Cerberus the Humanoid Robot:
Part II – Component Selection and Manufacturing

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ABSTRACT
This paper presents component selection and manufacturing details of the humanoid robot Cerberus. In its current phase, the Cerberus robot has eight degrees-of-freedom actuated by eight servos. Each leg has three servos, one servo at the waist and one to actuate the arms. The waist joint is used to shift the center of gravity to maintain balance as the robot moves in different gaits. Cerberus has wireless communication capability via remote control. In addition to the description of components, construction of the robot is also outlined in this paper.

Keywords
Humanoid Robot, Biped, Basic Stamp, Servo Control.

1. INTRODUCTION
In the construction of small bipedal walkers (under 24" and 10lbs), weight reduction is considered as the most important issue. A lightweight biped reduces the size of motor required for operation (and lowers the associated cost). Further, a lightweight biped will allow all of its other essential components to be carried on board, such as its processor, sensors, and power supply. A survey of typical actuation systems and microcontrollers are discussed briefly.

The body of the robot is typically made of lightweight plastics such as Lexan or PVC panels. An autonomous biped robot, "BARt-UH", were made of custom-machined aluminum parts [1]; other commercial models have used aluminum sheeting that a typically very thin. Other specialized design competitions have made use of Lego Mindstorm™ parts [3].

Standard servos with built-in position control capability are suited for the actuation of smaller robots. The limited 180 degrees rotation of standard servos was not a major drawback when used in bipedal robots, except for some arm models that require 360 degrees of articulation. The servos of continuous rotation type are more suitable for vehicular platforms. For much larger robots, pneumatic actuators are more common.

Commonly used microcontrollers for the control of small robots included the Parallax, Inc. Basic Stamp II™ and the Pontech SV203 servo controller. Larger laboratory robot can be controlled via a PC, which confines the robot to the vicinity of the computer system.

The final biped design required the use eight R/C servomotors with as many sets of servo holders and C-brackets. The Homework Board containing the Basic Stamp II microcontroller was used to hold and run programs that controlled the robot.

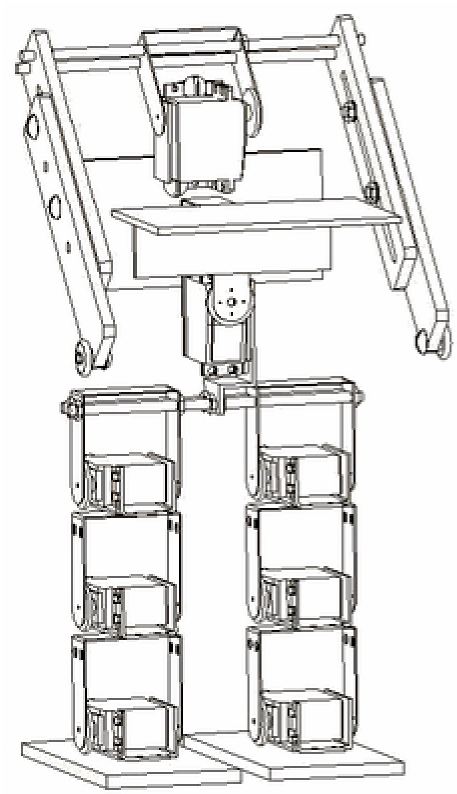

Figure 1: A Pro/E drawing of the final Cerberus design (chest plate in open position; control board not shown)

The robot carried a battery pack consisting of 4 AA high performance lithium cells (Energizer Lithium e^2). Other parts of the robot body, such as its feet, torso, and arms were made with 1/8" thick PVC panels. A detailed drawing of the final conceptual design is shown in Figure 1.

