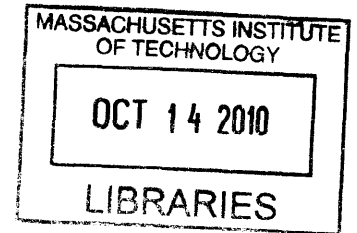


Semi-Autonomous Mobile Phone
Communication Avatar for Enhanced Interaction

by
Yingdan Gu

ARCHIVES



SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2008

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Signature of Author: _____

Department of Mechanical Engineering
May 9, 2008

Certified by: _____

Cynthia Breazeal
Associate Professor of Media Arts and Sciences
Thesis Supervisor

Accepted by: _____

John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

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Submitted to the Department of Mechanical Engineering
on May 9, 2008 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in
Mechanical Engineering

ABSTRACT

In order to take advantage of the present technology in cellular phones and to enhance the presence of phone user in a remote location, the process of designing the MeBot is started. The MeBot is designed to be a semi-autonomous robot that is aimed to embody the other side of the phone conversation in a more interactive way. This thesis covers the initial mechanical design of the MeBot. Major goals such as compactness, expressiveness, and manufacturability were attempted in the first two version of the design. The MeBot v1.0, built and tested, was able to prove the feasibility of the concept and generated some consumer response through the implementation of three degrees of freedom. Then MeBot v2.0, with six degrees of freedom, was designed to incorporate some improvements on the mechanical design. The latest mechanical design of the MeBot has capabilities to perform tasks such as traveling on a flat surface, lift and lower the phone, gesture and point with its arms, and rotate its entire upper body independently from the wheels. Overall, the degrees of freedom fortify the MeBot with capabilities to embody the user in an expressive way.

Thesis Supervisor: Cynthia Breazeal
Title: Associate Professor of Media Arts and Sciences

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1. Introduction and Background

The capabilities of mobile phone units are expanding at an unforeseen rate since the beginning of this century. Nowadays, most cell phones are able to carry and process a great deal of information beyond the level of audio signals. Recently, mobile phones have even started carrying built-in operating platforms and functioning similar to a small computer. At the same time, the wireless communication technology has also been developed to efficiently carry through a large amount of information. However, these ever-growing capabilities are not being utilized at their highest potentials through the current mobile phone units, and the modes of communication are still fairly limited. Using regular video communication equipments, each party's actions are usually captured by a low-resolution webcam and streamed to the screen on the other end where the sender has no control over what the receiver is receiving while losing a large amount of information from reducing a 3-dimensional action to a 2-dimensional playback screen.

In order to provide a sensible solution to this problem, the design of the MeBot was started. The MeBot is designed to be a semi-autonomous robot that is aimed to embody the other side of the phone conversation in a more interactive way. The MeBot is controlled from blue-tooth signals emitted from the on-board phone. The Bluetooth signals are converted from the wireless signals sent from the phone at the remote location, which is controlled by the user. The MeBot is an ongoing research project being conducted in the Personal Robots Group at the MIT Media Lab under the supervision of Professor Cynthia Breazeal, and graduate students Sigurdur Orn and Dan Stiehl.

Previous works done on remote embodiment has been focused on using the computer as a media where communication signals are sent via the internet and analyzed with the computers. One example is the Huggable, an

interactive therapeutic robot for use in hospitals, nursing homes, schools and other locations, developed in the Personal Robots Group at the MIT Media Lab. [1] It uses a website as an interface where an operator can control the robot from a remote location, thus to interact with the people in that remote location. Another example is the PRoP, a mobile proxy controllable over the Internet to provide tele-embodiment, developed at the Computer Science Department in University of California, Berkeley. [2] Nevertheless, there has not been work done on remote embodiment using the computing power of cellular phones, and that is what this thesis is focusing on. Moreover, this thesis also focuses on making a device that is ready to be commercialized rather than being a research instrument.

