

Design of Transmission Mechanisms for the Head
of the 'Huggable' Robotic Teddy Bear

by

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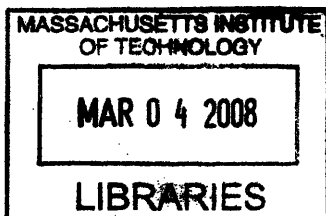
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of the 'Huggable' Robotic Teddy Bear**

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**Submitted to the Department of Mechanical Engineering
on January 18, 2008 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in
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ABSTRACT

The head of the Huggable teddy bear, a robotic companion for use in hospitals, schools, and other locations, must contain three degrees of freedom. It must contain transmissions allowing it to nod up and down, tilt side to side, and move its eyebrows and ears to convey emotions. In addition to the desired movement, care must be taken to integrate the transmissions such that they do not interfere with each others movement. The transmissions themselves must be silent and back drivable in order to appear more lifelike

The resulting design allows for all of the desired degrees of freedom and was designed with silence and back drivability in mind. The transmissions are formed together into one mechanical head mechanism to which all other components in the head, such as speakers and controllers, can be attached.

The design is currently being built and tested.

**Thesis Supervisor: Cynthia Breazeal
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1. Introduction and Background

The Huggable is an interactive therapeutic robot for use in hospitals, nursing homes, schools, and other locations.¹ It is currently being created in the Personal Robots Group in the MIT Media Lab, under the direction of Walter Daniel Stiehl and Cynthia Breazeal. The Huggable has many potential uses, such as a substitution for pet therapy in hospitals or an early education teaching aide in schools. All of these uses require the Huggable to have life like motion and be able to respond to and interact with the environment.

This thesis will focus on redesigning the head of the Huggable. The head of the Huggable offers a wide variety of design challenges. The transmissions must be silent in order to avoid unnatural noise. The transmissions must also be back drivable, such that the Huggable's motion when moved by a user mimics the compliance of a real creature. The head itself must contain the actuation mechanisms for the nod motion, tilt motion, and eyebrow and ear motion. These three degrees of freedom must leave enough space in the head for a speaker, cameras, speaker controller, and USB drives while being teddy bear head shaped; the transmissions will ideally be able to conform to contours similar to that of a live animal's head, rather than being simple boxes.

This iteration of the design focuses on creating a head mechanism that contains and integrates the transmissions for the three degrees of freedom present in the head. A previous head design contained only an eyebrow and ear mechanism.² This design used belt drives for the eyebrows and cable

¹ Stiehl, W. D., J. Lieberman, et al. (2005). The Design of the Huggable: A Therapeutic Robotic Companion for Relational, Affective Touch. AAAI Fall Symposium on Caring Machines: AI in Eldercare, Washington, D.C.

² Levi Lalla, *A Design of Actuation Mechanisms for Use in the "Huggable" Robotic Teddy Bear*, June 2006. Department of Mechanical Engineering

drives for the ears. The eyebrow and ear mechanisms were not coupled as they are now. In addition, the eyebrow mechanism had two degrees of freedom; the inner edge and the outer edge of each eyebrow could move independently of each other. This allowed for a greater degree of emotions. But these mechanisms took up all of the space in the head available to actuation mechanisms, and the head's transmissions for the other degrees of freedom were placed in the body. The current design iteration of the head mechanism must contain the eyebrow and ear transmission as well as the transmissions for the nod and tilt motion. As such the current design has one actuation mechanism with one degree of freedom that manipulates both the eyebrows and ears. While this limits the emotional display of the Huggable, the significant amount of space this frees is an acceptable trade.

The current design will not make use of cable drives and belt drives, but rather timing belt and gear drives. The cables and belts proved to wear easily, often needing to be replaced, and were more prone to slipping, giving inaccurate position readings, than timing belts or gears. These changes from the earlier iteration of the head design will make the transmissions more robust.

The previous design contained transmissions for the eyebrow and ear motion, while the current design must contain transmissions for the nod and tilt motions as well. The current design for the head, similar to the previous design, must be quiet, back drivable, and compact.