2. REQUIRED PARTS FOR FINAL DESIGN

Based on the finalized design concept, the following parts were required for the construction of the robot:

i. Actuators at eight (8) joints

ii. Microcontroller unit

iii. Remote control unit

iv. Battery pack

v. Light weight construction materials

2.1 Actuators

a) Hydraulic actuators are mainly used in large robotic systems where large payloads are required. Hydraulic systems can be used in linear as well as rotary actuation. The single action type can be controlled to move and exert a force in one direction, while the double action configuration is bi-directional. Hydraulic actuations tend to be very reliable because of their mechanical simplicity.

b) Pneumatic actuators use compressed air for actuation, and they require lower chamber pressure than hydraulics. Pneumatic actuators have been successfully applied to small lightweight robot actuation [2]. Pneumatics produces less force than hydraulics and is less compliant. Their main advantages include a lightweight framework, and can achieve high speed actuation when setup appropriately.

Braided pneumatic actuators (BPAs) represent a more recent development in pneumatic actuation systems. The expansion of the bladder inside an expandable fiber mesh results in a muscle-like contraction [6, 7]. The actuator is significantly lighter than a standard air cylinder while capable of producing greater forces.

c) DC motors, AC motors, induction motors, and stepping motors are the main types of electromagnetic actuation system. In lightweight robotic systems, a special type of DC motors – the RC servomotor – is used most frequently. Servomotors are lightweight and compact in size. Servomotors have built-in circuitry for position control, and their gearbox allows for controlled motion and high torque output.

2.2 Actuators

a) The Mini Board was developed at Massachusetts Institute of Technology (MIT) for a robot course and design project. The Mini Board uses the Motorola 68hc811e2 microprocessor with 2048 bytes of internal, EE PROM and 256 bytes of RAM, which stores approximately 2000 instructions. It can directly supply power to four DC motors and receive inputs from many sensors. It can be programmed in 6811 assembler code or C for stand-alone operation, or it can serve as a serial-line based controller operated by a desktop computer.

b) The handy board is the extended version of the mini board. Some of the important features of this handy board include small board size (4.25 x 3.15 in), 52 pin Motorola 6811 microprocessor at 2 MHz, 16 x 2 character LCD screen, inputs for 7 analog and 9 digital sensors, 38 KHz IR receiver and transmitter.

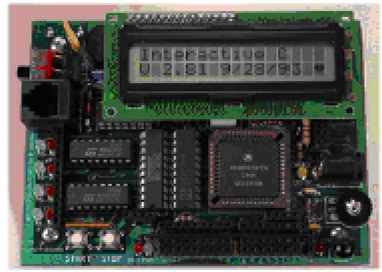

Figure 2: The Handy Board is an improved version of the Mini Board

c) The Bot board uses popular 68HC11 microcontroller with a minimum configuration designed for general purpose and also for the robotic applications. Some of the features of this Bot board are; it has a small size of 5 x 7.5 cm, is capable of controlling up to 4 R/C servos.

d) Basic Stamp is a small microcontroller where a PIC microcontroller is embedded inside its design, and is developed by Parallax. This microcontroller with its operating system embedded within requires only a program to run it. The language used to run this microcontroller is the Basic language. Some of the important features of the Basic stamp include an ability to count cycles on a pin; 16 input / output lines, which are usually used to connect to LED's, potentiometers, push buttons, shift generators and speakers; generating PWM signals and sine waves; PBASIC interpreter; non-volatile EEPROM; resonator; and a 5-volt regulator. When 5-to-15 volts are applied, the interpreter reads and executes the PBASIC instructions from the EEPROM. BASIC stamps are used in educational institutions, industrial applications, and hobbyist robotics projects. Usually BASIC stamps are able to execute up to 10,000 interpreted PBASIC instructions per second.

Figure 3: The Basic Stamp II also come printed on the Homework Board

e) The Pololu servo controller can control up to 8 R/C servos. The servo controller comes in two different configurations, where one can control a maximum of eight R/C servos and the other controls up to sixteen R/C servos. The interface with the computer to the servo controller is usually through an RS232 serial port or a TTL serial line at baud rates (maximum number of bits of information, including control bits, that are transmitted per second) of 1200 to 38400 baud. Some of the features of this servo controller include its small size of 1.45 x 1.7 in, eight servo ports, and a power supply with a range from 5.6 to 25 V. The only disadvantage of this servo controller is that it does not have a port to connect any sensors.