The initial mechanical design of the MeBot is presented in this thesis. It will focus on three major characteristics: compactness, expressiveness, and manufacturability. It is envisioned that the ultimate version of MeBot will be small enough to have portability similar to that of a cellular phone, because the MeBot will ultimately be used as an accessory to a cellular phone. Meanwhile, while preserving the portability, the design will also attempt to add as many degrees of freedom as possible beyond the simple actions of driving on flat ground. This is to fortify the MeBot with as many ways as possible to interact with its environment and to embody the other end of the conversation as accurately as possible. It should be noted that facial expression elements such as eye brow and ear movements are not attempted at this point simply because the phone itself will be able to carry the face of the user. In other words, the degrees of freedom that will be added will contribute to the MeBot being able to perform tasks with its arms such as gesturing and pointing. Lastly, the design is also meant to be commercialized, which acts as a constraint in two aspects: cost and consumer comfort. The design will employ fairly low-cost parts while trying to consider consumer comfort such as low noise-level and easy control. Applications of the MeBot

include, but are not limited to, conference calls, family events and educational setting.

Currently, the MeBot is being built to specifically accommodate Nokia N810 mobile phone, which is equipped with a Linux operating system. However, this will change in the later stage of the design process where the MeBot will be able to accommodate more styles and forms of cellphones. The MeBot will be controlled by the mobile processing unit inside of a cellphone, which will be taking input directions from the other end of the communication. The electronic portion of the robot design will be done by Sigurdur Orn Adalgeirsson (G) from the Personal Robots Group in the MIT Media Laboratory.

2. MeBot v1.0

2.1 Preliminary Form Factors

The first step of the design process was to decide the overall form. Several plans were proposed and most of them agreed on the use of two-wheel driving system with differential driving. However, there were two schools of thoughts regarding the expressive portion of the design. One proposed that the MeBot be made into an alien-like creature with functional appendages so to appeal to the technological-advanced consumers who would like products to be quirky and unique. On the other hand, others proposed that the MeBot be made into a humanoid creature with arms and hands so to better embody the user.

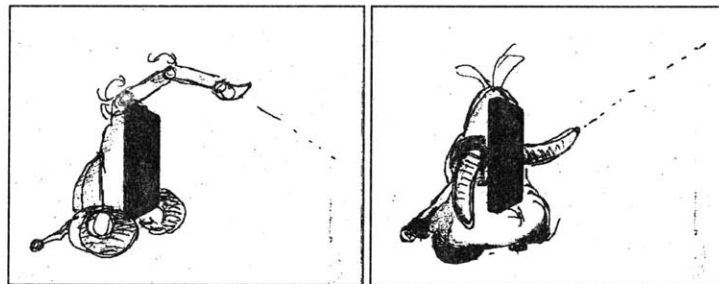


Figure 1 The proposed designs were made to not resemble human form with the use of a single arm (left) and antennas (right). These were made to add more character to the MeBot thus to give it a more fun and toy-like feel. (Concept Sketches by Guy Hoffman)

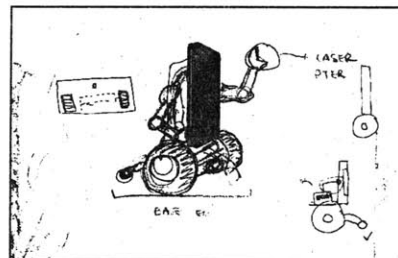


Figure 2 A sample of the more human-like design resembled the human shape better with the use of two arms and two hands. This was to give the MeBot a more realistic feel. (Concept Sketch by Guy Hoffman)

Ultimately, the more human-like form was chosen because it would be easier to control from a user point of view. It would be more natural for a user to control a device that behaves more or less like him.

2.2. Design

In order to prove the feasibility of the product and obtain consumer feedback for the concept, a very simple first version of the MeBot was designed and built. The first version included three degrees of freedom: two for driving and one for neck up and down. Also, all custom-made plates were made out of clear acrylic for the purpose of easy prototyping, and this will be changed in future revisions.

2.2.1 Driving

The first version employed a driving system that included two driving wheels that each was connected to a servo motor and placed on either side of the MeBot. Even though servo motors tend to be large in size and noisy, they were still used in this version in order to more accurately control the position of the MeBot. To steer, the two driving wheels would be driven at different rotational speed. A caster wheel was placed in the front of the car to support and assist steering.

