Mechanical Vision Stabilization for a Bipedal Humanoid Robot

First Iteration
Summer 2009

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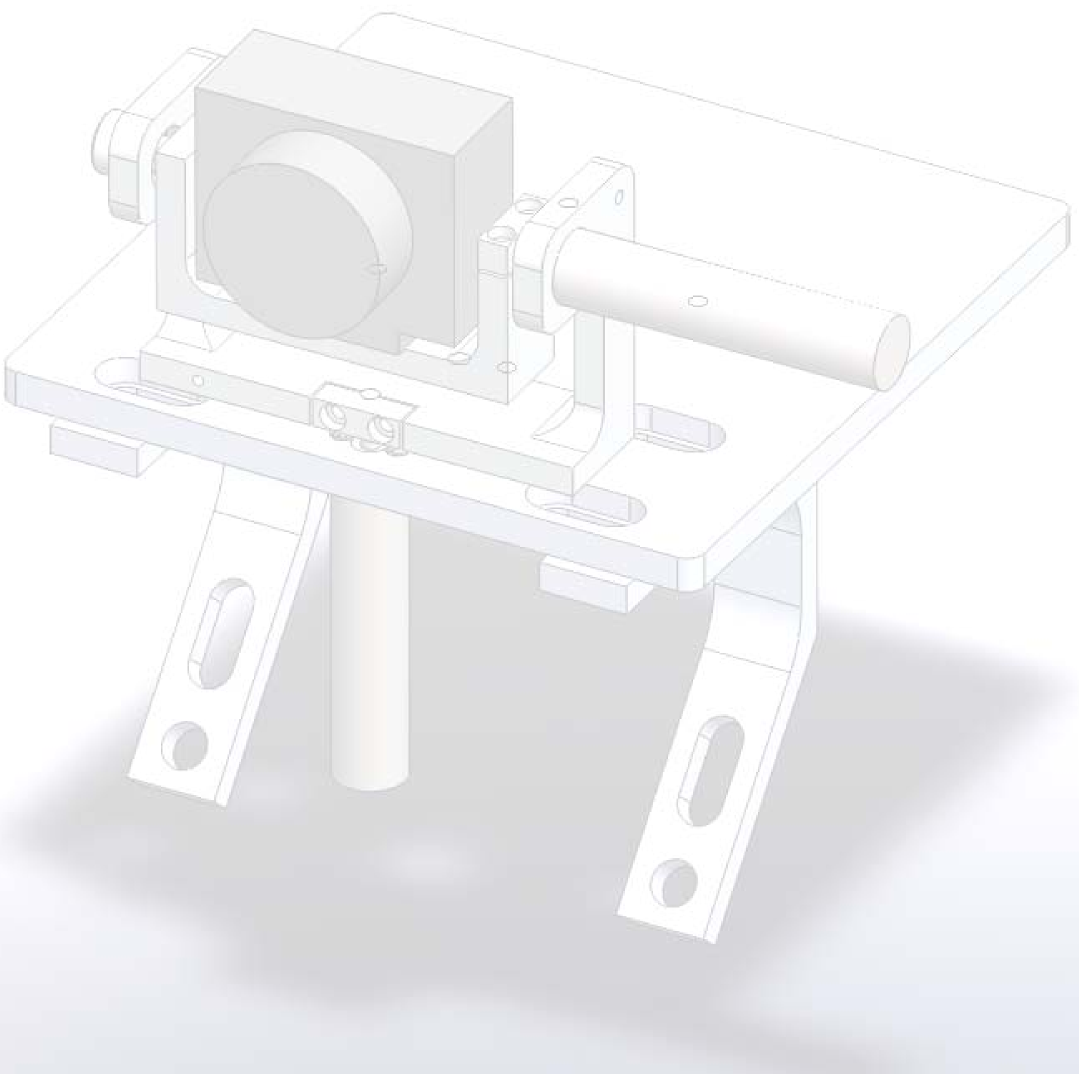

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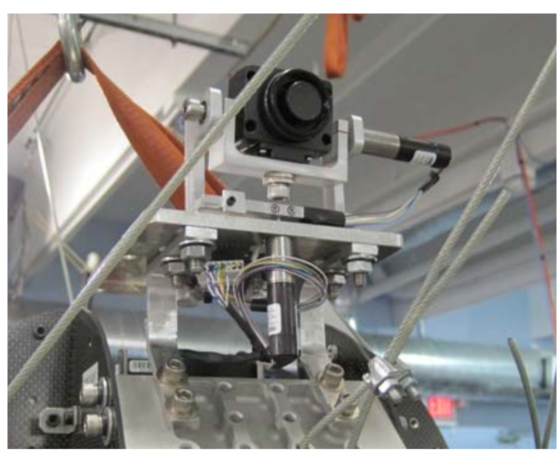
Design Process:

To begin the design process for the first iteration of the biped head we performed background research on existing robotic head systems. Some of the systems explored were the Harvard head, Mertz, and KTH. From reading these reports we compiled a list of specifications that we could design our robot head against. We created a house of quality to compare requirements and specifications (Appendix I).

The next step was to determine the design goals. Camera stabilization can either be performed passively or with actuation. Each method has benefits and downfalls. Passive systems are harder to control but require no power and can be very responsive when calibrated correctly. Dynamic control requires programming and power but it can be very accurate with high encoder resolutions and motor acceleration. In the end, we determined that actuated stabilization would be the best because it could get the camera close to where we need it during motion and any small disturbances could be eliminated via image stabilization software. We planned to design a gimbal with two motors individually dedicated to pan and tilt. Roll was ignored because data from the gyroscope during biped operation showed that it was not much of a factor. Eliminating one degree of freedom also helped simplify the design problem.

After determining what basic type of head we would be creating, we began creating SolidWorks files corresponding to the various parts of the design. The design consisted of a base plate that would attach to one of the existing breast plates on the robot with two mounting brackets, a pan bracket, and a tilt bracket. These brackets were designed to fit together and support a single Point Grey Firefly MV digital camera. Two motors were chosen to fit on one side of the pan bracket (to control tilt) and under the base plate (to control pan).

A Real Time Devices ESC629ER servo motor controller board was chosen to handle the control aspect of the head. We had to write a driver that could interface between programming in Java with Borland JBuilder 2006 and the ESC629ER. Additionally, we wrote code to interface the head with the rest of the IHMC biped so that it could be run simultaneously with the existing software.



Timeline:

June 11, 2009	Ordered two motors from MicroMo.com
June 15, 2009	Machined base plate and mounting struts
June 17, 2009	Sent part drawings to machine shop and ordered the RTD ESC629ER motor controller
June 22, 2009	Received motors from MicroMo.com
June 24, 2009	Received RTD board as well as some miscellaneous McMaster parts
June 26, 2009	Began driver construction for ESC629ER
July 8, 2009	Mailed RTD board back to RTD as an RMA. It seems that LM629 chips do not work properly
July 9, 2009	Ordered new motors/encoders with wires because the ribbons on the other motors are torn
July 13, 2009	Received the repaired RTD board. Confirmed proper operation.
July 14, 2009	Combination of motors and control board works! Installed hard stops on the head
July 21, 2009	Achieved smooth, rapid motion from system. Sine wave output as well as random positioning.
July 24, 2009	Slider board is hooked up to the computer and the Yobotics! GUI is working.
July 28, 2009	Connected joystick, finalized the code
July 30, 2009	The head is hooked up to the robot and operates properly!

