MODULAR ROBOTIC LOCOMOTION SYSTEMS

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ABSTRACT

This project concerns the development of modular components that can be used to quickly put together robotic locomotion devices. This system will allow a single robot to complete multiple tasks or navigate through various terrain simply by changing its configuration. The modules will include modular connectors that can be easily detached and reattached from the mainframe, allowing one module to be replaced with another. Several applications include walking, climbing, and possibly swimming. This will lead to decreased costs because a single modular robot will be used in place of many specific robots. Work has been done on developing a leg module that includes three degrees of freedom; hip rotation, raising the leg, and bending the knee driven by three motors. CAD/CAM tools are presently being utilized to generate the basic modules in a manner that allows for easy production and assembly of multiple units. The modular legs can be plugged onto a main body to rapidly configure a robot with four, six, or more. Software modules that can be tailored to the given modular configuration will be developed.

1. INTRODUCTION

1.1 Robotics

The Robotics Institute of America defines a robot as a programmable, multifunctional manipulator designed to move material, parts, tools, or specialized devices, through programmed motions for the performance of a variety of tasks. One robot may consist of as little as one manipulator and one processor. Another may consist of several manipulators, a number of complex systems, an arrangement of computers, and even a mobile platform. The possibilities are endless.

Most general-purpose robots are designed to include a selection of devices called end effectors, effectors, or tools. The end effectors chosen depend on the intended field of application. "Each mode of motion of the end effector of the robot constitutes a degree of freedom. Actions of the end effector itself (such as grasping) are not considered degrees of freedom. If the end effector is mounted onto a wrist, the modes of motion of the wrist are included in the total degrees of freedom of the robot." Translation in each of the three axis directions and rotation normal to each of the three planes is termed the "six basic degrees of freedom". Each joint of the robot may or may not add a degree of freedom.

The traditional robot is designed with a monolithic approach, that is, with one application in mind. A new robot therefore would have to be designed and constructed each time another application is needed, or every time an improvement is made. With a modular approach, robots could be designed to allow for interchangeability. One robot could be constantly utilized for various applications simply by changing the end effector. The modular approach would also allow for easy implementation of improvements to existing robots.

1.2 Robot Systems

Several typ es of robotic systems are in use today. Examples include servo systems, point-to-point systems, continuous path systems, and computer systems.

Servo systems are simply feedback systems that move by command of a computer or control device. They were originally developed in the 1920s' for regulators and remote steering. During World War II, servo systems were perfected for gun control. Both these earlier robots and the more sophisticated systems of today use linked servo axes that can be designed to provide continuous motion in limited space. [Zeldman, 1984]

Point-to-point systems work by processing digital information on a discrete basis. When a single signals is fed into a servo robot, the system moves to that point. Once another signal is fed into the system, the robot servo mechanism moves to follow that point. The continuous feeding of signals causes the displacements from point to point. Depending on how complex the point generating system and its computer software are, robots can be made to cover thousand of points in space. With such a large amount of points available, a continuous path can be approximated. Although until recently point-to-point systems were considered, with improvements in digital memory they have greatly improved and are now almost as versatile as continuous path systems. With today's technology, the distinction between point-to-point systems and continuous systems is becoming obsolete.

Continuous path systems generate an ongoing flow of analogue signals into the servo mechanisms. The robot path moves along the signal path, describing a smooth contour in space. In earlier robots, system signals were produced by moving the arm through its task while in a teaching mode. These signals were produced by transducers coupled to the robot's arm and then recorded on tape. Commands or error signals generated by the tape playback were fed into the servo systems. This created the continuous path signals needed to repeat the original operator motions.

Computers are the most sophisticated solution to robot sequencing problems; most modern servo robots use them. Robots are approaching more human-like capabilities as they become more capable of dealing with sensory feedback information. The size of a robot often depends on the size of the computer utilized to control it. The computer is usually housed outside of the robot because of its extremely large size, but as computers become smaller they will soon be is housed inside the robot body. This will aid the sensory feedback process and minimize or even eliminate rearrangement costs.