2. Design

The desired design attributes are silence, adequate gear ratio while still being back drivable, adequate range of motion, and compactness.

2.1 Transmission Guidelines

Although each transmission served a different purpose, there were common elements shared by all.

In order to achieve quiet actuation, timing belts and pulleys were used as much as possible. But they take up much more space than gears, which are in turn much noisier than timing pulleys. A compromise was reached by using timing pulleys for the first couple stages of a transmission and using gears for the last stage. The last stage of the transmission moves slowly, as it has already passed through a significant gear reduction through the timing pulleys. This slow movement, along with the fact that there is only one gear stage, reduces the noise made by the gears. Plastic gears were used in order to decrease the weight.

Each transmission was built using the same basic principal of parallel plates of quarter inch delrin connected by 4-40 stand offs with the gears and pulleys mounted to eighth inch shafts which sat in bearings between the plates. As the design progressed so did this guideline. The parallel plates were reduced to eighth inch, except for main load bearing plates, in order to conserve weight. A separate motor plate, set in from the other plates, was created to mount the motor to and prevent it from sticking out of the mechanism. When combining transmissions holes were rearranged and added such that they could share a plate. Although each transmission has a different purpose and

gear ratio, the general materials and method for creating each transmission stayed constant throughout each individual transmission design.

2.2 Motors and Torques

Many motors were considered when choosing which motors to use in the Huggable³. Forty-seven motors from the MicroMo and Maxon distributors were compared, to find one that was of a small size yet still had reasonably high torque. The Faulhaber 2232 012 SR motor was eventually chosen, as it had the most agreeable compromise between size and output torque. This motor had a recommended torque, T_i , of up to 10 mNm (about 0.09 lb in) and a recommended speed, Ω_i , of up to 8000 rpm, while having dimensions of less than an inch in diameter and only one and a quarter inches in length. Once the motor was chosen, calculations and testing could commence to examine what size gear ratio, R , would be required for each degree of freedom.

The output torque of a gear transmission, T_o , can be determined using the equation

$$T_o = RT_i \quad (1)$$

and the output speed, Ω_o , using the equation

$$\Omega_o = \frac{\Omega_i}{R}. \quad (2)$$

If the desired output torque is known, the gear ratio required to output that amount of torque can be computed by rearranging equation (1) into

$$R = \frac{T_o}{T_i}. \quad (3)$$

In order to determine the desired torque, the force applied to the output shaft F , in this case the weight of the moving body, must be estimated, as well as

³ Motors researched by Maria Prus (MIT Mechanical Engineering Undergraduate, '10), Summer 2007

the perpendicular distance, d , from the center of mass of the moving body to rotation point. These estimations can then be combined to determine the desired output torque using equation

$$T_o = Fd . \quad (4)$$

Therefore, the gear ratio can be determined using the equation

$$R = \frac{Fd}{T_i} . \quad (5)$$

The weight of the head⁴ was estimated by determining the mass properties of all the elements of the previous design and adding them together. The total weight of the head was estimated to be two pounds. The maximum perpendicular distance from the center of mass of the head to the rotation point, occurring when the head is at its most extreme angle, was estimated to be two inches. These estimations indicate that a gear ratio of about 45:1 is required. Applying a factor of safety of two indicates the head should have a gear ratio of at least 90:1. As such, this was set as the target gear ratio for the neck nod. However, the neck tilt transmission does not need to support the full weight of the head. It was estimated that the neck tilt only moved about one and a half pounds of the head, resulting in a required gear ratio of about 33:1. Adding a safety factor of two indicates that the neck tilt transmission should have a gear ratio of at least 66:1.