Requirements and Specifications:

A full list of user requirements and specifications along with values from other robot heads and target values for the first iteration can be found in Appendix I. Most of our initial target values were based on information from the other robot heads. Many of the specifications for the other robot heads were intended for a stationary robot head with the ability to perform task such as tracking objects. Since this does not match our design goals, it is satisfactory and even expected that our values do not meet each of the individual targets. (Refer to Appendix A)

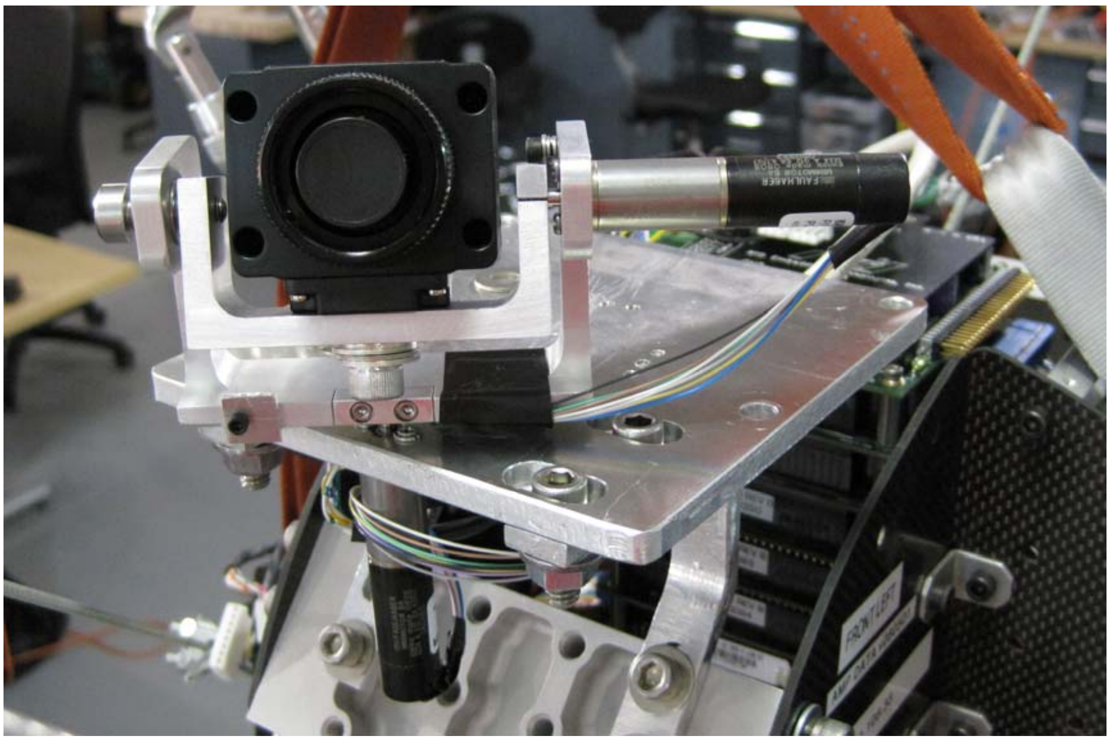


Figure 1: Complete head mounted on biped

User Requirements Met

- *Total weight* – The total weight is approximately 580g which is considerably less than the target of 2kg. This is due to the simplicity of the design. The first iteration is intended just to test the capabilities of the camera stabilization with 2 DOF.

- *Cost* – Total cost without the standalone PC/104 stack barely exceeds $2000. The target value was intended just to give a rough estimate and, similar to other estimates, assumes a head with more capabilities.

- *Height/Width/Depth* – The dimensions of the head were chosen based on the human head and other robot designs. Since all of these have more capabilities and DOF our head was able to remain well within those goals.

- *Tilt speed* – Specifications for speed were based on other robotic head designs. Though the human can move its eyes at a rate of 800 deg/s, robot heads have only been capable of 180 deg/s, so we chose that as a goal. The motors for both pan and tilt that we chose (with much more torque than necessary to move our lightweight head) are rated at 1284 deg/s no load speed. This is 1.5 times the speed of a human eye.

- *Tilt range* – We wanted the head to be able to look straight up or straight down just as a design goal. The gimbal that we designed is able to move freely in any direction up to any desired angle (not taking wires into consideration). Though there is no need to go above 90 degrees and the head will merely be looking at itself if it looks below 90 degrees down. However, with the existing hard stops the camera is limited to about 80 degrees in the downward tilt direction.

- *Pan speed* – This specification was set to be the same as the tilt speed since there is no distinction between human eye movement in pan or tilt. The motor used for tilt is also used for pan so this requirement is also met.

- *Pan range* – Ideally the head should be able to look at anything on the horizontal plane by having a range of 360 degrees. This number is not necessary for other robots because they are intended to sit in a corner and follow objects, but there are some situations where an operator may wish to see behind the robot. There is no mechanical block on the pan motor so the head is capable of looking all the way around. As with the tilt bracket, a hard stop is implemented and limits the head to about 180 degrees in either direction.

- *Tilt resolution* –Selecting an encoder that would arrive for assembly on time proved to be more difficult than assumed, but we managed to select an encoder that achieved a much better resolution than the desired resolution of .01 degree. It provided a resolution of 0.0055 degrees.

- *Pan resolution*– The pan resolution is the same as the tilt resolution. This is because the encoders for both axes are the same. This again is much better than the initial resolution designation of .01 degree.

- *Number of actuators* – Originally we thought it would be best to move the head in pan and tilt (two actuators). This would account for most of the motion due to walking. We assumed that roll could be handled by image stabilization software or controlled passively. Our design has an actuator for pan and for tilt so the specification is met.

- *Number of significant parts* – Not including motor screws and fastening bolts the robot head has 11 parts. This meets our goal of 13 parts which was an approximation with the intent of keeping the design simple and robust.

User Requirements Not Met

- *Degrees of freedom* – Originally, we designed for a third degree of freedom: roll. This would be a passive degree of freedom. Due to the fact that there is very little range of motion in the roll and this is a basic design, we did not include a roll DOF at all.

- *Roll range* – Since the roll DOF was eliminated, there is no range of motion for the roll axis.

- *Number of position sensors* –Just as we did not meet the 3 DOF target value, we did not meet the position sensor target value of 3. Since the roll degree of freedom was eliminated there was no need for a position sensor for that axis.

- *Number of cameras* – We only included one camera on the first iteration, as opposed to the two that we thought we would. The two camera concept was to allow for stereo vision. This single camera is satisfactory in the endeavor to link with John Carff's work.

- *Image resolution* – Achieving an image resolution of 1 megapixel for video is not as easy as we initially thought. Instead of purchasing a new video recording device, we stuck with the camera that we already purchased, providing 0.307 megapixel video resolution.

- *Range of vision* – The range of vision number is also dictated by the previously purchased camera. A range of vision of 90 degrees is not obtainable by the current camera. Instead, we can only achieve a range of 44 degrees.

- *Number of microphones* – Initially, we designed for two microphones to mimic human ears. Since this is a basic design, we did not include microphones at all as they would be a very easy addition in the future and unnecessary at this point in the design process.

Explanation of Design Selections:

Motor Selection (encoders and gear train included)

The two DC gear motors were selected using two main movement criteria: maximum desired speed and maximum desired acceleration of the main camera(s).

The desired average speed was to be a minimum of 180 deg/s, which is the approximate capability of previous heads that we researched. Ultimately, we desired a speed of 800 deg/s, which is the capability of the human eye. Converted to more useful units, this leads to a minimum rotational velocity of ***30 RPM*** and a desired rotational velocity of ***133 RPM.***

To achieve the desired acceleration, we need to investigate motor torque. $\tau = I\ \alpha$
Using SolidWorks®, the mass moment of inertia for the assembly was calculated about the pan axis and the tilt axis. The pan axis MOI: I = 705000 g*mm^2 = ***7.1E-04 kg*m^2***
The tilt axis MOI: I = 40000 g*mm^2 = ***4.0E-05 kg*m^2***

Using a trapezoidal velocity profile reaching maximum velocity in approximately 1/20th of a second, acceleration numbers were calculated. The necessary acceleration was approximately ***10 revolutions per squared second.*** This lead to two separate torque numbers, ***47.2 mNm*** for pan and ***2.7 mNm*** for tilt, assuming the two carriages are well balanced. The motor we selected can produce ***1.8 mNm***. This translates to 1.8*64*.70 = Torque*Reduction Ratio*Efficiency = ***80.6 mNm***. The gear reduction also translates to a maximum output speed of 214 RPM.

Overall, the motor has a minimum factor of safety of 80.6 / 47.2 = ***1.71***. This FOS is to account for any unknown friction, which we think will be the greatest factor resisting motion. Also, the FOS can account for the motors not included in the moment of inertia calculations. This setup also allows for a maximum speed greater than that of the human eye.