Actuation: HS-311

HS-311, manufactured by HiTech, was used in the first design to actuate the wheels. It was a fairly inexpensive yet reliable servo motor with capabilities of a 90 degree turn. In order to make it applicable to the driving situation, it had to be fixed so that it was able to turn all the way around.

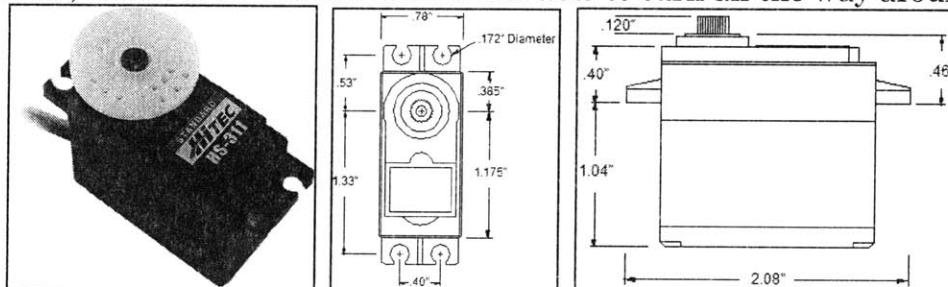


Figure 3 A modified version of HS-311 with capability to turn a full 360° was used in the driving module of MeBot v1.0.

Transmission: Pinion Gear

The interface between HS-311 and the driving shaft was provided by a servo horn and a pinion gear. A 24-tooth gear that was made to be able to attach to the shaft of any HiTech servo motor was used. Figure 4 shows the servo horn.

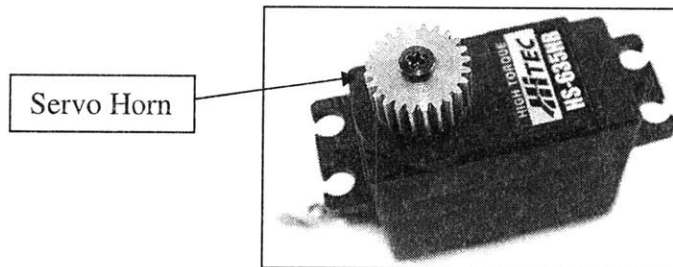


Figure 4 The 24-tooth servo horn gear has a pitch diameter of .5" and outside diameter of .542". This was used to drive a pinion gear.

It was found that the servo horn could not directly interface with the driving shaft due to spacing issues, so a pinion gear was used. The pinion gear was selected to match the diametral pitch and the pressure angle of the servo horn. A 36-tooth aluminum metal gear with diametral pitch of 48 and pressure angle of 20° was selected. On the .25" driving shaft that was connect to the wheel, a 24-tooth driving gear was fixed on using the set screw that was in the hub of the gear. The servo horn gear, the pinion gear and the driving gear formed the driving transmission.

Output: RC Tire

In order to satisfy the compactness and commercializing constraint of the MeBot, it was decided to use a regular RC car tire with a very small diameter. The center of the wheel fit a shaft of .125" in diameter, which was smaller than the diameter of the driving shaft. To solve this problem, a centered hole was drilled through the driving shaft to fit the other end of the

.125" shaft and then the two were held together using a cotter pin. Rubber tire with AT tread pattern was chosen and shown in Figure 5.

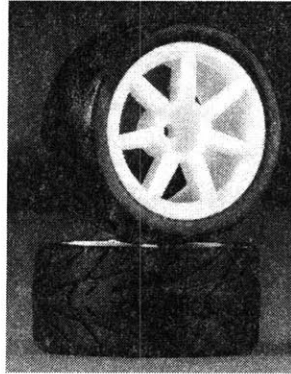


Figure 5 Premounted Wheels for the Team Associated 18R Rally Car series were chosen, with features including an OD of 1.8" and width of .87".