2.3 Order of Degrees of Freedom

The head must contain a mechanism that allows it to nod up and down, tilt side to side, and move the eyebrows and ears. This mechanism itself must rotate left to right; the transmission for the rotation is located in the body. In

⁴ Head weight and distance information estimated by Nicolina Akraoff, Kristopher B. Dos Santos (MIT Mechanical Engineering Undergraduate, '10) and Maria Prus (MIT Mechanical Engineering Undergraduate, '10), Summer 2007

order to achieve these three degrees of freedom careful thought must be put into the order of transmission, regarding where each transmission is attached to the next.

Ultimately the stacking of the transmissions resulted in a design (figure 1) featuring a mechanism consisting of a “main head block” which tilts, nods, and rotates attached to a “neck block,” containing the nod and tilt transmissions. The neck block is in turn attached a rotating base plate.

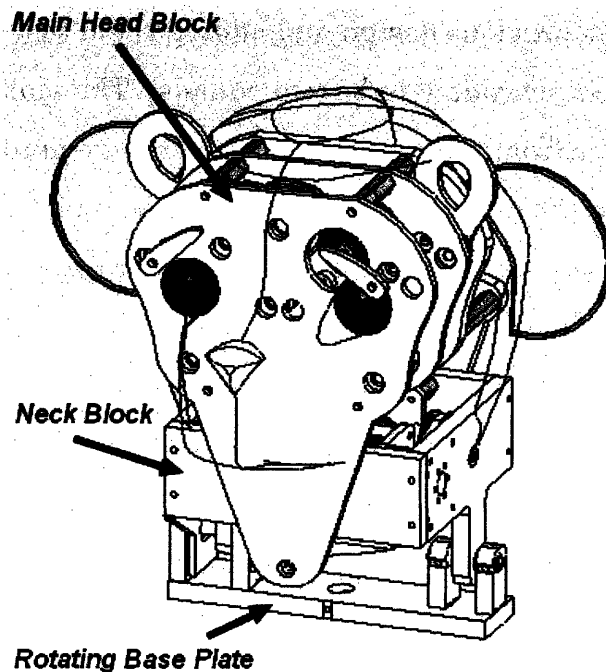


Figure 1: A dimetric view of the head mechanism, including the nod, tilt, and eyebrow/ear transmissions and outline of what the bear will look like with skin.

The “neck block” (figure 2) rotates and nods, but does not tilt. Putting the nod before the tilt proved a better design than vice versa because the range of motion desired for the nod is larger than the range of motion desired for the tilt. It is better to have the whole head move with the larger range of motion, even though the extra weight is undesirable, because then the separately moving pieces of the head can be more easily placed such that they do not knock into each other and hinder movement. If the hierarchy was reversed,

the moving pieces would need a much larger amount of clearance, and would therefore take up more space.

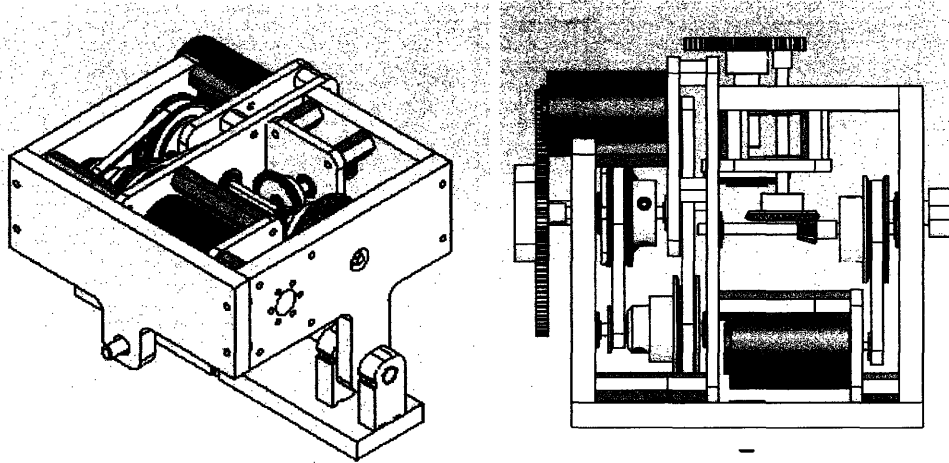


Figure 2: An isometric and top view of the neck block

The rest of the head, the “main head block”, is attached a rotating shaft in the neck block. The main head block rotates, nods, and tilts. It consists of the eyebrow/ ear transmission as well as all the remaining head elements.