1.3 Sensory Robots

Sensory robots are at the highest level of today's technology. on them is increasing, especially in artificial vision but also on the sense of feel, and already practical applications. Sensors can provide some limited feedback to the robot so it can do its job. The sensor sends information, in the form of electronic signals, back to the controller. Sensors also give the robot controller information about its surroundings and its own position. Robots are now provided with artificial sight, and can touch and hear through the use of sensors. With one or all of these senses coupled into a robot, human activity can be simulated. Robots can also be designed and programmed to get specific information beyond what our five senses can tell us. For instance, a robot sensor might "see" in the dark, detect tiny amounts of invisible radiation, or measure movement that is too small or fast for the human eye to see.

Advanced robots must not only perform complex movements but also be capable of evaluating their environment. The example robot arm in figure 1 is equipped with four kinds of sensors:

1. A position indicator that senses where the arm is located.

2. A strain gauge that measures the weight of the load so the arm does not overexert itself.

3. Heat sensors that alert the arm to the temperature of the object it is handling, so that the robot can be programmed to avoid objects that are too hot.

4. Pressure sensors that enable the robot to "feel" objects so it can handle delicate items without damaging them.

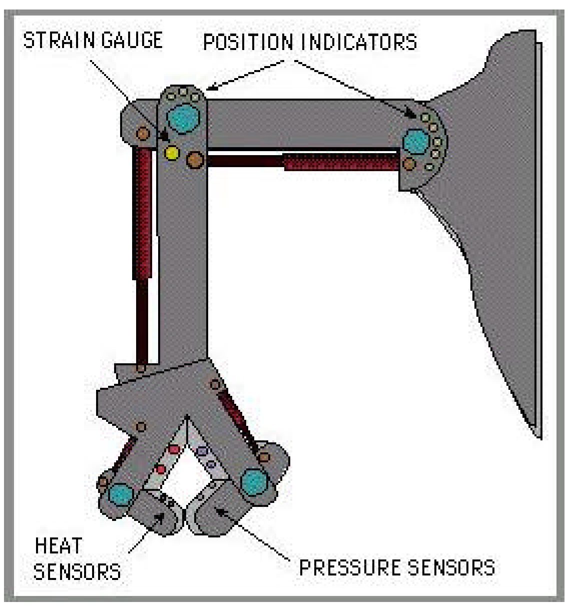

Figure 1: Robot arm sensors

2. PROBLEM STATEMENT

Designing a truly modular robot involves several considerations. The modules must be designed as a completely separate entity from the main body. The physical and electronic components of the modules must allow the module to “stand on its own”. Components such as the motors should be self-contained in the leg. The module’s connector must be designed to be easily replaced. The physical and electronic connectors must allow for easy attachment and detachment from the body. The leg must also allow room for the electrical components to fit neatly onto the leg. The motors as well as other components should be protected from the outside environment. Finally, the complete robot must be as lightweight as possible.

3. MECHNICAL DESIGN

3.1 Leg Module Design

The mechanics of the modular robot system involve the locomotion of the robot. Several types of gait could be chosen for the robot. Research was done on different types of gaits as well as their advantages and disadvantages. Since the robot may have more or fewer legs attached at a given time, research was done on how and why various multi-legged things walk as they do. Six legs were chosen as the target amount to transport the robot. Tests will be performed on this module and depending on the results received, improvements and more designs will be made.

Since six legs were chosen, a hexapod gait was researched and simulated. Many different gaits are possible with six legs. For instance, the legs can move in pairs; the pairs can refer to front, middle, and hind feet. Other “paired” gaits, are the “long trot” (left front + right hind, right middle + left hind, right front + left middle) and “half-track” in which the two front legs move together, while the remaining four legs move in a tetrapod trot.

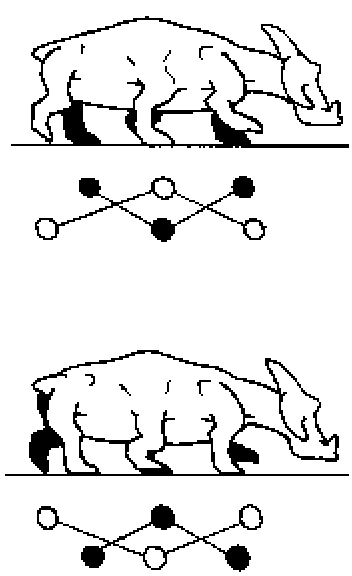

Figure 2: The Hexapod tripod gait.