Driving Module

The HS-311 servo motor, the transmission and the tire formed the entire driving module that was supported by two custom-made bearing plates made of .25" clear acrylic plate. Figure 6 shows the module as a whole.

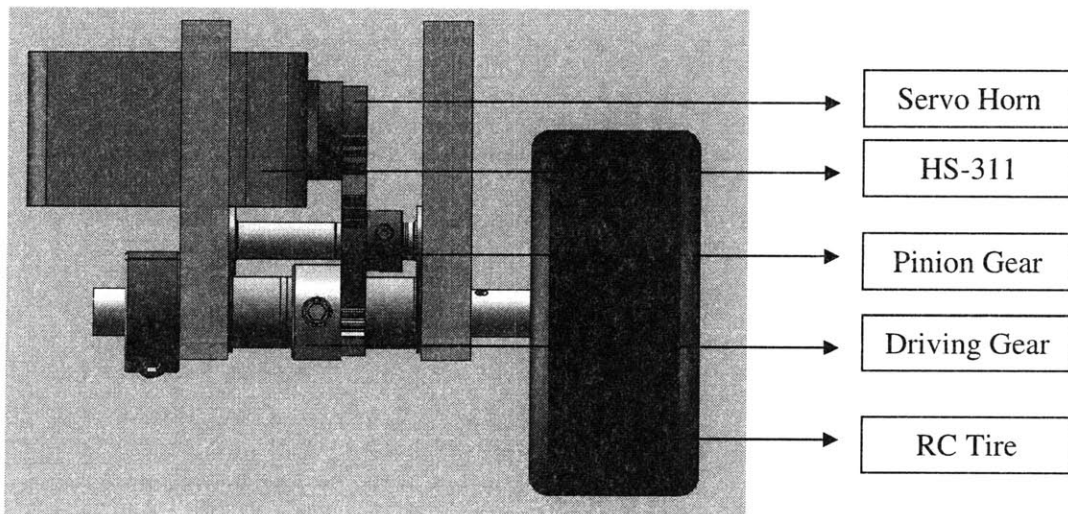


Figure 6 The servo motor is controlled by the on-board circuit board and it outputs to the transmission, which drives the wheel.

The HS-311 was mounted on the plate farther away from the wheel, which fixed the position of the servo horn. The pinion gear and driving gear

were both on their own shaft, so their linear movement was constrained by spacers that filled up the unoccupied spaces. The wheel was kept at a certain distance from the bearing plate using a shaft collar on the opposite end of the driving shaft. The distance between the two bearing plate was kept 1" from each other using female #4-40 aluminum standoffs (not shown in the figure).

2.2.2 Neck Module

The other degree of freedom included in the first version of the MeBot was the neck tilt. The purpose of this module was to create a cradle for the cellular phone that would be controlling the movements of the MeBot and to provide the phone with the ability to tilt up and down so that the camera could capture a wider range of the environment surrounding the MeBot, letting the controller have a better awareness of the remote location.

Actuation: HS-311

The HS-311 servo motor was also selected to provide the motion to the neck module. The one used for this module was not modified to turn 360°, so the neck only had a range of 90°, with the horizontal position being neutral at 45°. Through bench level testing, it was also found that the torque out put of the servo motor would satisfy the power requirement to lift the phone and its cradle.

Transmission: Direct-Drive

A bigger driving gear was used in the neck module, so direct drive could be achieved without spacing complications. A 48-tooth aluminum gear with diametral diameter of 48 and pressure angle of 20° was selected to be mounted on the driving shaft using the set screw in the hub of the gear.

Output: Phone

The servo motor and the gears form the driving system that output power in order to lift and lower the phone in its cradle. The phone specifically used in this version was the Nokia 810, which was reported to weigh about 0.226 kg. The output shaft used in this module had a diameter of .25". The

driving system should be able to output enough power in order to move the phone up and down 45° each way.