As apparent by the mechanism exceeding the limits of the outlined bear head, this design is not as small as desired. However, it serves the purpose of creating the necessary motion so will be built and tested. Further slight modifications could easily result in this basic design conforming to a more desirable shape.

In addition to the mechanism containing the transmissions for the three degrees of freedom, the head must also have adequate space for elements such as a speaker and controller, and possibly USB drives. The space available for these elements (figure 3) is equal to roughly 7.5 inches cubed (1.5” x 2” x 2.5”) for the speaker and 17.5 inches cubed (2” x 2.5” x 3”) for the other elements.

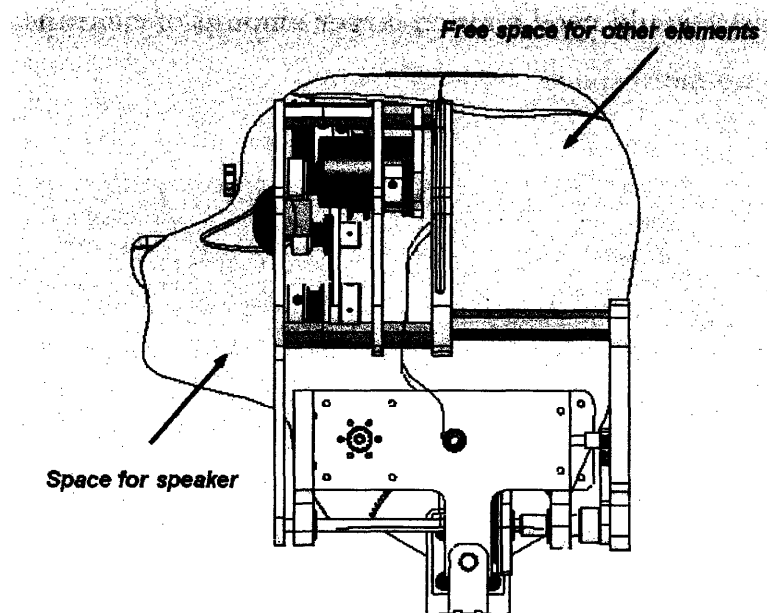


Figure 3: A side view of the head, showing the space available for elements besides the head mechanism.

This will provide adequate space for the necessary components.

3. Motion

The motion of the Huggable head consists of four elements: rotate, nod, tilt and eyebrow/ear.

3.1 Rotate

The rotation transmission is located in the body⁵ of the bear. It outputs to a large vertical shaft with travels up the bear through the top of the body. The rotating base plate (figure 4) of the head mechanism attaches to the shaft by a bolt placed through the middle of the shaft and the plate. Attached to the plate are bearing blocks for the shafts about which the neck block and rest of the head rotate.

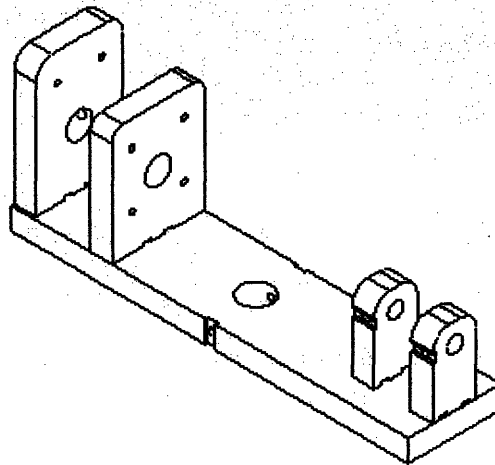


Figure 4: An isometric view of the rotating base plate of the head mechanism. The four smaller plates attach the nod and tilt transmissions to the base plate

⁵ Currently being designed by Kristopher B. Dos Santos (MIT Mechanical Engineering Undergraduate, '10) and Yingdan Gu (MIT Mechanical Engineering Undergraduate, '08)

3.2 Nod

The nod transmission controls the motion of the Huggable head looking upwards and downwards (figure 5).