The encoder was selected by approximating a desired output resolution, referencing the previous head designs. Initially we desired a resolution of .01 degree. The encoder we selected was a 256 count encoder, allowing 256*4 = 1024 positions due to quadrature. After gearing, this resolution is 1024*64 = 65536 ticks per resolution. That translates to a resolution of 0.0055 degrees.

The only concern with the motors is their shape. Each motor roughly resembles the size and shape of a AA battery. With the current positioning, the motors protrude off the sides of the head which could cause balance issues and interference with other components. However, with the head as small as it is balance is not an issue and there is plenty of room for rotation.

RTD ESC629ER Servo Motor Controller

The ESC629ER is a motion controller board that will provide a quick and easy means of providing motion control to the two brushed motors on the head while receiving feedback from the optical encoders. The controller is a PC/104 board that will be able to easily connect to the computer boards used at IHMC.

One of the greatest benefits of the ESC629ER is that it has dual axis motor control powered by an internal power supply providing +12V at 500mA max power. Presumably, it would not need any eternal power supply or amplifiers to power up the motors or the encoders. However, after testing, we found that it requires a +12V power supply since the PC/104 was not providing enough power through the pins. For this first iteration it is good to have all of the components packaged together as much as possible with simple connections. Well labeled screw connectors on the face of the board provide the power signals to the motors from the 12V power supply. There are two channels for the incremental encoder inputs as well. The encoders attach to the face of the board via screw connectors. These connectors provide +5V to the encoders for power. The ESC629ER is capable of running a closed loop system controlling position, velocity, or current via PWM based on the feedback from the encoders. Interrupts make it easy to change the commands in real-time as the board receives input from the gyroscope or human user. Other features such as excessive position error stops prove useful for a homing process and overall safety.

Another PC/104 board from RTD is already used on the biped, so the memory mapping was that much simpler to take care of. Additionally, we know that the product interfaces and works well with the existing platform.

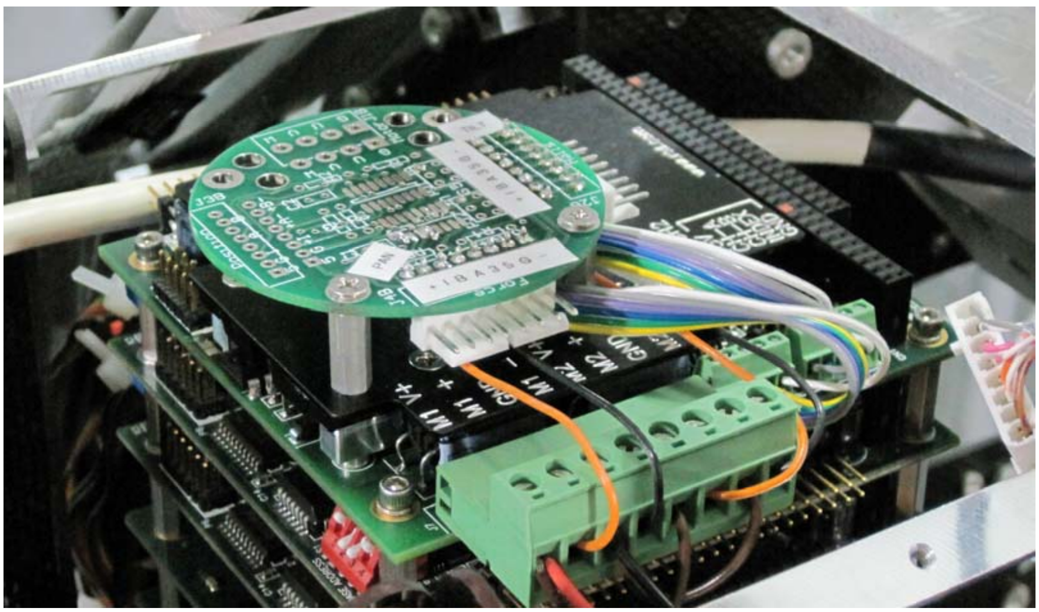


Figure 2: ESC629ER mounted on biped

Bracket Connection Selections

What proved to be one of the more difficult aspects of the design was determining how to connect the brackets while keeping moment of inertia at a minimum and maintaining good balance. We determined that for the first iteration it would be easiest to drive the shafts directly with the motors. This eliminated the need for any external gearing. Both the pan and the tilt brackets connect to their respective motor shafts via a screw clamp. These screw clamps are made by cutting out a section of the bracket around the shaft hole and threading two screws into it to apply pressure around the shaft. We considered gluing, but we wanted a solution that we could disassemble more easily.

The tilt bracket needed to have a shaft to support it on both ends (to avoid excessive radial forces on the tilt motor shaft). As mentioned, one side of the shaft was composed of the motor shaft clamped to the tilt bracket. On the other end we chose to use a shoulder bolt that would go through the pan bracket with a flanged bearing and screw into the tilt bracket. The shoulder bolt was positioned by making a countersunk hole for the shaft concentric with the shaft for the motor on the other side of the brackets. It was important to ensure the shafts be as in-line as possible.

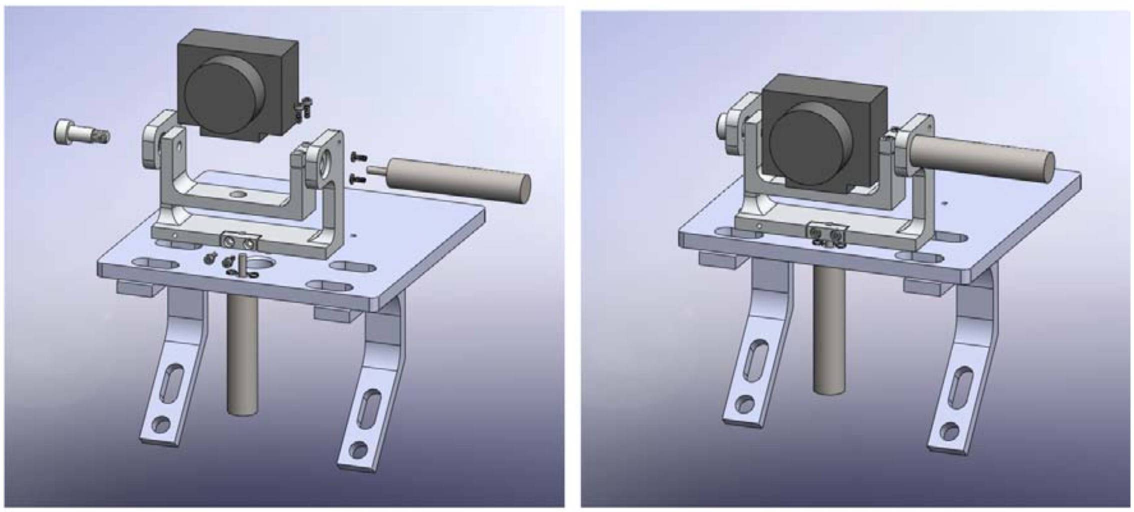


Figure 3: Exploded and unexploded views of assembly showing shaft connections

Pan and Tilt Bracket Tolerancing

Most of the measurements on the pan and tilt brackets are not completely crucial to the design as long as they are reasonably close to the desired values. The most important aspect of both brackets is making sure that the holes through the tilt axis are all concentric. This reduces friction in the joints and ensures that all the parts fit together well. Concentric tolerances are specified on both drawings.

On the pan bracket a few of the holes are toleranced specifically. The first hole is for the motor insert. This 6mm hole be constrains the position of the motor and is set up to be a slight press fit. The motor is set to +.023/+.015 and the hole is +.015/+.000. This ensures a press fit. On the opposite end of the bracket is where the 10mm outer diameter flanged bearing is inserted. This should be a tight fit, but not a press fit so a +.005/+.000 tolerance was used for the flange diameter +.000/-.005. Lastly, the 3mm hole for the pan motor it set to +.005/-.005 so the shaft with a -.006/-.012 fits in with some room to spare.

The tilt bracket only needs two well-toleranced holes. The first is identical to the 3mm hole on the pan bracket and is used for insertion of the tilt-motor. On the other side of the bracket is the countersink for the 6mm diameter shoulder bolt. The lever of action for the bolt is reduced by creating a tight fit here so the hole is specified +.025/+.000 for the bolt with diameter tolerance of +.000/-.025.