Neck Module

The servo motor, the driving gears and the phone in its cradle makes the neck module. Two bearing plates made from clear acrylic that were screwed onto the base plate of the MeBot acted as support for the output shaft of the neck module. Ball bearings for .25" shafts were press-fitted into the holes cut for the output shafts on these plates so that the shaft could rotate freely in the plates. Another two plates that were shaped into brackets connected the output shaft to the phone cradle. These brackets were fixed with the output shaft using set screws so that the cradle would move with the rotation of the output shaft. Figure 7 shows a top view of the module.

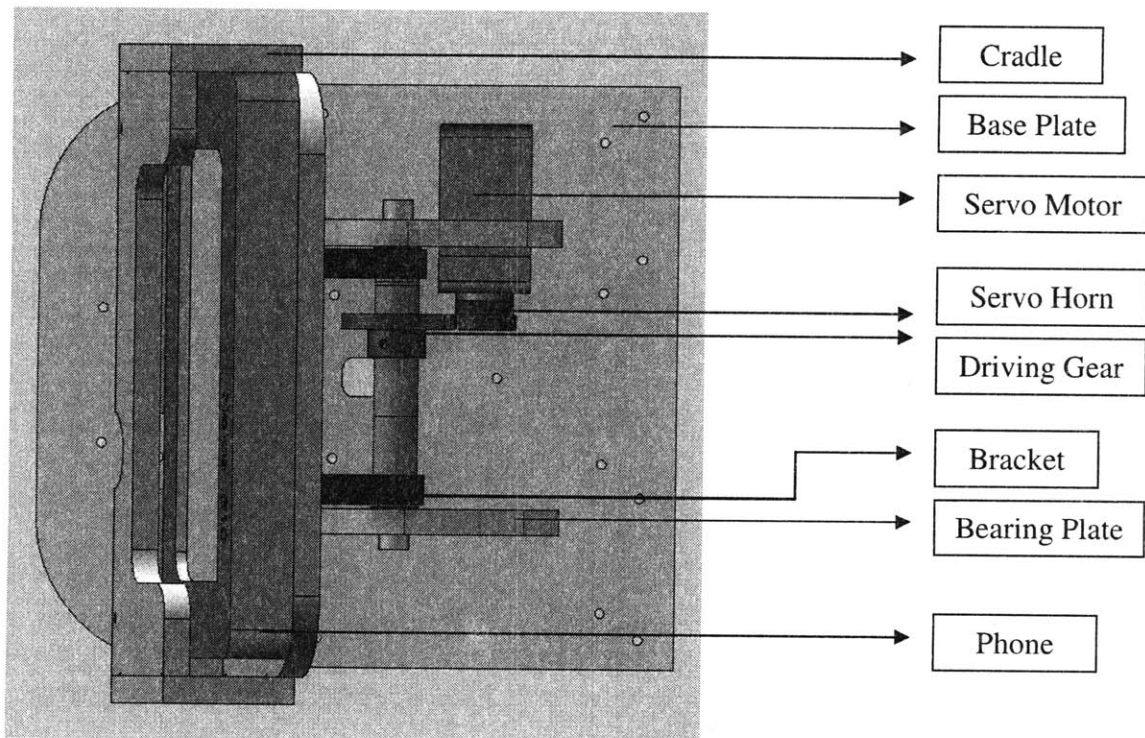


Figure 7 The Neck Module is controlled from the on-board circuit board which takes blue-tooth signal from the phone in the cradle. The servo motor takes the signal from the circuit board and drives the output shaft directly, which in turn moves the cradle through the brackets.

The servo motor was mounted on one of the standing bearing place, which secured the position of the servo horn. The driving gear was secured on the output shaft using both the set screw that's in the hub of the gear and exact spacers that filled the rest of the space on the shaft. As the shaft rotated, the brackets, which were set-screwed on to the shaft, also moved with it, which in turn caused the cradle to go up and down. The cradle was an open-top structure that was closely fitted to the outer dimensions of the phone. The inside bottom of the cradle was lined with felt so to increase the friction between the bottom of the phone and the acrylic plate, thus to prevent the phone from slipping in the cradle.