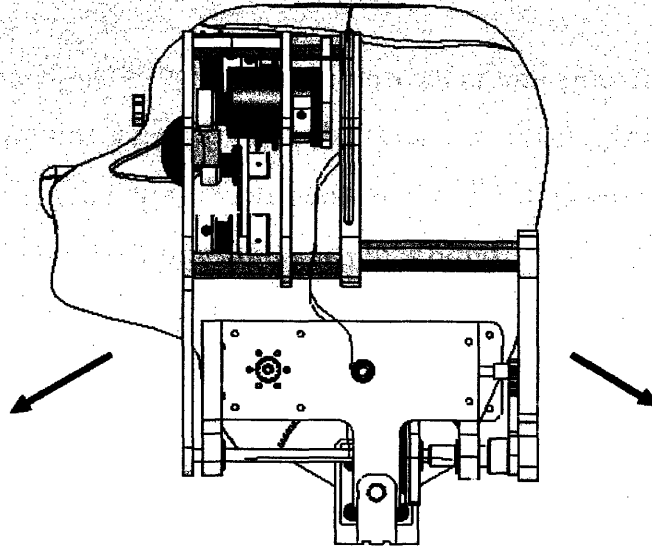


Figure 5: A side view of the head mechanism. The arrows indicate the direction referred to as “nod”.

This transmission must carry the whole weight of the head and have a range of motion similar to that of a human neck. The transmission has a gear ratio of 97.5:1, providing an output torque of 8.6 pound inches and an output speed of 82 rpm. It has a range of motion of about fifty degrees in each direction. Figure 6 gives a detailed look of the stages which create the nod transmission.

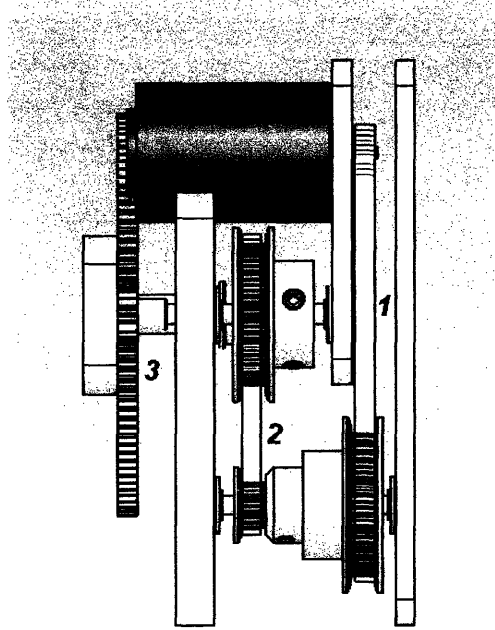


Figure 6: A top view of the nod transmission. Stage (1) and (2) are a timing belt connections and stage (3) is a gear connection.

The first stage is a 3:1 ratio using timing pulleys. The distance between these pulleys is larger than the minimum required for joining two timing pulleys of this size. This allows the second stage, again a 3:1 ratio using timing pulleys but this time the minimum distance apart, to move back towards the center of the nod transmission. Therefore stage three, a 130:12 gear ratio, is positioned in the center of the nod transmission, a desirable place for the head to nod about. The gear itself is cut to conserve space, as only one hundred degrees worth of teeth will be needed to deliver the desired range of motion. This large gear in stage 3 is attached to the base plate by two bearing blocks containing the nod shaft. The nod shaft runs through the bottom center of the nod transmission (figure 7), causing the it to rotate about the nod shaft as it runs.

