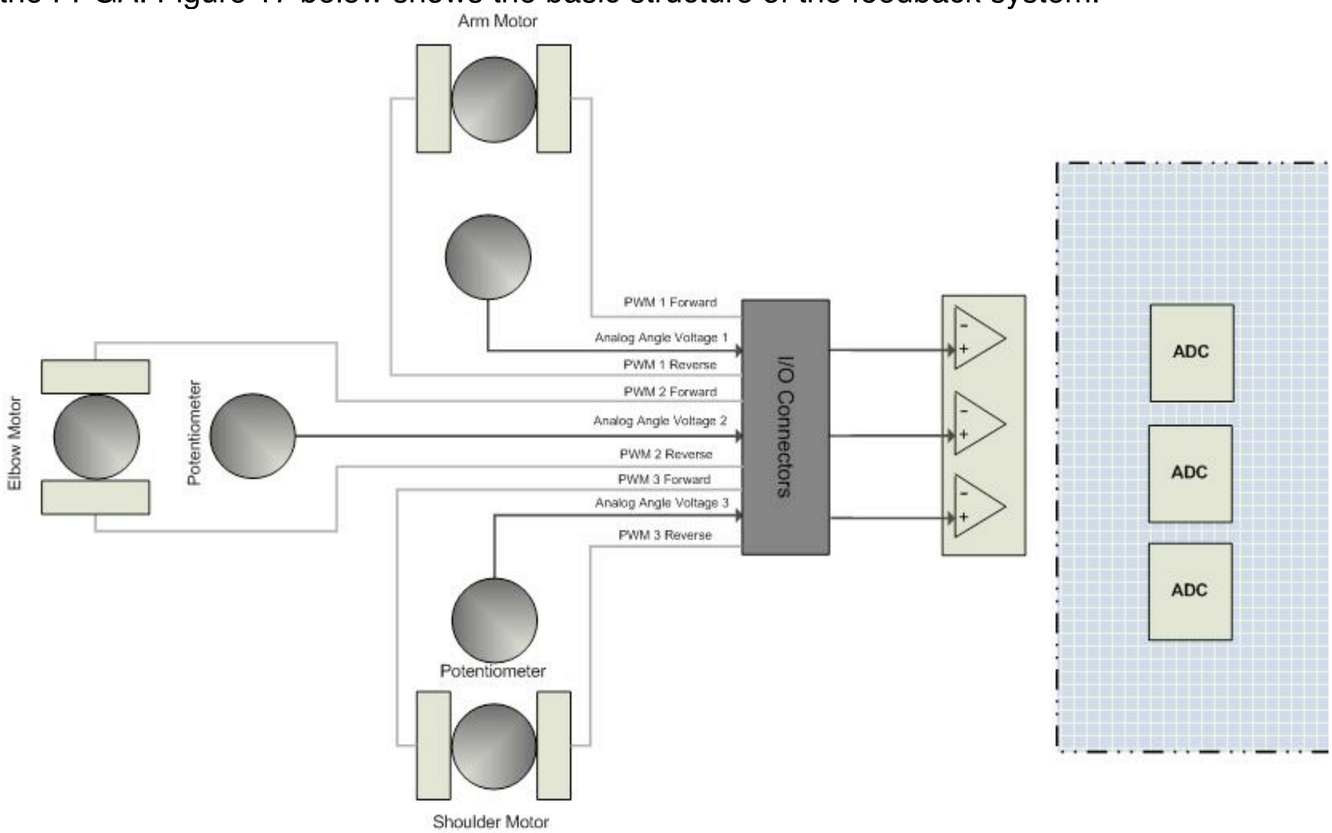

Figure 17: Feedback System Overview

The ADC component of the feedback system is shown below in Figure 18. The output of the rotary potentiometer is fed into the non-inverting input of the comparator (AnalogIn). The comparator compares AnalogIn to the output of the ADC module, and this result is fed into the XPS ADC block as AgtR. The XPS ADC block uses a binary search algorithm to determine the value of AnalogIn. A digital value stored in a register is converted into an analog voltage using the external RC circuit. This is fed back into the comparator and the cycle starts again. Figure 18 shows the Xilinx XPS ADC Module used in the FPGA. [9]