Legs can also move in threesomes rather than in pairs. The most important threesome gait is the tripod gait, (see Figure 2), in which the front and hind legs on one side move together with the middle one of the other side. We will attempt to simulate a paired gait as well as a threesome gait with our robot.

As the leg module is designed, we must consider what other modular locomotion component the robot might use. Different modules will be created for use when desired, such as wheels, legs, or arms, but legs are presently the focus of development. A three degree of freedom leg has been designed as shown in Figure 3.

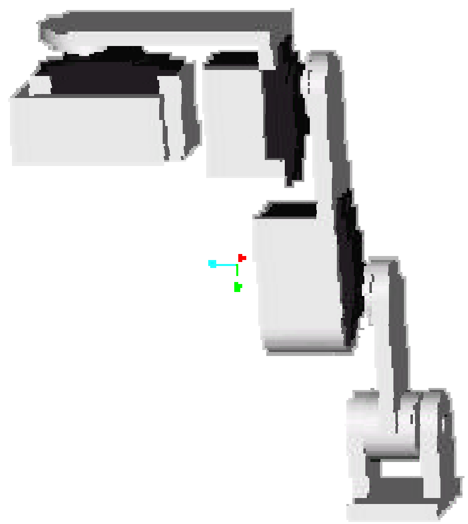

Figure 3: Pro-E model of Leg Module

The three degrees of freedom include the swivel of the hip, the raising of the leg, and the bending of the knee. This design allows the robot greater versatility and mobility when navigating through less favorable terrain. The joints of the legs will each be directly driven by RC servomotors, which are inexpensive, efficient, and lightweight. Static calculations were performed to select servo motors of proper size, weight, and torque. We placed the leg in a worse-case scenario when calculating the required stall torque.

The chosen servo motors must have the correct balance of size, weight, and torque output to provide optimal performance. Several Hitec Deluxe Servos were chosen based on the torque calculations that were done. Table 1 below shows selected data from the calculated static torque requirements. Table 2 provides the motor specifications.

Joint	Required Torque (static)	Torque (available)
Hip Swivel	28.1 oz-in	72.8 oz-in
Leg Raising	11.2 oz-in	51.8 oz-in
Elbow Bending	2 oz-in	51.8 oz-in

Table 1: Calculated static torque requirements.

Motor	Output torque	Voltage	Price	Speed
Hitec RCD HS-422	51.8 oz-in	6 volts	$12.99	0.17 s/ 60 deg
Hitec RCD HS-425BB	51.8 oz-in	6 volts	$12.99	0.17 s/60 deg
Hitec RCD HS-545	72.8 oz-in	6 volts	$25.99	0.17 s/60 deg

Table 2: Motor specifications.

3.2 Leg Module Construction

The leg module was designed using the 3D CAD package Pro-Engineer. Pro-Engineer is based on a parametric, feature-based, fully associative architecture that delivers a comprehensive suite of solutions for all areas of the development process. Pro-Engineer provides aid throughout the entire design process, from the product's conceptual design and simulation all the way through to the manufacturing. The leg links were constructed using the CAM package Quickslice and a Fusion Deposition Modeling (FDM) machine. The FDM process forms three-dimensional objects from CAD-generated solid or surface models such as the model created of the leg in Pro-Engineer. A temperature-controlled head extrudes thermoplastic material layer by layer. The advantage of utilizing the FDM machine is that the designed object emerges as a solid three-dimensional part without the need for tooling.

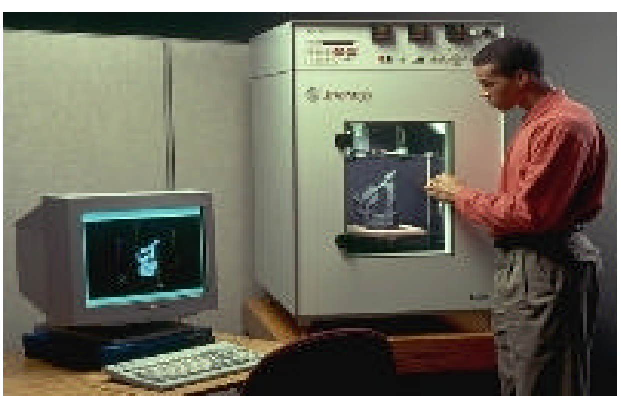

Figure 4: The FDM machine.