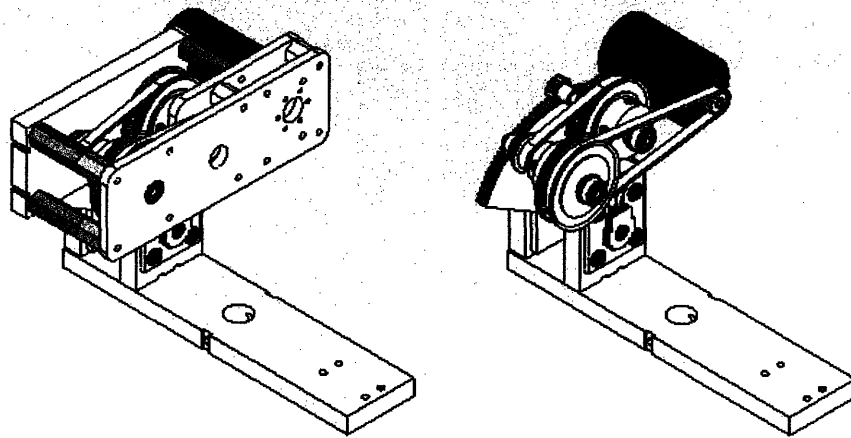


Figure 7: Isometric views of the nod transmission, complete and without plates.

3.3 Tilt

The tilt transmission controls the motion of the Huggable head tipping side to side (figure 8).

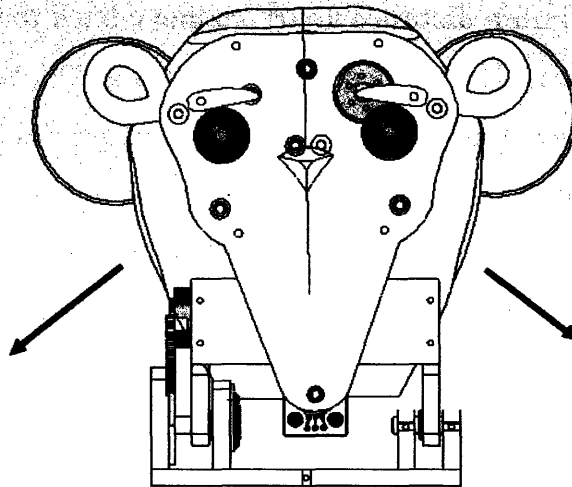


Figure 8: A front view of the head mechanism. The arrows indicate the direction referred to as "tilt."

This transmission must carry the weight of the main head block portion of the head and have a range of motion similar to that of a human neck. The transmission has a gear ration of 72:1, providing an output torque of 6.4 pound inches and an output speed of 111 rpm. It has a range of motion of about thirty degrees in each direction. Figure 9 gives a detailed look of the stages which create the tilt transmission.

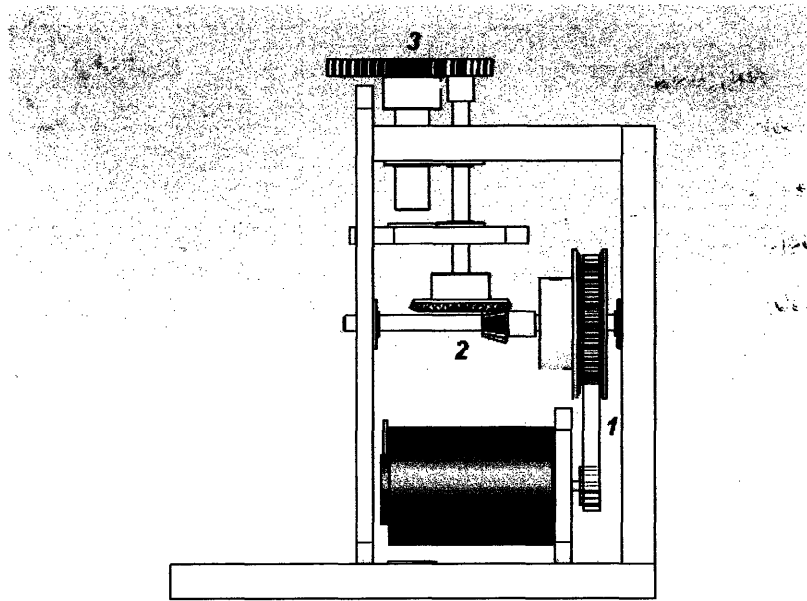


Figure 9: A top view of the tilt transmission. Stage (1) is a timing belt connection, stage (2) is a bevel gear connection and stage (3) is a gear connection.