Figure 4: One version of the Pololu Servo Controller can control up to 16 R/C servos

f) The SV203 Servo controller is used to control R/C servos when connected to a computer through RS232 serial port. This controller was developed by Pontech and can control up to eight servomotors. It has an embedded PIC16C73 microchip, and it accepts serial data from an RS232 port and outputs PWM signal to control R/C servos. Unused servo pins can be reconfigured to digital output in order to drive on/off devices. The board requires a power supply of 7-15 V and the A/D input power supply has a range of 0-to-5 V. This servo controller is very small in size compared to other controllers (1.4 x 1.7 in). The SV203B/C has the added feature of being able to run a standalone BASIC program on board through an 8K EEPROM (Electrically Erasable Programmable Read Only Memory). An optional IR (Infra Red) Receiver/Transmitter (IR 100) is also available to allow infrared serial communications. A 5-channel, 8-bit A/D input is available to read analog voltages between 0 and 5 Volts.

Figure 5: The SV203 Board is very compact, and comes with 8 R/C servo ports and 5 A/D input ports

3. PART SELECTION AND COST ANALYSIS

Standard servomotors were chosen for this project because of their low cost, easy of control, and low weight and compact size. The servomotors used in this project were the HS-422 standard servos with 57oz-in output torque at 6DCV (Figure 6). These motors weigh 1.66oz each, run on dual “oilite” bearings, and travel 60degrees in 0.16 seconds. The motors have a torque to weight ratio of 34.3oz-in per oz, and a torque to price ratio of 4.4oz-in per dollar; these figures are among the best in the class of standard servos (under 100oz-in range).

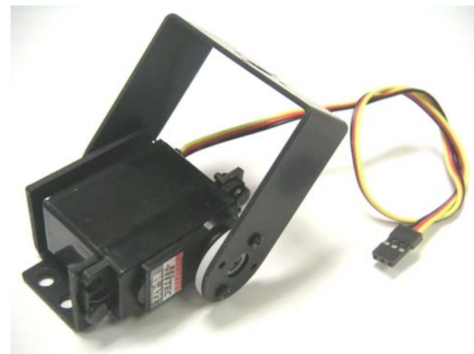

Figure 6: A single limb segment consisting of one standard servo, one servo holder, and one C-shaped bracket

The Basic Stamp II™ microcontroller was selected; it can hold up to 500 lines of code and control up to 16 servos simultaneously with its available sixteen (16) output ports. The Homework Board™, available from Parallax, Inc, with a surface-mounted BS II™, was used because it contained all the necessary circuitry ready for immediate use (serial port, power supply, etc). The Homework Board™ thus has the added advantages of compact size, lightweight, and cost-effectiveness.

The remote control system came from a small remote-controlled toy car. The part is inexpensive, and most importantly, the receiver is compact enough to fit on the breadboard on the Homework Board™ and it is very lightweight. The receiver chip can send two independent signals: one was to drive the motor of the vehicle, and the other to drive an electromagnet (for steering).

A set of eight (8) servo holders and C-brackets was also used to facilitate ease of construction. Other parts of the robot, such as the feet, the chest, and the back, were made using 1/8” thick PVC panels. The estimated cost of the robot is outlined below.

Table 1: Total cost of components used in the construction of the robot

Item	Unit Price ($)	Required Number	Cost ($)
Basic Stamp Homework Board	47.00	1	47.00
R/C Servo Motor (small)	13.00	6	78.00
R/C Servo Motor (large)	56.00	2	112.00
Servo Holder and C-bracket	20.00 (set of 2)	4	80.00
Remote Control	10.00	1	10.00
Batteries and Holder	12.00	1	12.00
		TOTAL	339.00

4. MANUFACTURING PROCESS

The construction of the robot can be divided into three phases:

1. Construction and assembly of robot body segments
2. Setup of Homework Board™
3. Implementation of remote control device

4.1 Construction and Assembly:

The use of all servos in the construction of the robot was limited to identical units of servo-holder-C bracket combination setup in a modular configuration. One such unit segment is shown in Figure 6.

