ArachnoBotics
Research
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February 8th, 2010

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Capstone Project: *Functional Specifications of the ArachnoBot™*

Dear Dr. Rawicz,

Please find the attached document titled *Functional Specifications of the ArachnoBot™*, for our ENSC 440 Capstone Engineering Project. Our objective is to design a 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 functional specifications serve as an excellent framework to aid our mechanical, electrical and programming teams while designing the ArachnoBot™ prototype. The document lists the important electrical, mechanical, user-interface and general requirements, among others, essential for the success of the prototype and the final product.

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 our proposal, please feel free to contact me by phone (778.893.3303) or by email (pranav_gupta@sfu.ca).

Yours sincerely,

Gupta

Pranav Gupta
Chief Executive Officer
ArachnoBotics Research Inc.

Enclosed: *Functional Specifications of the ArachnoBot™*

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Functional Specifications of the ArachnoBot™

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ENSC 305 - Steve Whitmore

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Executive Summary

"… to boldly go where no man has gone before." [1]

The above quote by Captain James T. Kirk from Star Trek epitomizes mankind's unquenchable thirst for exploration. History is filled with landmark scientific discoveries and engineering inventions that benefit the human race and pave the way for future generations of scientists and inventors. In the sciences and engineering these include the invention of the wheel, the telephone, the airplane, the transistor and digital computing along with countless other inventions. It is time to take exploration to its next phase of evolution. Fusing the power of 21st century robotics with humanity's desire to explore, ArachnoBotics Research Inc. envisions the next major landmark to be an autonomous walking robot capable of traversing any terrain, and any obstacles in its path.

Since its founding in late 2009, ArachnoBotics Research Inc. has set out plans for prototyping a small proof of concept model showcasing the latest in autonomous walker technologies. The ArachnoBot™ is designed to be a general proof of concept showcasing the control philosophy behind robotic hexapod walking platforms.

The first prototype ArachnoBot™ model is slated to be ready by the end of April 2010. Some important specifications of the first prototype are outlined below:

- Capable of traversing pre-programmed trajectories
- Less than 200 grams in weight
- Physical dimensions not exceeding 15 cm x 15 cm x 15 cm.

The production ready ArachnoBot™ will also meet the following specifications:

- Capable of autonomous navigation of complex terrain
- Capable of operation in extreme environments
- Operate using an internal power supply
- Can be controlled by a user in real time.

The following functional specifications are a roadmap for designing and testing the prototype ArachnoBot™, while also specifying many of the requirements for a production ready model. 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

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
MTTF - Mean Time to Failure
MTBF - Mean Time Between Failures
PID Controller - Proportional-Integral-Derivative Controller
PWM - Pulse Width Modulation
RoHS - Restriction of Hazardous Substances

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1. Introduction

The ArachnoBot™ is a fully autonomous, robotic hexapod with variable terrain scaling capabilities, making it suitable for a wide range of environments. Based on a project by the European Space Agency (ESA), the ArachnoBot™ system aims to fulfill the market need for a small, lightweight robot capable of scaling complex terrains, and vertical surfaces. 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™. **Figure 1** shows an example CAD model of what the ArachnoBot™ prototype model will look like.