2.2.3 The MeBot v1.0

In summary, the first version of the MeBot was built to be a proof for feasibility and to generate feedback from potential consumers. Servo motors, instead of hobby motors, were used, thus accuracy of manipulation was achieved in trade-off to the fairly high noise level generated by the servo motors. Also, only three degrees of freedom were built into the first version and all three were to be controlled from an on-board circuit board. The circuit board would take blue-tooth signal from the on-board phone, which would receive signals from another phone from a remote location. Figure 8 shows the complete design of the robot from three perspectives.

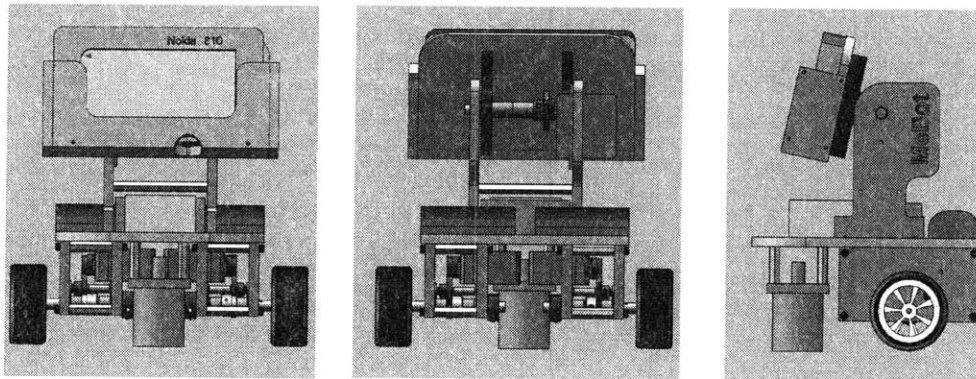


Figure 8 The complete design for the robot exhibits the two-wheel drive system with the caster wheel in the front, and the neck module which was designed to raise the cradle and the phone around a horizontal axis behind them. The bearing plates were designed with curves on the side in order to leave spaces for the wires to go through.

There was enough space left on the base plate of the robot that the different batteries required by the electrical elements and the circuit board were able to fit on there. Figure 9 exhibits the built product.

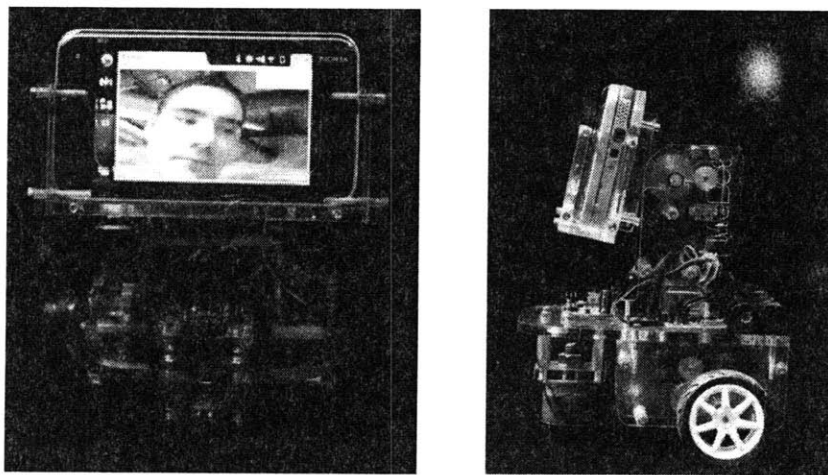


Figure 9 The first version of the MeBot had all custom-made bearing plates made out of clear acrylic. Circuit board and batteries were placed on top of the base plate. The phone was placed in the position of the robot where a face would be on a human.

2.3 Feedback

The design was built and demonstrated to potential consumers. The MeBot generated fairly positive response from the audience and was deemed to have great potential in a variety of settings, be it a conference call with a very involved participant fixing problems around him without physically being in the environment or a family event with a grandparent hugging a baby without the troublesome traveling. Additionally, there were several key improvements that will be implemented in the second version:

- 1) Servo motors needed to be replaced by hobby motors so that space can be conserved and noise level can be reduced significantly.
- 2) Two more degrees of freedom in the form of arms would be very helpful for point and gesturing. These arms would be driven by a belt-pulley system.
- 3) More efforts needed to be made to reduce the overall size of the robot.
- 4) The phone needed to be implemented as a vertical element so to make room for arms.
- 5) The head of the robot needed to turn independently instead of turning as a result of the base turning.