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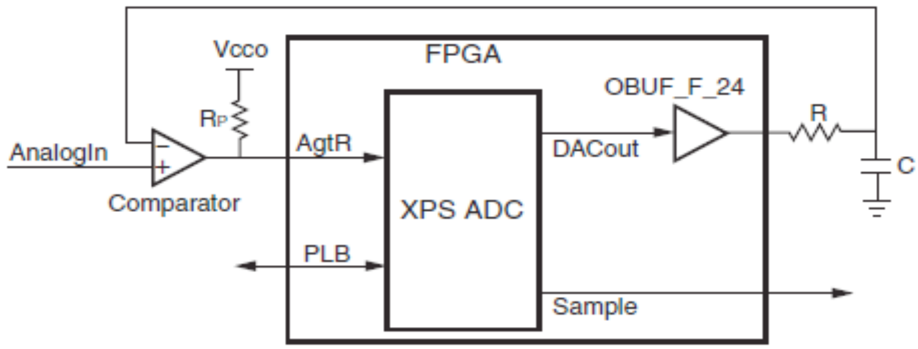

Figure 18: Internal Implementation of the ADC Module

The second part of the feedback system is the control algorithm. A simple PID algorithm will be implemented in software on the MicroBlaze processor for controlling the DC motors on each leg. As currently all the motors are the same model, the PID algorithm can be run in a loop for controlling all three motors on a leg. Although a hardware implementation of the PID controller would be faster and allow the motors to be controlled in parallel, the software implementations has been favored as it will be less complex to design and easily tunable in case the motors are changed. During testing, it was also found that running the processor at over 1MHz effectively allows all three motors to be controlled in pseudo parallel hence eliminating the requirement for a dedicated PID hardware module.

8. Circuit and PCB Implementation

The electronics of the robot are found on the two PCBs in the center. The top board serves as the brain of the robot, and houses the FPGA that computes all the trajectories for the joints of the robot. The bottom PCB is electrically connected to the top through headers and serves as the power distribution and actuation/sensor mechanism for the robot. The bottom board carries the motor drivers, comparators that are used for the ADC in the feedback loop, and all the power that is required for those parts.

The FPGA board was already shown in Figure 15. As mentioned, the power board will be attached underneath and will resemble Figure 19 [10].

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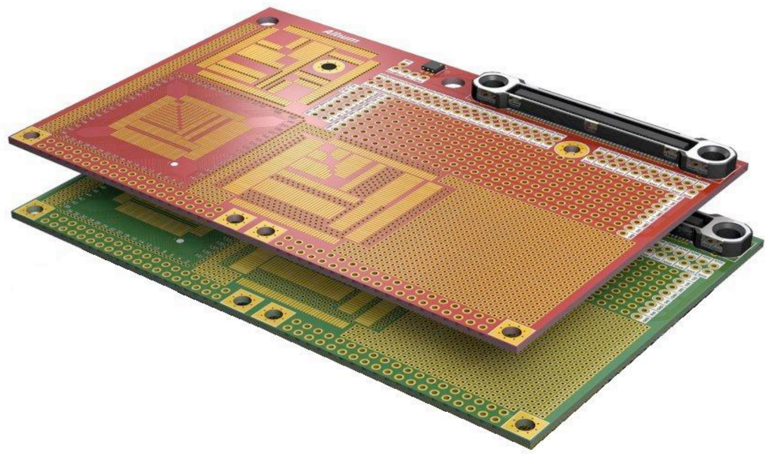

Figure 19: Stacked PCB Design

9. Power Distribution and Power Supply

The robot spider will use a single 3.3V power supply that will be decoupled for various components and bucked down to 1.2V for the FPGA core. An external power supply feed the bottom board and power will be routed throughout the spider from it. Table 1 outlines the voltage levels required for the operation of the individual components:

Table 1: Operating Voltage for Individual Components

Component	Operating Voltage
FPGA IO	3.3V
FPGA Core	1.2V
FRAM & SRAM	3.3V
MPC 17550 Quad HBridge Motor Driver (V_M)	3.3V
MAX 944/9144 Quad Comparators SOIC (V_{CC})[11][12]	3.3V
Murata SV01 Rotary Potentiometers (V_{CC})	3.3V

The major concern with the power distribution in the bottom PCB is the effect the inductive loads of the motors will have on the digital circuitry (motor drivers, comparators). Inductive loads often introduce voltage spikes into the circuit, which can damage the low voltage low current digital circuits. One must be careful to separate power and ground traces of analog and digital circuits on the PCB when dealing with larger current analog components.

One solution is to have separate power rails for the motors and the rest of the circuit. This adds flexibility in being able to independently control the motors and their speed. A more compact solution is to decouple the supply traces leading into the motors from the main 3.3V rail. This requires less external inputs and is a more efficient answer if designed properly.

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In designing the power rails, a hybrid solution in which a jumper setting on the PCB will determine whether the motors will be supplied power from the main 3.3V rail or from an external supply has been chosen. This allows flexibility to change designs even after PCB fabrication.