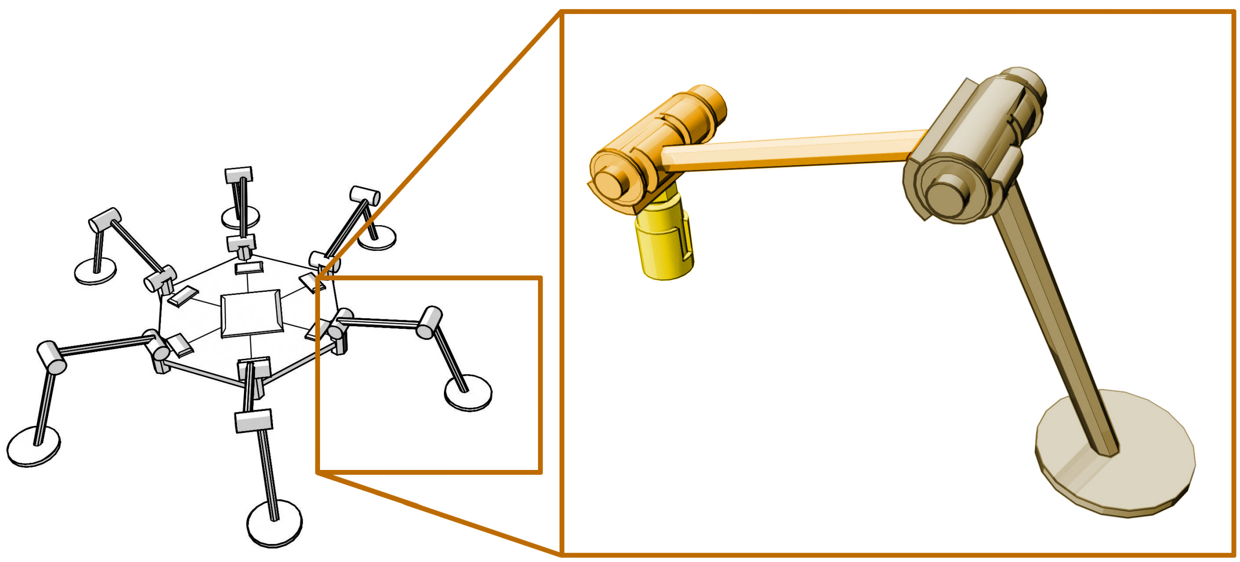

Figure 1: *Proposed ArachnoBot™ Design*

The ArachnoBot™'s innovative design concepts and realization are well suited to a wide range of applications: from exploration, to construction and repair. The easily programmable control interface lends itself to any level of automation while at the same time providing a structured framework with which to provide users total control of the ArachnoBot™.

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1.1. Scope

This document describes a complete list of the functional specifications needed to complete the ArachnoBot™ prototype model. Furthermore, additional specifications for the production ready ArachnoBot™ are also defined.

Any further specifications developed by ArachnoBotics Research Inc. will be added to this document pending approval from all Chief Officers, and will prompt an increase in revision number.

1.2. Intended Audience

The specifications encompassed by this document are expected to be the main design tenets of the ArachnoBotics Research Inc. management, and research and development teams. Through each stage of development, the functional specifications hereunto enclosed will be followed and tested against each stages final product. Each stage will not be considered as complete until the functional specifications are met.

Potential investors, customers, and incoming team members are also expected to have access to this document for a detailed product description of the final ArachnoBot™ production model.

1.3. Classification

The following classification system will be used throughout this document to describe each functional specification.

[FS-FSN-DM]:

FS = Functional Specification
FSN = Functional Specification Number
DM = Development Model

Of which, there are three types of Development Models:

- **I.** Prototype
- **II.** Prototype and Production
- **III.** Production

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2. System Overview

This section will describe the ArachnoBot™ system in the context of functionally, and is provided to help to understand the functional requirements presented in this document.

Functionally, the ArachnoBot™ system can be separated into a Control System and an Electromechanical System. **Figure 2** below shows the different components of each of the ArachnoBot™ system.