Bill of Materials:

The final design of the first iteration of the robot head for the biped has an overall cost of $2,066.28. This is well below the goal of $5,000. The bulk of the cost is from the motors and the control module. Due to complexity and desire for accurate machining, the pan and tilt brackets were sent out to be made by a local machine shop for a total of $275. Though it may have been quicker and cheaper to machine the parts at IHMC, these brackets need to maintain a relatively high tolerance. Other minor parts such as screws and bearings did not end up adding much to the cost of the head. There are a few parts not included such as the base plate, struts, and bolts to connect them together as well as electronics components obtained from the robot lab.

Table 1: Bill of materials for the first iteration robot head including information on all parts that had to be purchased

Bill of Materials			First Iteration				
#	**Description**	**Part #**	**Supplier**	**Puchased by**	**Date**	**Quanity**	**Price (unit)**
1	Drive Motors (Original)	1224A012SRK1752+PA2-100 ... +12/4 64:1+MG09	MicroMo	Bucknell	5/11/2009	2	$ 241.50
2	Motors/Encoders	1224V0059	MicroMo	IHMC	6/9/2209	2	$ 168.70
3	Interface Board	PA2-100	MicroMo	Bucknell	5/11/2009	2	$ 3.50
4	Shoulder Bolt	90278A334	McMaster	IHMC	5/17/2009	1	$ 3.37
5	Flanged Bearing	7804K141	McMaster	IHMC	5/17/2009	1	$ 11.69
6	Machine Screws (Flat)	91200A100	McMaster	Bucknell	5/11/2009	1	$ 2.75
7	Hex Head M2 Screws	91292A006	McMaster	Bucknell*	7/28/2009	1	$ 7.07
8	RTD Control Module	ESC629ER	RTD	IHMC	5/17/2009	1	$ 592.00
9	Firefly MV	FFMV-03MTC-CS	Point Grey	Bucknell	5/1/2009	1	$ 250.00
10	C-Mount to MVO Lens Adapter	NT53-675	EdmundOptics	Bucknell	5/4/2009	1	$ 21.00
11	6mm micro-lens	NT57-684	EdmundOptics	Bucknell	5/4/2009	1	$ 38.00
12	1.68mm micro-lens	NT59-776	EdmundOptics	IHMC	5/17/2009	1	$ 38.00
13	Pan Bracket	MACHINED	Mercury	IHMC	5/19/2009	1	$ 200.00
14	Tilt Bracket	MACHINED	Mercury	IHMC	5/19/2009	1	$ 75.00
						Total Price	$ 2,066.28

Programming:

Programming the head proved to be the biggest challenge in designing the first iteration of the biped head. We had to do all of the programming from the ground up using java programming language and JBuilder 2006 software.

The first step was to write a driver for the Real Time Devices ESC629ER Motion Control Board. This driver manages binary signals to and from the board by utilizing methods that simplify reading and writing data bytes to the two LM629 control chips in the board. Our first board had to be sent back eventually because it had a defect that was giving us a great deal of trouble in our programming. Most of the difficulty in writing the driver was the way that data bytes must be written and read from the LM629 control chips. The chips must first be switched into COMMAND mode, sent a command byte, switched back into DATA mode, and then the data bytes can be read or written. After sending a command byte of sending/receiving a second byte of data, a bit in the status byte is set to logic HIGH and a method must be implemented to wait on this bit to return to logic LOW before continuing to read or write to the LM629 chips. The driver ended up with about 800 lines of code.

Another class was made called "ESC629ERAxisController" that would create an object for one of the controller axes. In this class there are methods to set up initial conditions for the motors (such as homing and setting up initial parameters). There are other methods to change parameters during operation such as desired position and velocity and interrupts. This class also has a "doControl" method that updates the necessary trajectory parameters and is constantly run during robot operation.

To get the robot head working with the input devices (joystick and/or slider board) an embedded main is run on the PC/104 computer and a separate simulation class is run from a secondary working computer. The two computers are connected via TCP. Both input devices are connected to and detected by the working computer and this is where the Yobotics! Simulation Construction Set GUI is run. Data is constantly updated for all the "YoVariables" in real time and graphs can be created to show and compare variables. YoVariables are a special type of variable implemented by the Yobotics! Simulation Construction Set. Classes were created called "BucknellHeadOneSimulation" and "BucknellHeadOneEmbeddedMain" to serve these purposes. Another class, "BucknellHeadOneController", is essentially a code representation of the head system. It sets up the axes on the ESC629ER board by creating two ESCERAxisController objects (one for each motor). There is a BucknellHeadOneController object is created in the embedded main that controls and represents the entire robot head setup. See code for more information and documentation.

The majority of our time this summer was spent on programming the robot head. Some of the issues were due to uncontrollable problems such as a defective control board, but much of it was spend debugging and learning how to sync with the existing java programming used in the robotics lab at IHMC.

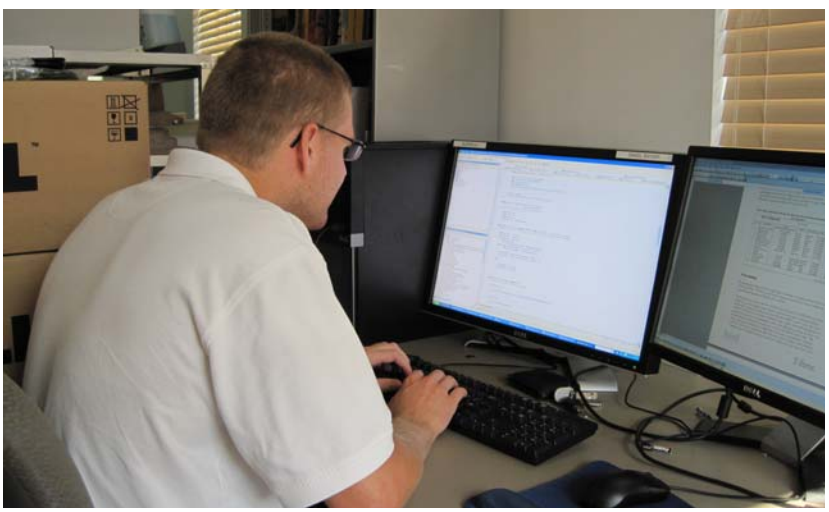


Figure 4: Nerd Alert!

Setup – Connecting the Head:

The entire system can be connected to either a solitary PC/104 stack or it can be added to the humanoid, which contains its own PC/104. If attaching to a solitary PC/104, the mechanical head must be rigidly connected to a table or other solid object in a manner that will not hinder the range of motion of the head. If attaching to the IHMC Yobotics!® Bipedal Humanoid, the struts that extend below the main base plate should be bolted to the breast plate located near the top of the humanoid. No matter to which platform the head is being mounted, the RTD ESC629ER Motor Controller will be placed on the top of the respective PC/104 stack so that the 104 male pins line up with the 104 pin female bus of the board below (Figure 4). Once this is done, the provided 16 wire cable with two 8-pin connectors on each end connects the circuit board located on the base of the head to the circuit board on the RTD Motor Controller via Molex .100KK connectors (Refer to Appendix B).