To further reduce noise issues the PCB will contain an embedded power plane (3.3V) and ground plane along with two signal layers. The addition of an entire plane for power purposes allows for the possibility of combining the motor circuitry to the main digital electronics on the board. Figure 20: Power Layer Distribution on the PCB shows the layer distribution on the PCB board. [13]

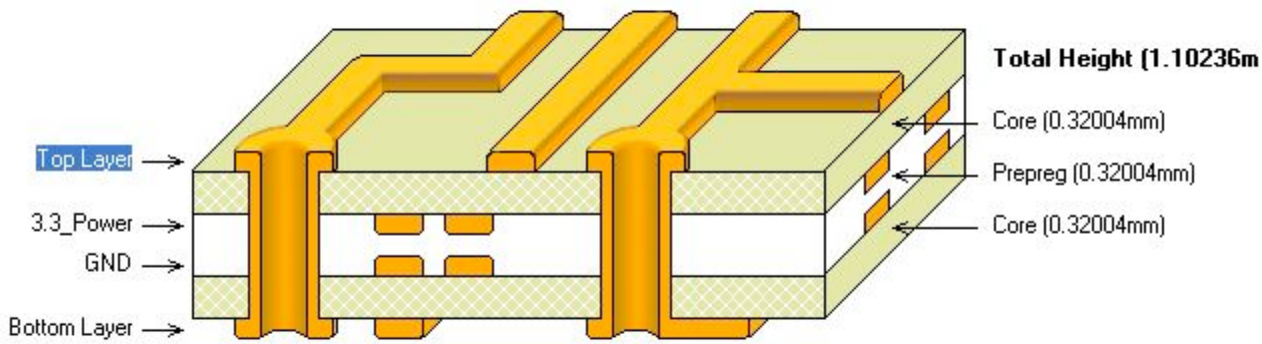

Figure 20: Power Layer Distribution on the PCB

10. User Interfacing and Control

The ArachnoBot™ prototype is an autonomous system that does not need to reply to the user. Later versions of the ArachnoBot™ will incorporate wireless control which will give the user more interaction. This will require both a computer based graphical user interface (GUI), as well as a reliable means of communication.

The current prototype will use LEDs on the FPGA module to indicate which mode the robot system is in **FS-60-I**. Additionally, all critical and important connections and pins will be clearly indicated. A silk screen on the PCB will mark connections and the role of ICs.

The prototype system is designed for mainly researchers and engineers knowledgeable with its operation and who will experiment with different controller configurations (e.g. tuning the PID). This can be done by writing new code to run on the MicroBlaze processors or by creating new HDL code for the internal FPGA system (**FS-52-II)**. The user interface is already provided by Xilinx EDK which does not abstract the user from all the complexity of the system. This is desirable from a researcher point of view and meets the requirement **FS-62-I**.

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11. System Test Plan

To test that the ArachnoBot™ prototype system meets the functional specifications, the following test procedures will be carried out. The tests provided here are mainly performance related.

TEST 1: Drive Module Electronics Test

Description and Procedure:
Drive Module should be tested prior to connecting to mechanical legs. An oscilloscope should probe the I/O connections on the Drive Module while the Processing Module sends commands to the leg circuitry.

An analog signal should be applied at the I/O connection of the potentiometer and test pins should be probed and value observed. This should be repeated for every I/O connection.

Outcome:
The current PWM signal should be observed at the I/O connections of each section of the Drive Module. The test pins on the Drive Module should indicate the correct binary value for the corresponding applied potentiometer signal.

TEST 2: Three Motor Single-Leg Test

Description and Procedure:
Perform individual leg trajectory command and movement. Measure power consumption. Repeat for each of the six legs.

Outcome:
Each robot leg should follow correct trajectory in a smooth fashion and stop completely once trajectory is met.

TEST 3: 18 Motor Horizontal Motion Test

Description and Procedure:
Perform full trajectory command. Motion should include Forward, and Backwards. All legs should move to complete trajectory.

Outcome:
Robot completes the trajectory commands in correct sequence and comes to a stop afterwards. This should be observed for each direction of motion.

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12. Conclusion

This document has outlined the design specifications of phase I of the ArachnoBot™ system. The prototype robotic system presented here is to be used as a base for further design improvements. Thus, the design of phase II and phase III ArachnoBot™ systems will build on this design. Ultimately, the final form may change to meet higher functional specifications.

To meet the functional specifications of the improved phase II and phase III systems, the incorporation of more complex subsystems and more involved testing of those subsystems will be required. For this reason, it is recommended that design interfacing and reuse of the prototype system presented here be practiced extensively to minimize design time.

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