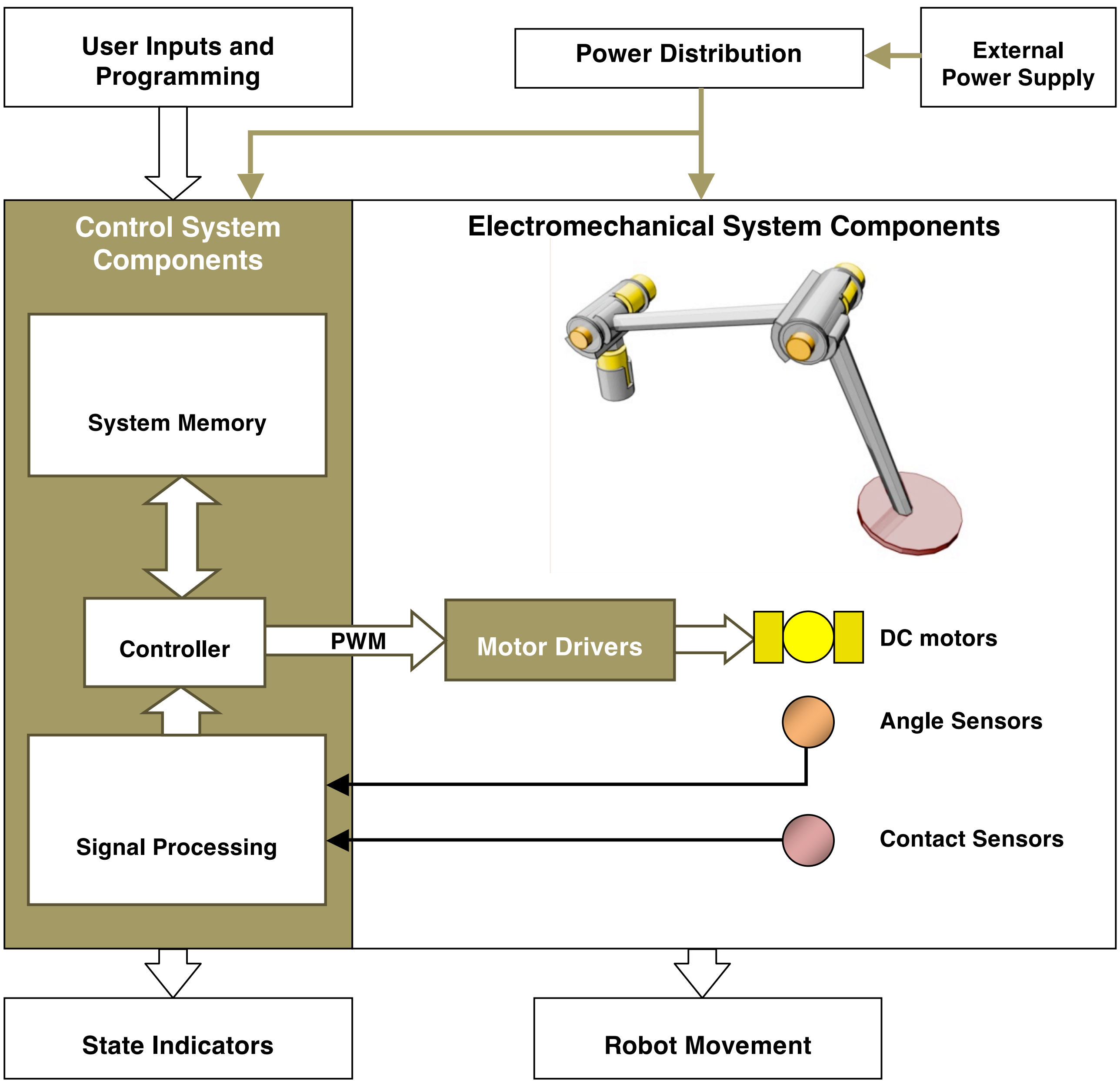

Figure 2: *Functional System Block Diagram of the ArachnoBot™ Prototype.*

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The main purpose of the ArachnoBot™ system is to coordinate and carry out movement. The ArachnoBot™ has six independent legs, symmetrically placed around the main body. Each leg has three joints each, providing 3 degrees of freedom (DOF). The 3 DOF allow the robot to traverse complex uneven terrain and even begin climbing on vertical surfaces.