The file of the leg module design is exported from Pro-Engineer as a stereo-lithography (.STL) file and imported into Quickslice. The .STL file is then used in Quickslice to prepare the object for synthesis. Quickslice mathematically slices the conceptual model into horizontal layers. Toolpaths are then created and the .STL file is converted into a .SML file. This file is then sent through the computer by downloading the path data to the FDM machine and constructed. The system operates in the X, Y, and Z axes. In effect, it draws the model one layer at a time. The FDM machine is used because it allows for easy rapid prototyping. Figure 5 diagrams the process.

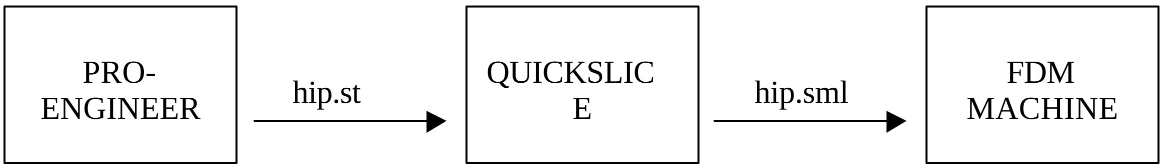

Figure 5: The Fused Deposition Modeling process.

3.3 Body Design and Construction

The main function of the body is to provide space for the control components and to provide docking stations for the modules. The body must also be as lightweight as possible in order to use the motors as efficiently as possible. The body is supported by an aluminum frame. The rest of the robot's body, e.g., the module docking station, is made out of Plexiglas. The body includes eight module docking stations: six stations along the sides for the leg modules, and two stations in the front and back for the sensor modules. Room in the center of the robot has been set apart for the main electronics and computer that will be used to control the robot. (See Figure 6) The body was constructed using the mill machine in the Manufacturing Technology Labs located in the basement of the Towne Building at the University of Pennsylvania.

Figure 6: A Pro-Engineer model of the body's aluminum frame.

Figure 7: A Milling Machine

Milling machines are among the most versatile and useful machine because they can perform a variety of operations. The milling machine was used to machine out the module docking stations on the robot as well.

3.4 Modular Connectors

The modules need to be connected to the body as efficiently as possible. The electrical, mechanical, and computer components of the leg must all connect to the body's components. As stated above, the module must stand on its own. The modules' connectors must allow any module to be connected to it. The design setup involves the use of a module docking station in which the module would be placed into. This includes an adapter that would hold the module, and a port that the adapter would be placed into.

In order to efficiently design and use the module connectors, thought must go into the different types of modules that would be used. Different modules would need to be attached in various ways depending on their application. The different modules that were taken into account include a wheel module as well as the leg module that was discussed above. An initial conceptual design of the wheel module was made to aid with the design of the module connector. Each wheel module consists of two motors. One motor would be used to steer the wheel and the other would be used to drive the wheel.

In order to keep the design modular, the same port would need to be accessible to all modules. The design of the module's ports can be seen in figures 8 and 9 below. There is an upper open part of the port that modules such as the leg module would be attached.

There is also an open lower part of the port that modules such as the wheel module would be attached to. The module connectors include a key slot that would work as a track in which the adapters could be slid into.