Each leg of the robot consists of three such modules. Both legs were constructed to move in the Y-Z plane only (see Figure 7 below). The torso was fixed to the hip (consisted of a pair of upward-extending C-brackets). The torso motor however, was pivoted about the X-Y plane. The shifting of the center of gravity (COG) of the torso segment is the key in achieving static walking.

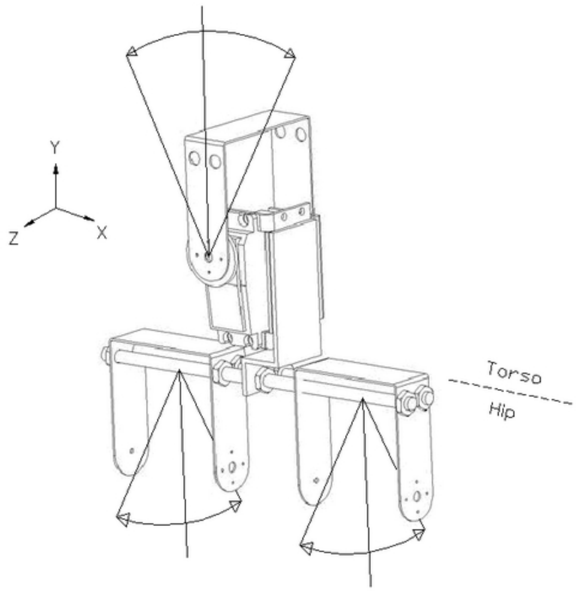

Figure 7: The torso rotated about the Z-axis (X-Y plane) whiles the legs moves about the Y-Z plane

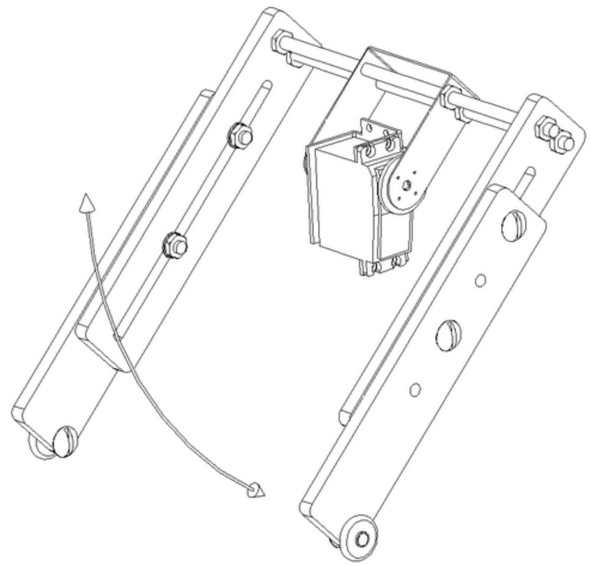

Figure 8: A pair of telescoping arms actuated by a single servomotor

The selection of the final design concept with 8 degrees of freedom (DOF) meant that only one servo was used to actuate both arms (Figure 8). This did not distract from the functionality of the arms since they were used only in assisting the torso to move between the upright and leaned-over positions. The two arms were made of the PVC panel and were fixed to the torso at the C-bracket via two threaded rods. The arms were passively telescoping and they can reach between 6” to 10”.

4.2 Homework Board™ Setup

The Homework Board™ was housed to the inside of the chest panel. The chest plate is rotably hinged at the lower torso, and it can be swung open to expose the main circuitry for initial setup and subsequence maintenance (see Figure 9).