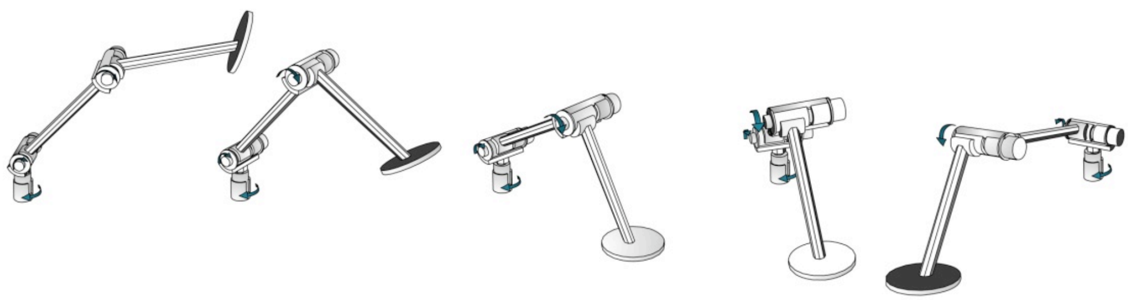

Figure 3: *Synchronized Motor Motion Completes a Desired Trajectory*

2.1. Control System

The Controller, along with the whole Control System, is built into the main body, and can control each joint independently. **Figure 3** shows how a certain trajectory of one leg can be completed. By moving separate legs in the correct manner simultaneously the rigid structure of the robot spider can move forward altogether.

2.2. Electromechanical System

Each joint of the Electromechanical System features a single motor, a drive train, and a position sensor. Positional feedback through PID control aids the Controller in carrying out accurate trajectories even with external disturbances. Additionally, contact sensors are provided on the end effectors of each leg for force feedback, allowing the controller to know if a leg has made contact with a surface.

The ArachnoBot™ prototype model is designed to run from external power, although the production model will have designs for an internal power supply. For this reason, low power consumption and a standby state will be incorporated into the design of the ArachnoBot™.

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3. Functional Specifications

3.1. General Specifications

FS-1-II The ArachnoBot™ must be aesthetically pleasing.
FS-2-II The weight of the ArachnoBot™ must not exceed 200 g.
FS-3-I Total dimensions must not exceed 15 cm x 15 cm x 15 cm when all the legs are stored in the home position.
FS-4-III Total dimensions must not exceed 9 cm x 9 cm x 9 cm when all the legs are stored in the home position.

3.2. Electrical Specifications

FS-5-II The ArachnoBot™ will need one motor per joint.
FS-6-II The ArachnoBot™ will need one position sensor per joint.
FS-7-III The ArachnoBot™ will need one pressure sensor per leg.
FS-8-III An electrical port must exist so as to support external sensors.
FS-9-II An electrical port must exist so as to support diagnostics equipment.
FS-10-I An electrical port must exist to support an external power supply.
FS-11-III An electrical port must exist so as to support a dual-purpose power / data cable.
FS-12-I All electrical components must be replaceable.
FS-13-II A storage medium must exist to supplement the Controller.
FS-14-III The ArachnoBot™ must support an on-board wireless module capable of transmitting signals to a minimum of 40 meters.

3.3. Power Specifications

FS-15-III The ArachnoBot™ must contain power management circuitry.
FS-16-II The ArachnoBot™ must be power efficient.
FS-17-III The ArachnoBot™ must support a standby mode to conserve power.
FS-18-I The power supply must supply sufficient energy to power the controller, all the sensors, and all the motors at same time.
FS-19-II The ArachnoBot™ must support the use of an external power supply.
FS-20-I External power will be provided through a common 5V power supply.
FS-21-I The external power supply will have a cable with a minimum length of 1 meter.
FS-22-III External power will be provided through a dual-purpose power / data cable.
FS-23-III The ArachnoBot™ must contain an internal battery.
FS-24-III The internal battery must provide at least 100 minutes of power during standby.
FS-25-III The internal battery must provide at least 10 minutes of power during movement.
FS-26-III The ArachnoBot™ must contain a method to recharge the battery.
FS-27-III The power supply must supply sufficient energy to power the controller, the sensors, the motors, and recharge the battery at the same time.