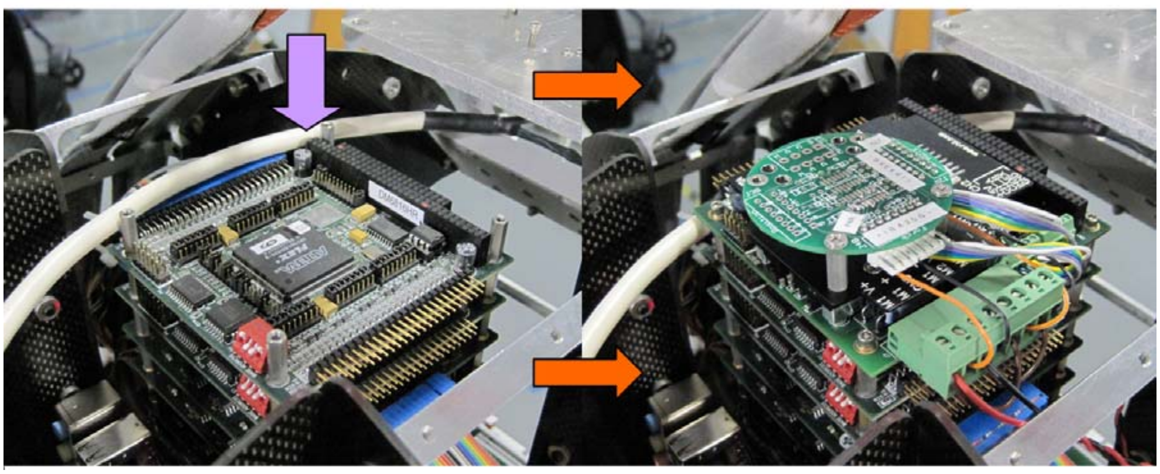


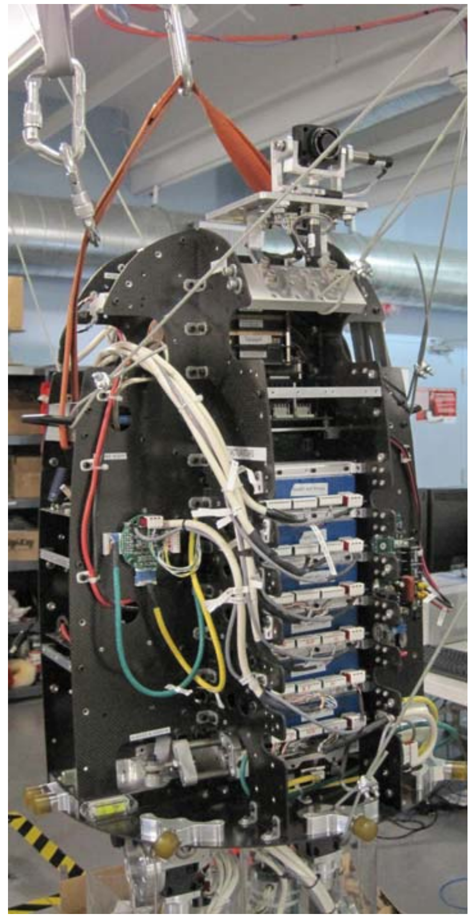
Figure 5: RTD board connecting to top of biped PC/104 stack

Operation – Running the Head:

1. Set the current project in JBuilder 2006 to RobotHeadControl
2. Run the simulation file, "StartGUI," on the working computer
3. The build on the working computer should send over a .jar file created by the archiving function "Jarify."
4. In the Jarify the name of the .jar file and the main class to be used are specified
5. The .jar file is sent to the PC/104 computer via Ethernet by the "Send2Solaris" batch file
6. The Yobotics! Simulation Construction Set GUI will start on the working computer
7. In the terminal on the PC/104 computer run the .jar file
8. After the .jar file has started up click "Connect" in the GUI
9. Variables can be altered and graphs can be created in the GUI
10. If a Saitek x52 joystick or an Evolution UC-33 slider board is connected they will be recognized by the working computer and be able to control the robot head

Summary:

Overall, the head does a good job stabilizing the camera during biped motion. The motors seem to be more than fast enough to move the camera to adjust for any level of shaking the robot might encounter. By mounting the camera on the biped we were able to prove, also, that the program can be easily integrated into the existing biped control programs.



There are still a few problems with the first iteration. Inaccuracies in the stabilization are caused by two primary factors: gearhead backlash and poor camera lens mounting. The gearhead used for each of the motors has a backlash of up to three degrees. This means that even with the high accuracy of the encoders, positioning of the camera is limited to an error of three degrees in both pan and tilt. Higher frequency rattling is introduced by the lens mount. A micro-lens and C-mount adapter are used in combination to bring the image into focus. However, the lens must be screwed in only partially to achieve the correct focal length which results in a loose connection. This problem could be fixed using some type of adhesive, but for the next iteration a more secure connection or better lens is desirable.

The hardware has a couple other features that do not pose problems in the current iteration but may cause difficulties in future iterations. As mentioned, the motors are not an ideal shape and it is especially not ideal to have them sticking off of the head at ninety degree angles. On the next iteration it would be good to find shorter, wider motors or to design gearing that allows the motors to be placed more space efficiently. Another issue with the current motor setup is that the entire pan-tilt mechanism is resting on the shaft of the pan motor. With the current lightweight design this is not an issue, but for future iterations that will likely be larger and heavier this type of connection cannot be used. Also, the circuit boards for connecting the motors are the same ones used to mount on the series elastic actuators on the rest of the biped. For futures iterations custom circuit boards would be preferred.

Lessons Learned:

- Make sure all parts can be purchased and will arrive in a timely fashion. Motors that are out of stock and have an 8-10 week lead time cannot be included in a "quick, initial prototype." Thus, it is wise not to waste time designing for parts that have an 8-10 week lead time. This does, however, put restrictions on some of the components; many of the "perfect" components may not be obtainable in a timely manner.

- In a design, consider how it will be assembled. Run through the steps necessary to take the design from bare parts to a fully assembled device, making sure that the necessary tools can be used to insert and secure the parts.
    - i.e. A small screw or bolt can be inserted here or there, but we can't maneuver the screwdriver or wrench to tighten it!

- When selecting components that will be purchased and not designed (such as motors, motor controllers and encoders), plan ahead. Purchase components that will be compatible with each other and with other devices with which it will be interfaced.

- During the design process, think about how the part will be manufactured or machined, and design accordingly. This includes the actual machine (mill, lathe) as well as bit size (1/4", 1"). This will necessitate rounds and fillets in most places. Rounds and fillets also make parts look more professional.

- Threads are not a good locating feature. If locating is necessary such as in a precision pin joint, use the shoulder of a shoulder bolt or bearing bolt for precise location.

- If two features require alignment, try as hard as possible to create them in the same machining process.

- It is important to have design reviews as often as possible. For these design reviews, it is best to use someone who has not designed any part of the device to critique and analyze (you should probably also make sure they are competent with mechanical design/devices).

- Be sure to incorporate hard stops into the system whether it is in software or hardware. A burnt out motor could take weeks to replace.

- When programming be sure to plan ahead. Creating lots of small methods is better than long confusing ones and documentation is useful when returning to old code.

Future Work:

Second Iteration:

The second iteration will be designed to address the weaknesses of the first iteration while including useful additional features such as stereovision. Most of the programming will be entirely compatible with a second iteration so the changed will be primarily in the hardware. We plan to make a larger version that will be able to incorporate more cameras and as a result the motors and drive system will have to be redesigned as well.

Also, the next generation head will include a gyroscope, rigidly mounted to the same base to which the head is attached. This will allow the head to operate as an independent system, not relying on the code or electronics of the IHMC Bipedal humanoid. Including a second gyroscope located very near the head will produce more accurate and representative positioning, improving the response of the stabilization algorithms.

Features:

- Zero backlash gear train
- Stereovision capabilities
- Address high pitch PWM whine
- Incorporate a local gyroscope
- Customized circuit boards
- Eliminate lens "jiggle"

Supplies for PC/104 Stack:

- Tri-M Engineering Mobile Power Supply
    - Model HE104+DX 108-Watt
- Diamond Systems Analog-to-Digital I/O Board
    - Model DMM-32X-AT
- Real Time Devices Motor Controller
    - Model ESC629ER
- Access I/O Products Motherboard
    - Model ETX-NANO-104
- Access I/O Products Memory Card
    - Model CompactFlash Industrial (4GB, 8GB), install Solaris OS
- Heat Sink
- Processor/Modem? Sits just beneath the motherboard

Seeing in Three Dimensions

The basic concept behind a human beings three-dimensional depth perception is the two separate inputs from the eyes, one from each eye. Biologically, the retina is only capable of transmitting a two-dimensional image to the brain. Given the disparity between the human eyes, the images record objects at slightly different viewing angles. A human's three-dimensional perception stems from the brain's ability to combine these two separate two-dimensional images from the retinas.

In order to reproduce this effect for "telepresence," it is necessary to take advantage of the brains ability to take separate two dimensional images and combine them. Naturally, producing such a mind trick has been used as a means for income. In industry, there are multiple ways of tricking the brain to perceive three dimensions from two dimensional images.

A common way is using color filter glasses and an image composed of two separate colors usually cyan and red. The same image is printed on a single plane, one in each color and offset from one another. The cyan filter over one eye eliminates the cyan image and the red filter over the other eye eliminates the red image. This effectively allows each eye to see a different image.