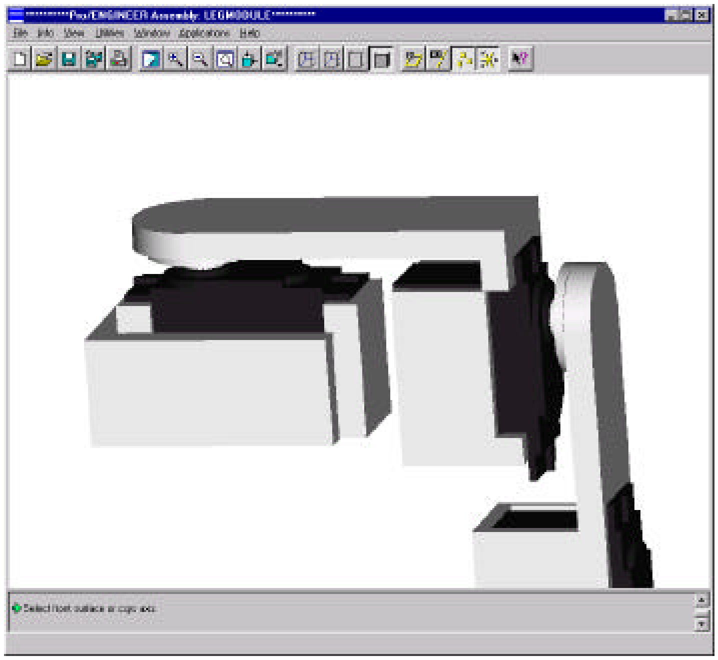

Figure 8: A side view of the leg module

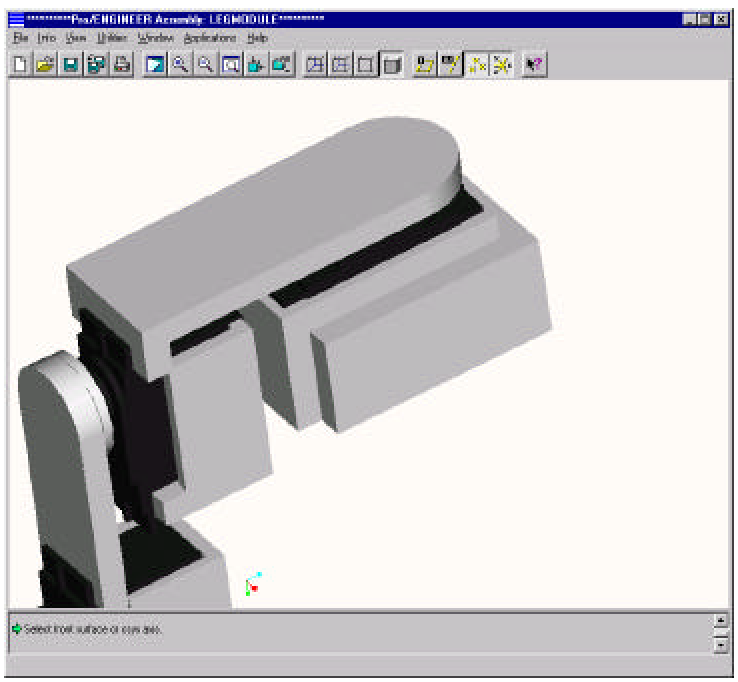

Figure 9: A top view of the leg module.

4. DISCUSSION AND CONCLUSIONS

We will use the present robot as a prototype to test out different options throughout the design process. The module will undergo several design changes until we decide on a suitable design for our purposes. The final module design will include a connector that will be chosen to ensure quick attachment and detachment from the body. If possible we will package the electrical connectors and the mechanical connectors all in one connector, which would greatly reduce connection time. The software and control code will also be implemented and tested to ensure that we receive the proper results.

The construction of the leg modules will now be done manually when possible. The FDM machine is not always consistent, and the leg links and parts generated using the FDM machine are not always accurate. The FDM machine may need to be calibrated; it may have been knocked into during construction of the part. In order to avoid this, Plexiglas material may be utilized as machining material. The CNC machine may also be used when machining parts made out of aluminum. G-code would be generated from a Pro-Engineer file for each part that would need to be machined.

Several other modules may be used with this robot. They include an arm module that could possibly be used to pick up objects. A tail is also being discussed that could help with locomotion. The last module we may attempt to design and use would be a module that would allow the robot to swim.

This research will continue as senior design work and will be completed in January.