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3.4. Mechanical Specifications

FS-28-II The ArachnoBot™ must be able to stand under its own weight, even while no power is supplied to the motors.
FS-29-II The ArachnoBot™ must provide sufficient force to provide movement on the vertical plane.
FS-30-III The ArachnoBot™ must provide sufficient force to provide movement on the vertical plane.
FS-31-III Each leg must contain a Factor of Safety (FOS) of 5.
FS-32-II Mechanical elements must be replaceable without affecting critical electrical functions.
FS-33-II There will be three Degrees of Freedom per leg.
FS-34-II Each joint must provide space for a position sensor.
FS-35-II Each joint must provide space for a DC motor.
FS-36-III Each joint must provide space for a torque sensor.
FS-37-II Proper wire management to the electrical elements at each joint must be an integral part of leg design.
FS-38-II End effectors must provide sufficient contact friction to support movement.
FS-39-III End effectors must support a variety of electrical attachments.
FS-40-III End effectors must provide space for a pressure sensor.
FS-41-III End effectors must support an adhesive attachment for vertical travel.

3.5. Controller Specifications

FS-42-II The Controller must have an auto-shutoff feature in case of a cataclysmic event.
FS-43-II The Controller must be able to move all joints independently.
FS-44-II The Controller must be able to move all joints at the same time.
FS-45-II The Controller must be able to determine each joint's position.
FS-46-III The Controller must be able to interface with a variety of external sensors.
FS-47-III The Controller must be able to determine the torque applied at each joint.
FS-48-III The Controller must be able to determine the force applied by each leg.
FS-49-II The Controller must be able to interface with every sensor simultaneously.
FS-50-II The Controller must be able to interface with a computer.
FS-51-II The Controller must be programmable and support debugging.
FS-52-II The Controller must have tunable PID parameters for motor control.
FS-53-III Each ArachnoBot™ must be able to communicate with other ArachnoBot™s nearby.
FS-54-III Each ArachnoBot™ must be able to communicate with a host controller.
FS-55-III Each ArachnoBot™ must be capable of relaying commands from the host controller to other ArachnoBot™s.

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3.6. User Interface Specifications

FS-56-I Users must be able to start and stop the ArachnoBot™'s forward movement.
FS-57-III Users must be able to fully control the ArachnoBot™'s movement.
FS-58-III Users must be able to set goal positions for the ArachnoBot™.
FS-59-II Users must be able to remotely stop the ArachnoBot™'s movement.
FS-60-I Visual indicators for system power and system status must be placed on the main body of the ArachnoBot™.
FS-61-II Users must be able to see the current status of the controller.
FS-62-I Users can see all low-level operations of the controller.
FS-63-III Users can typically only see high-level operations of the controller.
FS-64-III Users will be able to feel the status of the ArachnoBot™'s movement through a force feedback system.

3.7. Performance Specifications

FS-65-I The ArachnoBot™ must be capable of walking in a straight line.
FS-66-III The ArachnoBot™ must be capable of performing motion primitives.
FS-67-III The ArachnoBot™ must be capable of navigating complex surfaces.
FS-68-I The ArachnoBot™ must have a maximum speed of no less than 1 cm/s.
FS-69-III The ArachnoBot™ must have a maximum speed of no less than 5 cm/s.
FS-70-III The ArachnoBot™ must be able to perform a full 360° turn in its own footprint.
FS-71-II The Controller must be capable of autonomous navigation of its terrain once its goals are defined.
FS-72-II Maximum data throughput between digital components of the controller should not exceed 400 Kbits/s [2].
FS-73-II Maximum clock frequency should not exceed 20 MHz to adhere to low power requirements (**FS-16-**).

3.8. Environmental Specifications

FS-74-I The ArachnoBot™ prototype will operate in a test environment, on a flat, 2D surface with no obstacles.
FS-75-III The ArachnoBot™ will operate on complex 3D surfaces.
FS-76-III The ArachnoBot™ must be capable of operating in extreme environments.
FS-77-III The ArachnoBot™ must be capable of operating in outer space.

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4. Standards

4.1. General Standards

FS-78-II The ArachnoBot™ must be ROHS compliant, as defined by the European Parliament [3].

FS-79-III The ArachnoBot™ will not cause any harmful interference, as defined by the FCC [4], the CRTC [5], and corresponding European Telecommunication standards.