The more modern way to produce three-dimensional images is by using field sequential 3D programming. The images for the left and right eye alternate. This effectively produces a 60Hz image for each eye. There are a few options for viewing this video feed. The first is a video headset meant for the field sequential 3D feed. Another option is to use a monitor or display with a 120Hz refresh rate in conjunction with shutter glasses can "decode" the signal to produce 3D. For the latter, in order to ensure that each eye only sees the image it is supposed to, shutter glasses operating at 120Hz alternately close the shutters of each eye so that it matches the alternating images produced by the screen.

Initial Proposal

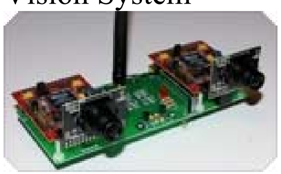
Theoretically, if each eye is isolated and then fed slightly offset images, the brain should combine them to create three dimensional perceptions. We propose doing this by implementing two separate video cameras. The feed from the left camera will be fed to the left eye, and the image from the right camera will be fed to the right eye through a special pair of goggles.

Comparable Systems

Robonaut:

Judging by the pictures, we think that they are using the nVisor SX. It costs $23,900. We are currently waited for Peter to contact NASA to inquire about the camera/lens.

Stereo Vision Cameras

Brand/Product	***Description***	***Cost***
Bumblebee 2.0 BB2-03S2 	• IEEE-1394 Firewire Interface • Sony 1.3" progressive scan CCD • 12cm baseline • 648x488 at 48fps • 342g • 2 x M12 microlens mount • 157 x 36 x 47.4 mm • http://www.ptgrey.com/products/bumblebee2/index.asp • Point Grey	$2,000
Surveyor Stereo Vision System 	• Headers for 8 servos • 512x384 at 43fps 48 disparity • GPL Open Source, basic processing features • WiFi through antennae • Exposed circuit boards • Built in dual motor driver, 1A per motor • http://www.surveyor.com/stereo/ • Surveyor Corporation	$550
PCI/104 nDepth™ Vision System 	• PCI/104, camera, lenses, cables, software • 6cm baseline • 752x480 stereo vision camera • 30fps 92 disparity • 1/3" wide-VGA CMOS digital image sensors • 4.25 x 1.5 x 1.25 in • G2 system creates 3D object maps • http://www.focusrobotics.com/docs/focus_ndepth_pci_brief.pdf • FOCUS robotics	$3,995
DeepSea Stereo Cameras 	• Used on Stanford Little Dog http://www.stanford.edu/class/cs229/proj2007/Kim-GettingThePositionAndThePoseUsingStereoVision.pdf • Range 40, 62, 83 HFOV • Aptina MT9V022 CMOS imagers • 3cm, 6cm, 8cm, 14cm, 22cm, 33cm baselines • 512x480 at 200 fps • http://www.tyzx.com/PDFs/Tyzx%20DS%20Cameras.pdf * TYZX	$4,995

Video Goggles (HMDs)

Name	***Description***	***Price***
i-glasses 920 3D 	• Resolution: 920,000 Pixels Per LCD • Aspect Ratio: 4:3 • Color Depth: 24 bit color • Field of View: 35 degrees diagonal • Video Input: Composite A/V • Video Input Format: NTSC/PAL/SECAM • 3D Video Format: Interlaced 3D Video • Audio: Double Channel Stereo • Power Supply: 1,000 mAh Rechargeable • Battery Life: Approximately 3.5 hours • Weight: 2.4 ounces	$379.95
i-glasses i3TV 	• Resolution: 800 x 600 • 1.44 Million Pixels per Display • Field of View: 26 Degrees Diagonal • Virtual Image Size: 70" at 13' • Color Depth: 256 Levels per Color (True 24 Bit) • Contrast Ratio: 75 to 1 • Focus: 13' TBR • Eye Relief: 25mm • Exit Pupil: 17mmH x 6mmV • Convergence: 7'10", 100% Overlap, TBR • Refresh Rate: Flicker Free 100hz display rate • Audio: Full Stereo • PAL/NTSC/SECAM: Composite or S-video Input • Input Frequency: 50 or 60 Hz (25 or 30 Hz Interlaced)	$899.95
Visette Pro 	• Resolution: 640 x 480 • Pixels: 920,000 Pixels per Display • Field of View: 60 Degrees Diagonal • Eye Distance: 60-70 mm adjustable • Stereo: 2 independent channels (no sync needed) • Inputs: VGA, Composite NTSC or PAL • Weight: Approx. 840 g (incl. battery) Adjusts to Fit all Individuals • Control Features: On / Off, Brightness, Contrast, Focus and IPD • AC Adaptor Included: 110-130V AC or 220-240V	$3995

CyberMind Visette45 SXGA 	• Dual Input SXGA (1280x1024) • 45 deg FOV • Can pretty much customize to whatever you want	$12,900
Kaiser ProView SR80 	• Dual Input • 80 deg FOV • Fits 5% of females, 95% of males • If you care to know more, see the price.	$27,500

Multiplexer (3D Encoder)

Name	***Description***	***Price***
Dimension Technologies Inc 3D Video Encoder	Two video inputs s-video output Either field sequential or side by side	$2500

**1-888-813-6950   Ask for Arnie*

Summary of Findings

It seems that stereo vision is primarily used for three-dimensional mapping, object recognition, and navigation. The benefit of two integrated cameras is that the computer can use disparities to determine values for depth. Since the cameras only display two-dimensional images, this adds the third dimension.

Of course, the technology is still far from perfect. While image processing software is capable of producing 3D image maps, they have a lot of error and "spikes". This makes it difficult to use solely visual equipment for navigation and tracking systems.

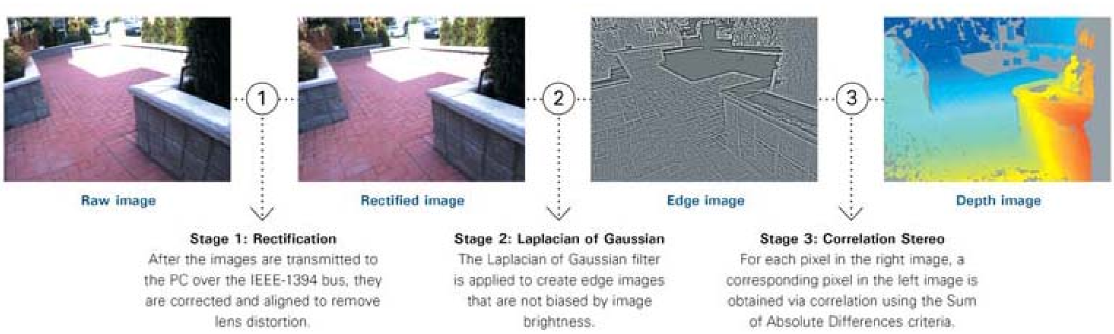


Figure 6: Image from Point Grey displaying the type of manipulation and degree of accuracy from using stereo vision systems

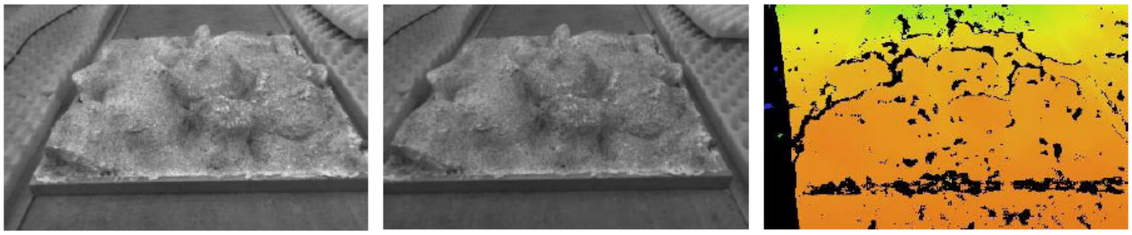


Figure 7: Left, Right Images and Depth Map from stereo vision, made by Tzyx Inc. taken from "Getting the Position and the Pose Using Stereo Vision" by Youngjun Kim http://www.stanford.edu/class/cs229/proj2007/Kim-GettingThePositionAndThePoseUsingStereoVision.pdf

The second figure is seen from a camera mounted above a Little Dog. As seen in the Depth Map, the software is not accurate enough to provide visual data that can be used for navigation. However, it does provide a useful visual aid that could be used to supplement other data.