3. MeBot v2.0

With the confirmed feasibility gained from v1.0, it was decided to re-design of the robot with specific improvements in mind. The second version of the robot would incorporate more degrees of freedom, providing the robot with arms to point and gesture and the neck rotating independently. The movement for the arms will be provided by a belt-and-pulley system while the neck-rotate would be driven directly from a motor. Also, v2.0 would use hobby motors instead of servo motors, and this would be able to both reduce the size of the robot and make it quieter. Figure 10 provides a simplified schematic of the organization of the 6 degrees of freedom.

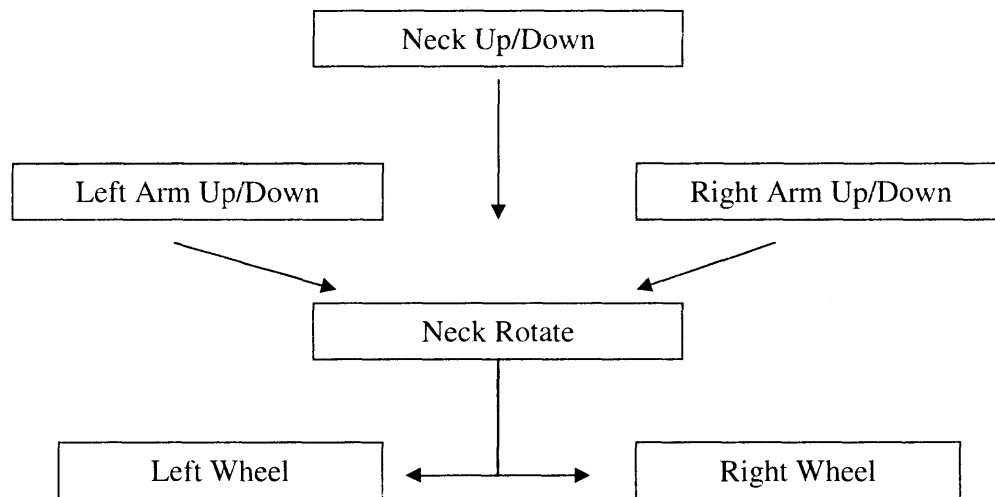


Figure 10 The degrees of freedom above the neck-rotate would be built on top of the neck-rotate, so they would move with the neck-rotate. The upper 4 DOF's would be built above the level of and separate from the wheels, so they would all move as a section with the movement of wheels.

3.1 Calculation

Motor selection was a critical stage in the revision process. In MeBot v1.0, servo motors were used because of their strong output torque and ease of control. However, the size of the servo motor was not compatible with the

goal of compactness in this project, and it also would cause the total cost of the robot to increase, which would prevent it from being commercialized easily. In order to improve that, it was decided to use conventional low-cost motors. It was also decided that only one type of motor be used in all the degrees of freedom to make motor control simpler. Out of the six degrees of freedom, the one that would need the most output torque was the neck module, since it had to lift and lower the phone and the cradle, which accounted for a majority of the weight of the robot. Calculation was done to determine the torque need of the neck module, the following calculation was done. The following assumptions were made during the process:

- The maximum speed the neck needed to move at was 180° per second.
- The motor could take 2 seconds to achieve maximum speed
- The axis at which the phone was rotating was located .036m behind the phone and cradle