FS-80-III The ArachnoBot™ will accept any interference, including that which may cause undesired operation, as defined by the FCC, the CRTC, and corresponding European Telecommunication standards.

FS-81-III The ArachnoBot™ will follow proper ESA [6] standards where necessary.

4.2. Reliability

FS-82-I The ArachnoBot™ must have a mean time to failure (MTTF) of 10 minutes.

FS-83-III The ArachnoBot™ must have a mean time between failures (MTBF) of 30 days.

4.3. Documentation Standards

FS-84-II Documentation will be written in English.

FS-85-II Documentation will adhere to the ArachnoBotics Research Inc. style guide.

FS-86-III An overview of the ArachnoBot™ production model will be written that explains, in common language, the features, functions, capabilities, and expansions, of the ArachnoBot™.

FS-87-III A user manual will be created for the ArachnoBot™ outlining the user interface software provided with the ArachnoBot™.

FS-88-III Furthermore, a detailed manual defining the Controller states, as defined in **FS-61-** and **FS-63-,** will be created.

FS-89-III Documentation must be sufficiently thorough and detailed such that no on-site training is necessary for users to control, repair, or upgrade the ArachnoBot™.

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5. System Test Plan

The system test plan will be broken down into several main stages in order facilitate the testing of the robot. Each stage will have numerous subtests not shown below. The test plan outline below can be thought of as a visual demonstration of each phase of development.

5.1. 3 Motor Single-Leg Test (No Motion Trajectory)

- The prototype Control system will control three independent motors (joints) on the same leg.
- Each joint will move to the desired position set by the controller.
- The test will involve moving all three motors simultaneously at the maximum load. As the motors rotate, the power drawn will be measured and compared to their maximum power ratings of the motor and power supply. Multiplying by six will give us an estimate of the total power required for the ArachnoBot™.

5.2. 18 Motor Horizontal Forward Motion Test

- The prototype Control system will control 18 independent motors (joints) on six legs.
- Each joint will move to the desired position set by the Controller.
- The ArachnoBot™ will move in a straight line on a clean and flat surface.
- To confirm the power estimate in 5.1, all 18 motors will move simultaneously at their maximum loads. The total power drawn will be measured and compared to power ratings of motors and power supply. Coefficients of temperature will be used to ensure proper thermal characteristics.

5.3. 18 Motor Horizontal Backward Motion Test (Production Model)

- Same test as 5.2 but using different trajectories for joint angles.

5.4. 18 Motor Horizontal Turning Test (Production Model)

- Same test as 5.2 but using different trajectories for joint angles.

5.5. 18 Motor Vertical Forward Motion Test (Production Model)

- The ArachnoBot™ will start on a smooth, flat vertical surface and proceed to climb.
- All 18 motors will follow a preconfigured set of input angles to follow.
- As in 5.2, the maximum power draw will be measured.

5.6. 18 Motor Horizontal Forward Motion to Vertical Forward Motion Transition Test (Production Model)

- The ArachnoBot™ will start on a smooth and flat horizontal surface. It will move forward, reach the vertical surface, and readjust itself to proceed moving vertically.
- At every step of the way, power drawn will be measured and recorded.

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6. Conclusion

The ArachnoBot™ program launched by ArachnoBotics Research Inc. is the platform off of which a whole class of walker technologies will be launched. The program will be rolled out in three phases, each implementing different levels of functionality.

The goals of the first phase will be to realize basic motion functionality of the robot. Higher level commands will be input to the robot via a high level interface and the commands will be translated into control logic for the drive systems on the robot. The commands will be either remotely programmed into the robot's controller or stored in internal memory.

The second phase of development will incorporate full mobile control and vertical wall scaling capabilities to the robot. This will include an update to the control interface from phase one and the incorporation of a force feedback mechanism for detecting change in surface orientation.

The third phase of development includes finalizing the ArachnoBot™ production model with the aim of implementing a fully autonomous module on the robot; making it capable of navigating terrain without an external operator.

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7. References

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7.1. Photo References