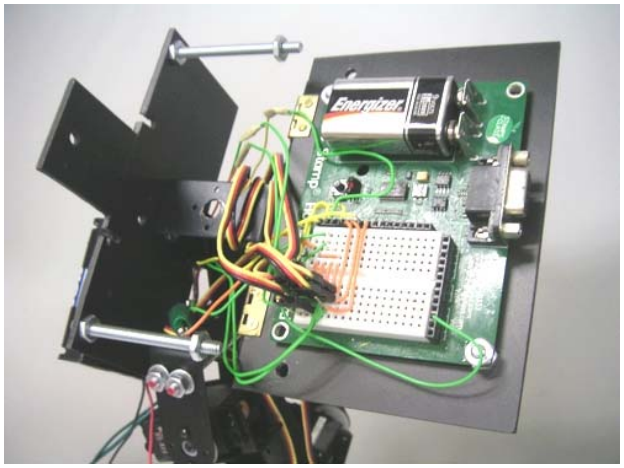

Figure 9: The Homework Board™ as installed on the robot chest plate in the open position

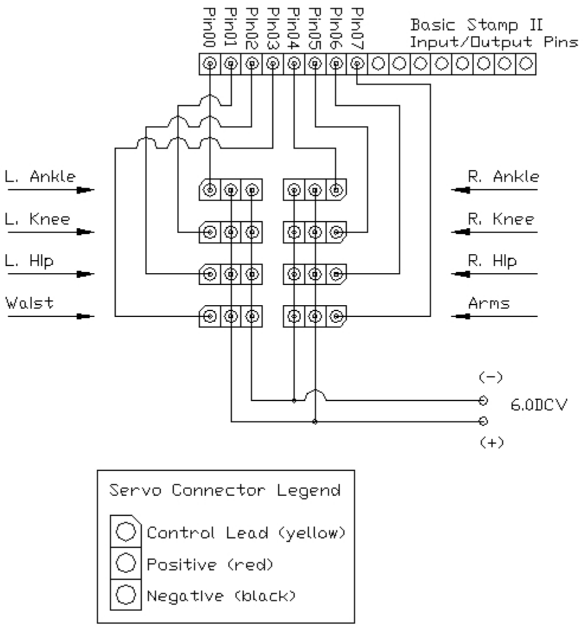

Figure 10: Circuit diagram showing the connection of eight (8) servomotors to the controller

All servos are placed in a parallel circuit with power supplied by a 4-pack AA battery. The parallel arrangement, as seen in Figure 4, allowed the servo connectors to be closely packed on the breadboard, thus leaving space for the remote control unit and other sensors (see Figure 10). The battery pack is carried on the back (torso) of the robot and it helps to counter the weight of the Homework Board™ on the chest.

4.3 Homework Board™ Setup

The output signal that controls the DC motor (in the toy car) at the receiver end of the remote control system is used as an input to control the robot. The weak input signal is amplified using a transistor; the DC output port on the Homework Board™ was tapped as the power supply, and the amplified positive voltage was registered as a "high" on one port designated as an input port.

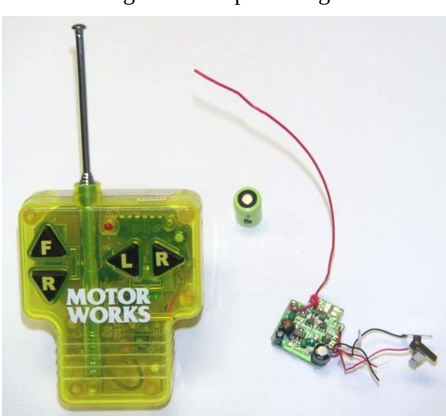

Figure 11: The transmitter and receiver of the remote control unit from a toy car

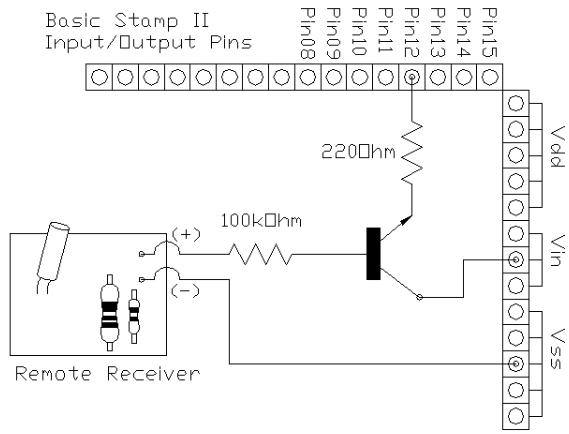

Figure 12: Circuit diagram showing the connection of the remote receiver to the Homework Board™