The first stage is a 3:1 ratio using timing pulleys. The distance between these pulleys is the minimum required for joining two timing pulleys of this size, while still having at least five teeth of the smaller pulley engaged at all times. This allows the second stage, a 3:1 ratio using bevel gears, to be as close as possible to the first stage. The bevel gears change the direction of the path, now making it perpendicular to the nod shaft. A bevel gear proved to take less space than simply putting the whole mechanism in line with the tilt shaft. Following the bevel gears, stage three, an 8:1 gear ratio, connects

to a large gear also cut to conserve space. This gear rotates with respect to the nod transmission. The tilt shaft rotates with this gear, as does the main head block, which is attached to this gear and the tilt shaft. The tilt transmission itself (figure 10) remains stationary with respect to the nod transmission.

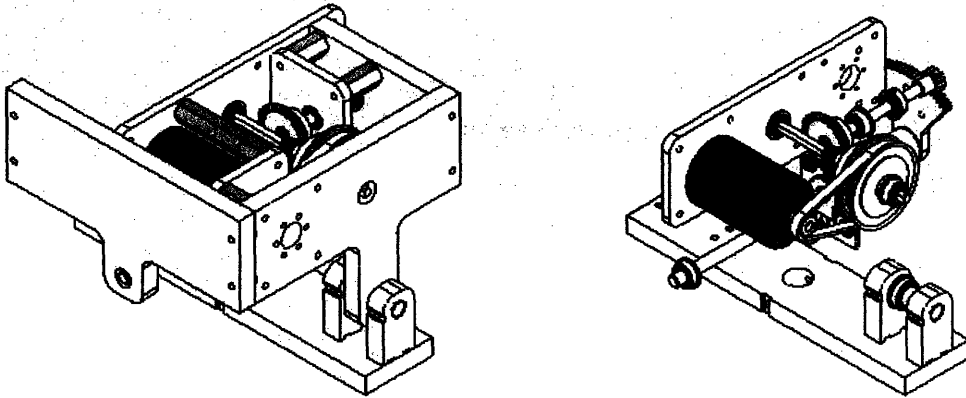


Figure 10: An isometric view of the tilt transmission, complete and without plates.

The tilt transmission would be smaller if the motor were flipped 180 degrees from its current position, with the back pointing out of the nod transmission rather than towards it. The whole left plate could have been brought in (with a hole cut for the end of the motor). But doing so would place the final stage much farther from the center of the neck block. This would make it impossible for the tilt shaft to be located in the center of the neck block. A one to one stage could get the tilt shaft back towards the center, but would take up too much space and make the tilt transmission longer than the neck transmission. Therefore, the orientation of the motor had to be reversed. Although the more compact design would have worked for the tilt transmission by itself, when integrating it with the nod transmission it had to be altered because of the added geometric constraints.

3.4 Eyebrows and Ears

The eyebrow ear transmission presents a slightly different challenge from the nod and tilt transmissions. In addition to being compact and silent the eyebrow/ ear transmission must also ensure that the eyebrows and ears move in appropriate directions and orientations with respect to each other.

The eyebrow/ ear transmission (figure 11) was designed by Kristopher B. Dos Santos (MIT Mechanical Engineering Undergraduate, '10) and only slightly altered to allow for attachment to the rest of the head mechanism. The front plate was extended to attach the transmission to the tilt shaft. A back plate was added and bolted to the final gear of the tilt transmission, allowing the transmission to tilt. The other elements of the head can also be bolted to this back plate.