Overall, it seems to be worth a shot to get one of these stereo vision cameras at least to try it out and test its capabilities. There are lots of benefits over laser scanners such as size and that the software can produce not only depth images but 3D images for a user interface.

Revised Proposal

For the best 3D experience, the best option would be a headset with a two channel video input. The two video inputs would come from two cameras with controlled vergence. While producing a decent 3D experience, using stereovision cameras would not produce the premium 3D experience because the two cameras are oriented parallel.

If a dual input video headset is not used, it becomes necessary to implement the 3D Video Encoder (Multiplexer). This interlaces the left and right camera feeds into a single video stream. This video stream would need to be "decoded" with a certain type of video headset such as the i-glasses i3TV or special display devices with shutter glasses.

Recommended stereovision camera: Bumblebee2/DeapSea

Recommended headset: Visette Pro

- Dual input VGA
- Upscale HMD, but relatively cheap

Stereovision cameras should be used if camera vergence is not a desired characteristic for the robot head. If vergence is a factor, two separate cameras must be used.

Vendors and Contact Information:

- Edmund Optics
  - www.edmundoptics.com
- MicroMo (Faulhaber)
  - www.micromo.com
  - Phone: (800) 807-9166
  - 14881 Evergreen Ave. Clearwater, FL 33762
- McMaster Carr
  - www.mcmastercarr.com
- Mercury Machining
  - www.mercurymachining.com
  - Contact: Brian Granger
  - Phone: (850) 433-5017
  - 1085 W Gimble St. Pensacola, FL 32502
- Point Grey Research
  - www.ptgrey.com
  - Phone: (604) 242-9937
- RTD Embedded Technologies, Inc.
  - www.rtd.com
  - Contact (Technical Support): Willy
  - Phone: (814) 234-8087
  - 103 Innovation Blvd. State College, PA 16803

Appendix A. House of Quality for the Vision Stabilizing Robotic Head

	Specifications	Total weight	Cost	Height	Width	Depth	Baseline	# of DOFS	Roll range	Roll friction	Tilt speed	Tilt range	Tilt eff.	Tilt acc.	Pan speed	Pan range	Pan eff.	Pan acc.	# of position sensors	# of actuators excluding camera functions	Average power	# of cameras	Camera frame rate	Image resolution	Range of vision	# of mics	# of significant parts	Lifetime
	Units	kg	$	cm	cm	cm	cm		deg	N-m	deg/s	deg	%	deg	deg/s	deg	%	deg			W		fps	MP	deg			hrs
	Direction of Improvement	↓	↓	↓	↓	↓	↑		↑	↓	↑	↑	↑	↓	↑	↑	↑	↓			↓		↑	↑	↑		↓	↑
	↓↓ **Requirements** ↓↓																											
Basic	Durable	*	*																								*	*
	Attach to body																										*	
	Stereovision		*																			*						
	Stable Vision									*	*				*													
	Pan														*	*	*	*		*								
	Tilt										*	*	*	*						*								
	Roll (yaw)								*	*										*								
Performance	Lightweight	*	*	*	*	*																					*	
	Inexpensive		*																*			*					*	*
	Low Energy	*	*	*	*	*															*							
	Compact	*	*	*	*	*																						
	Efficient																											
	Provide telepresence							*	*	*	*	*	*		*	*	*			*		*			*			
	Accurate position tracking		*				*		*	*	*	*	*	*	*	*	*	*	*						*			
	Minimize image distortion																					*	*	*				
	Active control of gains																		*									
Wow	Audio																									*		
	Modular																											
	Lighting																											
	Values																											
	Human	4	∞	19	15	19	6	?	±25	-	800	±40		2	800	±90		2				2				2		
	Harvard (1988)							7			70	35		0.036	150	130		0.036	3	3		2	30	0.2621		0		
	KTH	15					15-40	13			180			0.0072	180			0.0072		9		2	50					
	TRISH (1992)		16630	52	62	20	32	7			9			0.0007				0.00073	5	5		2		0.3355				
	Mertz (2004)	1.93		27.1	15.7	18	8.79	9											2/act.			2	30	0.3072		1		82+
	Our Target	<2	<5000	15	20	15	10	3	±30		180	±90	>90	0.01	180	360	>90	0.01	3	2		2	30	1	90	2	13	200+
									WHY?																			
	Actual Design'	Yes	yes	yes	yes	yes	yes	no	no	-	yes	yes	-	yes	yes	yes	-	yes	no	yes		no	yes	no	no	no	yes	yes
		0.58	2066	14.1	15.1	8.25	-	2	0	inf.	1284.4			0.0055	1284.38	360		0.0055	2	2	2	1	30-60	0.3072	44	0	11	lots