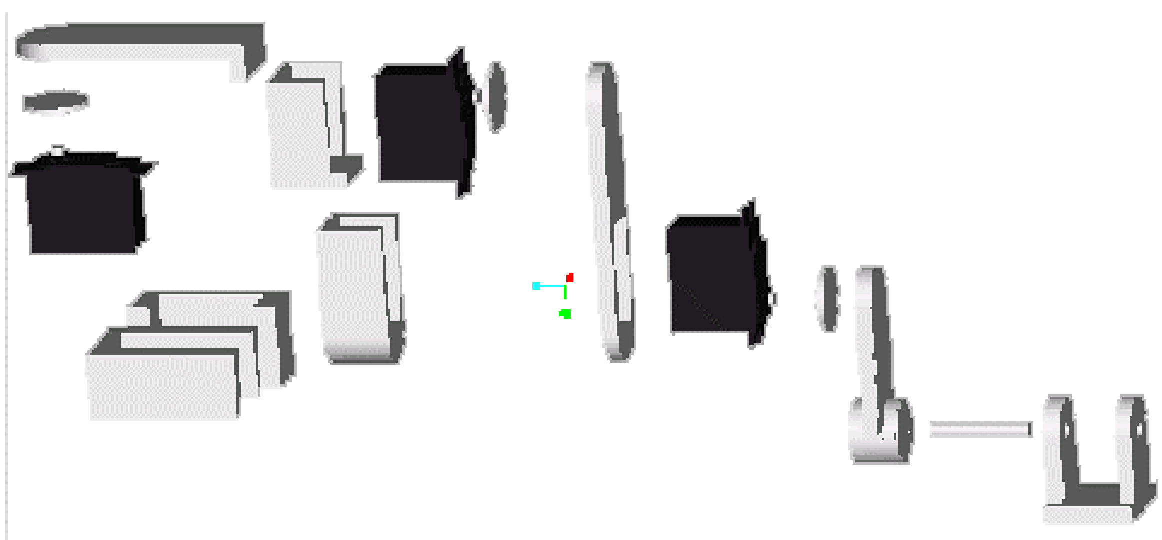

Figure 10: An Exploded View of the leg module before assembly

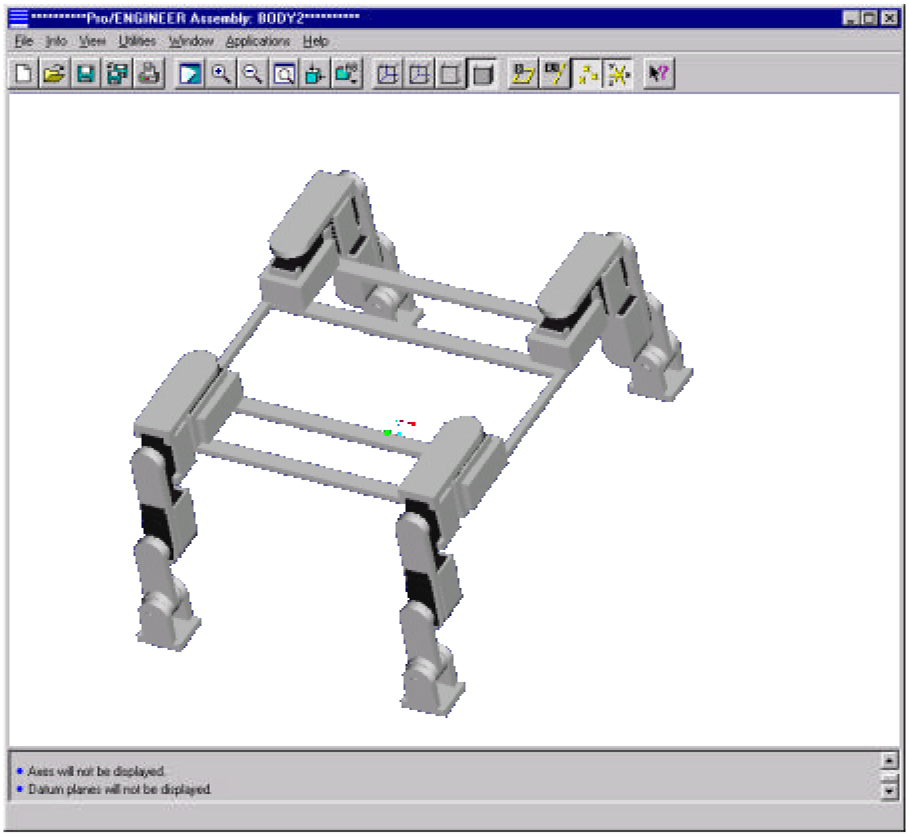

Figure 11: A Pro-Engineer drawing of the robot

6. ACKNOWLEDGEMENTS

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