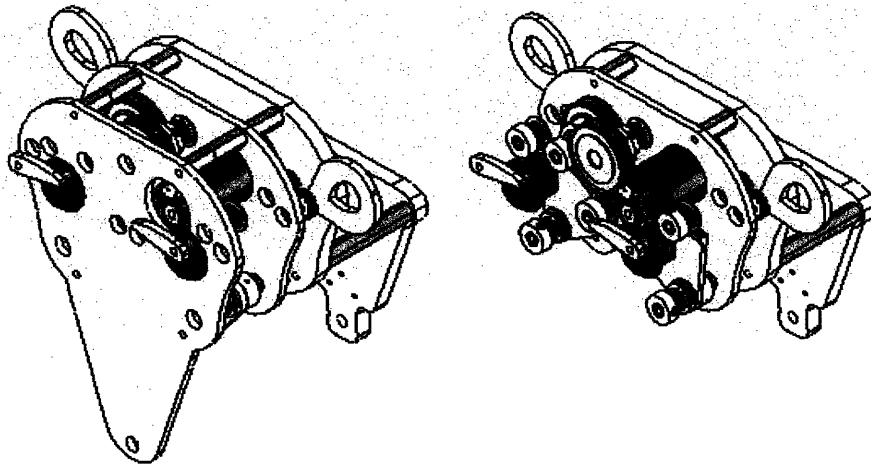


Figure 11: An isometric view of the eyebrow/ ear transmission, complete and without plates.

The eyebrow and ear mechanism moves the eyebrows and ears simultaneously either up or down, and in mirror image to each other (figure 12).

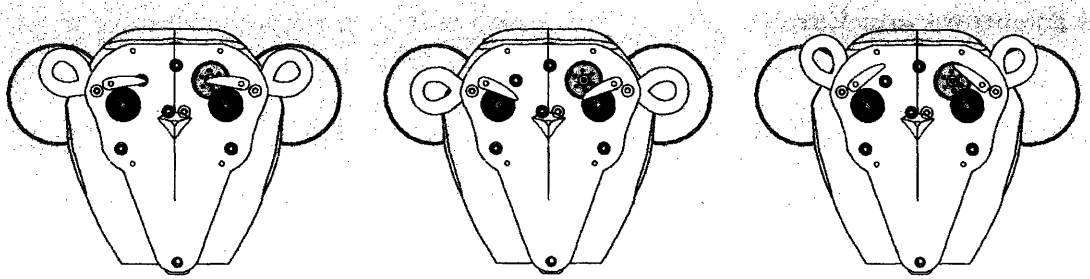


Figure 12: The range of emotions of the Huggable, from neutral to eyebrows and ears in the down position to eyebrows and ears in the up position.

This coupled motion is achieved by adding in an extra gear stage. When timing pulleys are attached, they move the shafts in the same direction. But when gears are attached they move in opposite directions. As such adding an extra gear stage allows the eyebrows and ears to mirror each other. The range of motion of the eyebrows and ears is about thirty degrees in each direction.

5. Conclusion and Future Work

This design for the head mechanism provides the necessary three degrees of freedom while moving quietly and being back drivable. This was achieved by using both gears and timing pulleys, combining them in an effort to gain the strengths of each: the silence of the timing pulleys and the compactness of the gears. Consideration was also given to the range of motion desired and which parts of the head would contain which degrees of freedom. While not as small as ideal, this design provides realistic and quiet motion. It is in the process of being built and tested.

Future work could easily decrease the size of the head mechanism. Creating custom made silicon cast pulleys would allow the area occupied by the pulleys to decrease, by combining two adjacent pulleys into one entity with a shared hub. While hubs are necessary to provide a place to secure the gear or pulley to the shaft and prevent the gear or pulley from tilting, two gears and pulleys next to each other on the same shaft could easily share a hub. As an added benefit, these custom pulleys would also weigh less than the metal pulleys currently used. This would allow the gear ratio, which already has a very high safety factor, to be decreased, possibly allowing for the elimination of an entire stage. Using this design as a starting point, the above suggestions and other modifications could easily be made to decrease the size of the mechanism.