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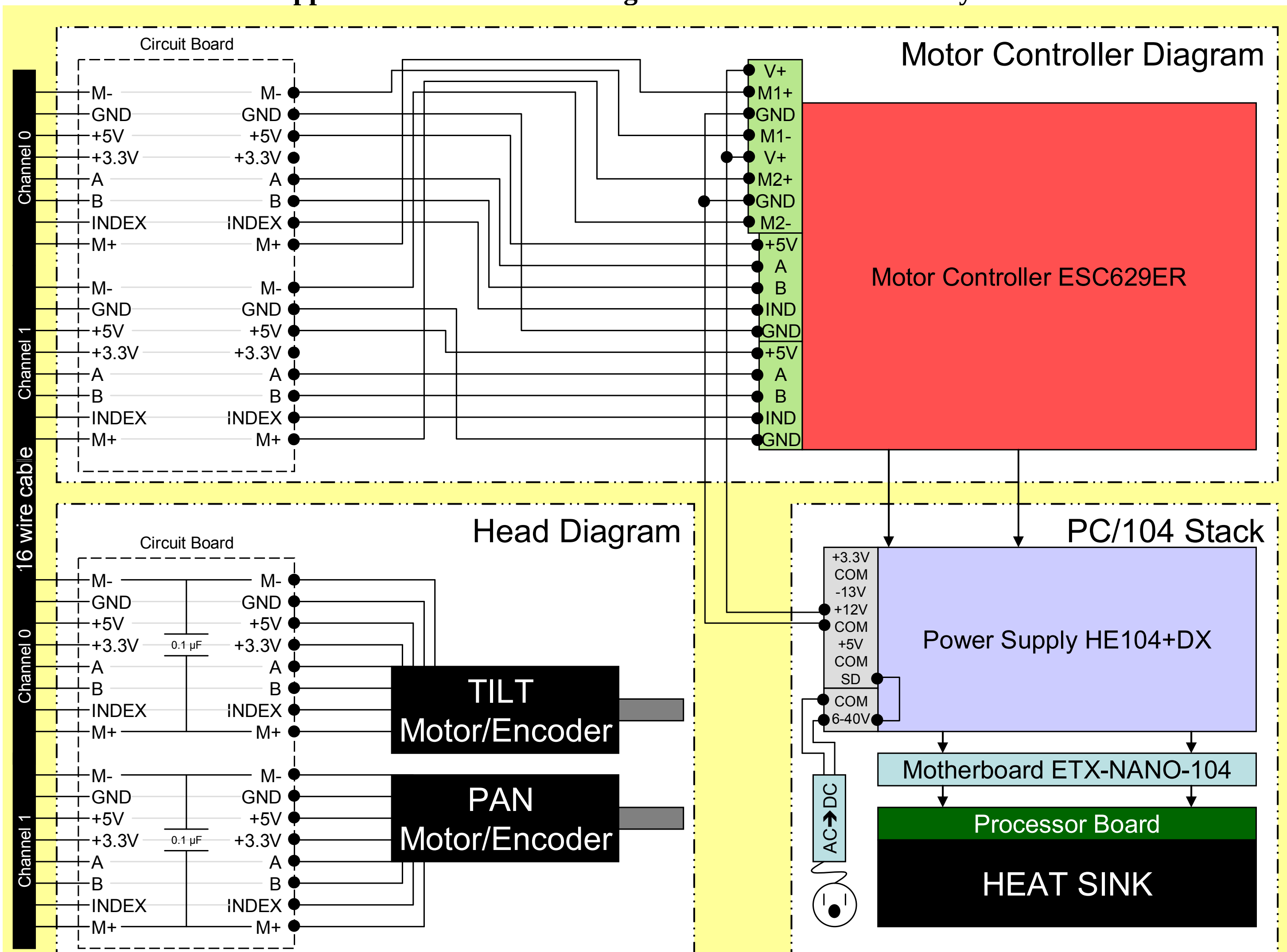
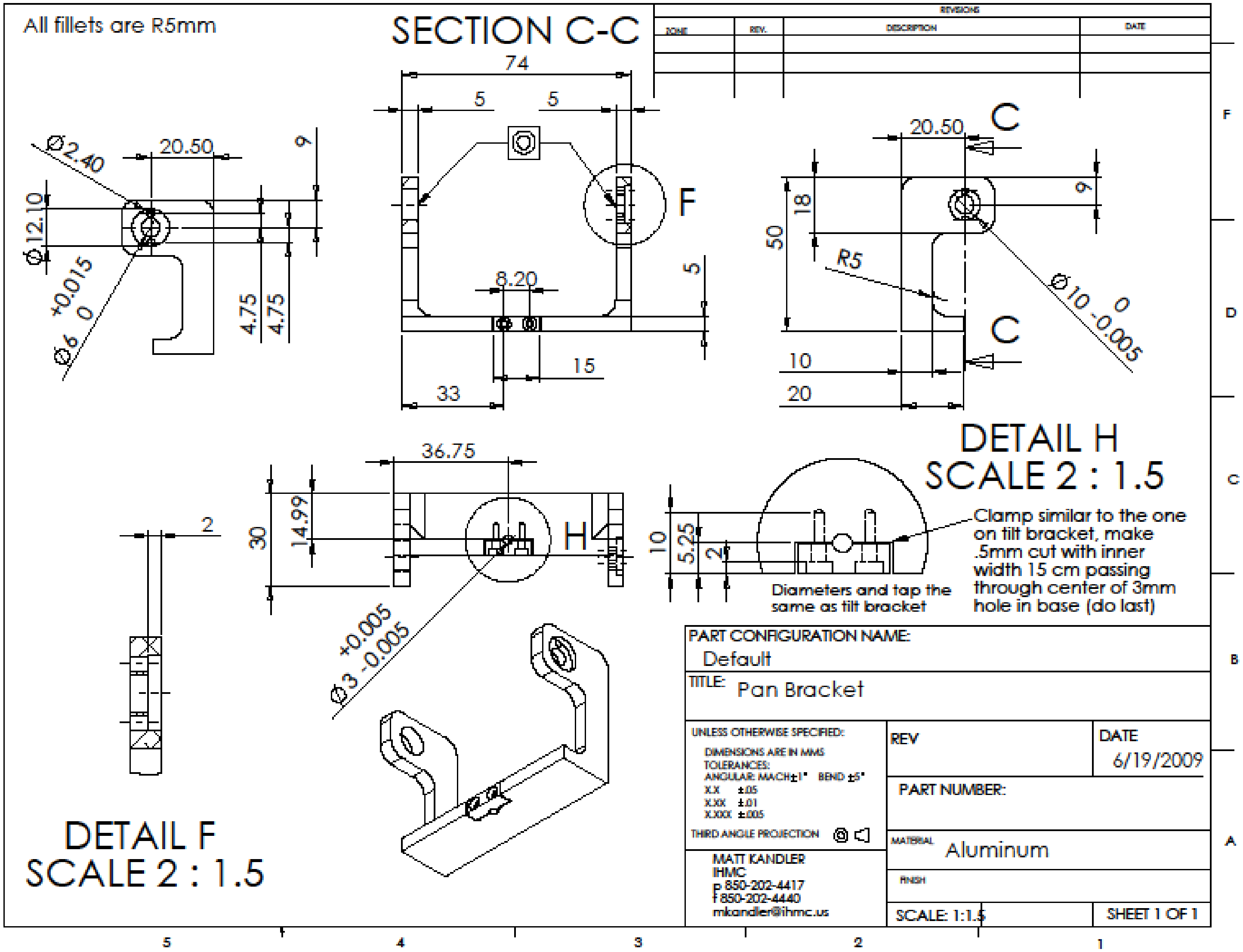
Appendix B. Electronics Diagram for the Stabilization System



*All connections to circuit boards should be made with 8-pin connectors, 1 per channel



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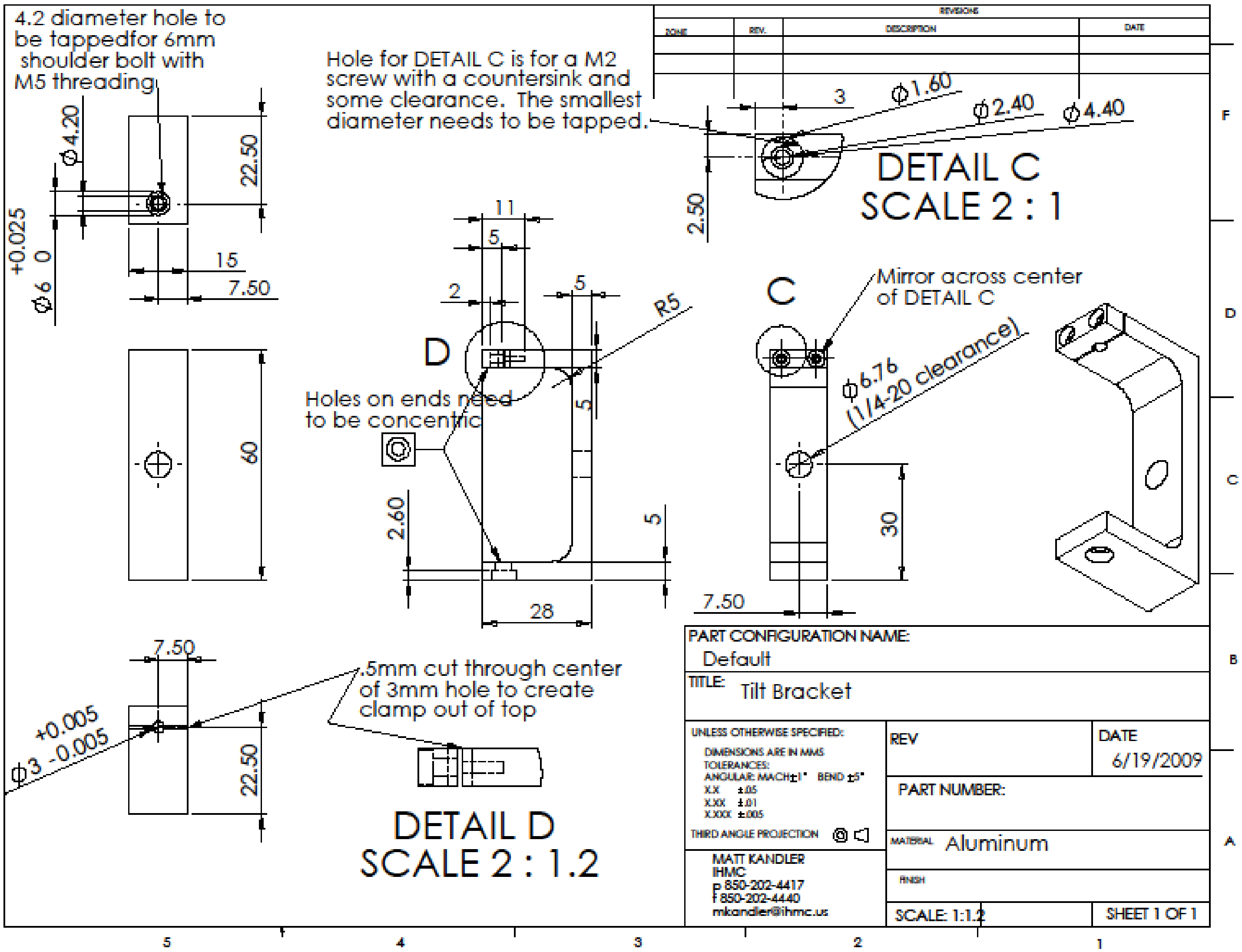

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