The input port – pin 12 – was set to receive signals from the remote control transmitter unit (Figure 12). The "Vin" ports on the Homework Board™ provide 9.0DCV to the collect pin of the transistor. When the receiver unit receives a "go forward" signal from the transmitter, the positive voltage signal its processor sent to the DC motor was redirected to the base pin of the transistor. This signal effectively acted as a switch and allows current to flow out of the emitter pin of the transistor, thereby registering a "high" on the Homework Board™ input port. The negative lead from the receiver is grounded to the Homework board at the "Vss" port.

Only one control signal was necessary for the robot to perform many tasks. The robot can be made to walk, crouch, stand, and stop using an appropriate algorithm. The use of counters in the program is one way this can be accomplished; the program can also understand if a button is pressed several times or has been held pressed for a few seconds.

5. CONCLUSIONS

The completed version of the robot measured 15" in height and 7.5" wide at the shoulder. Each foot measured 2.75"x5.5", and together covered a area of 5.75" width by 5.5" deep. The robot can stand upright un-powered (see Figure 6), indicating its COG is properly centered within the base area.

Preliminary data indicated that the ankle joints tended to yield when the torso leaned forward or backward by more than 15 degrees. When set to stand on one leg, the ankle was also the joint that failed to hold the weight of the robot. The servos at both ankles were therefore replaced with the more powerful HS-700BB servomotor. The new motors weighed 3.6oz each, and can produce 174oz-in of torque using a 6DCV power supply. Servos at the knees and hip were not changed because the HS-700BB was heavier, and the correspondingly larger servo holders and C-bracket would increase the weight of the robot even further.

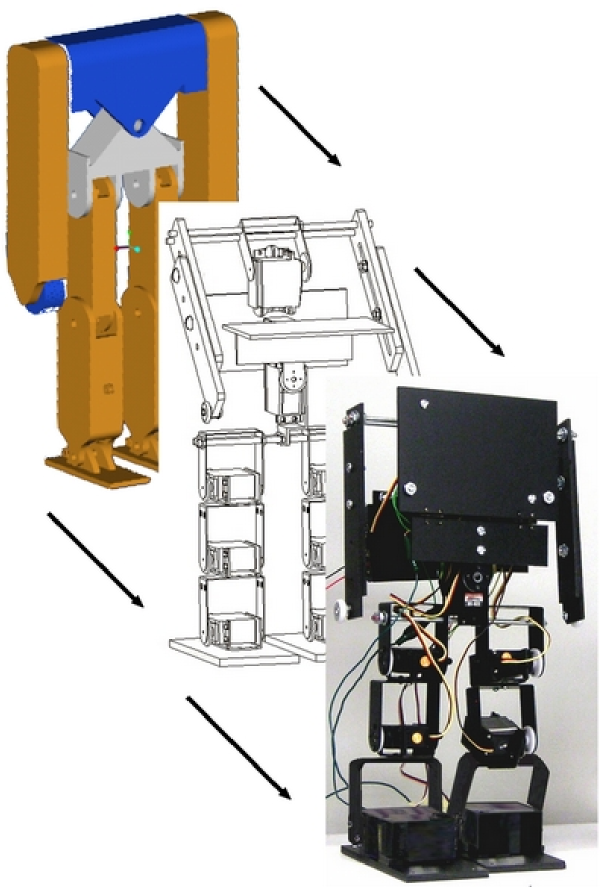

Figure 13: The finished robot standing without applied power to its servomotors

Once the control algorithm and program has been completed and implemented, a kinematics analysis was performed using video recording techniques. The results of the analysis further used to aid in the optimization of robot design and construction.

6. REFERENCES

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