GIVEN

$$\begin{aligned}
 m_{\text{robot}} &:= 2.4\text{lb} = 1.089\text{ kg} & \omega_{\text{phone}} &:= \pi \frac{\text{rad}}{\text{sec}} \\
 m_{\text{phone}} &:= .226\text{kg} & v_{\text{phoneRPM}} &:= \omega_{\text{phone}} \left(\frac{1}{2\pi} \right) \cdot 60\text{s} = 30 \\
 m_{\text{total}} &:= m_{\text{robot}} + m_{\text{phone}} = 1.315\text{kg} & \alpha_{\text{phone}} &:= \frac{\omega_{\text{phone}}}{t_{\text{setup}}} \\
 t_{\text{setup}} &:= 2\text{sec} & r_{\text{NeckShaft}} &:= .50\text{in} = 0.013\text{ m} \\
 m_{\text{phone}} &= 0.226\text{kg} & l_{\text{phone}} &:= 14\text{mm} = 0.014\text{ m} \\
 r_{\text{NeckShaft}} &:= .50\text{in} = 0.013\text{ m} & w_{\text{phone}} &:= 72\text{mm} = 0.072\text{ m} \\
 r_{\text{phone}} &:= 1.4\text{in} = 0.036\text{ m} & l_{\text{phone}} &:= 128\text{mm} = 0.128\text{ m} \\
 F_{\text{phone}} &:= m_{\text{phone}} g = 2.216\text{N}
 \end{aligned}$$

CALC

$$I_{\text{phone}} := \left(\frac{1}{12} \right) (m_{\text{phone}}) (l_{\text{phone}}^2 + w_{\text{phone}}^2) = 4.062 \times 10^{-4} \text{ m}^2 \cdot \text{kg}$$

Parallel Axis Theorem applied to offset

$$I_{\text{shaft}} := I_{\text{phone}} + m_{\text{phone}} r_{\text{phone}}^2 = 6.92 \times 10^{-4} \text{ m}^2 \cdot \text{kg}$$

$$\tau_{\text{Neck}} := I_{\text{shaft}} \alpha_{\text{phone}} = 1.087 \times 10^{-3} \text{ J}$$

$$\tau_{\text{motorNeck}} := I_{\text{shaft}} \alpha_{\text{phone}} + m_{\text{phone}} g r_{\text{phone}}$$

$$\tau_{\text{motorNeck}} = 11.315 \text{ oz}\cdot\text{in}$$

Through the calculation, it was found that the neck module would need about 11.3 in-oz of torque at a minimum. Adding a safety factor of 2, it would require a motor that could output about 20 in-oz of torque during normal operation. Using the assumption that motors normally output torque that is half of the stalling torque, a motor with a stalling torque of about 40 in-oz would be needed.

It was observed that most un-gearred motors did not output nearly enough torque as needed, so a decision had to be made between two solutions. The first was to use a transmission system that geared up the motor. The other was to use already-gearred motors. While more versatile, having a transmission system would take up much space and compactness was one of the major goals of this project. Thus, it was decided that small geared motors would be used.

After looking through the options, one motor was ultimately chosen for its powerful output and compact size – the NA4S made by Sanyo. The unit is shown in Figure 11.

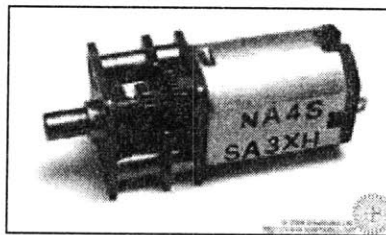


Figure 11 the NA4S had a stalling torque of 46 in-oz, which was comparable to the servo motor used in the first version. At the same time, the NA4S was about a quarter the size.

3.2 Design

With the new motor Sanyo NS4A, the whole design was able to be shrunk down to a robot 8.5in high, 1.5in in width and 4in in depth, which was more compact than the first version in horizontal cross section. Three more degrees of freedom were also designed into v2.0, two of them manifested

in the two independently moving arms and one in the rotating ability of upper section of the robot. The added degrees of freedom afforded the MeBot with more expressiveness and natural movement.

3.2.1 Driving

The basic driving mechanism was not changed much in this version. It was still a two-wheel drive system that turned with differential driving and with a caster wheel in the front of the vehicle for support and steering. The output shaft was still connected to the RC hobby wheel. With the newly selected motor, the pinion gear-system was no longer needed and the motor was put into direct drive to the output wheel shaft. Two identical gears were used to transfer power from the motor to the output driving shaft. Figure 12 exhibits the new wheel assembly.

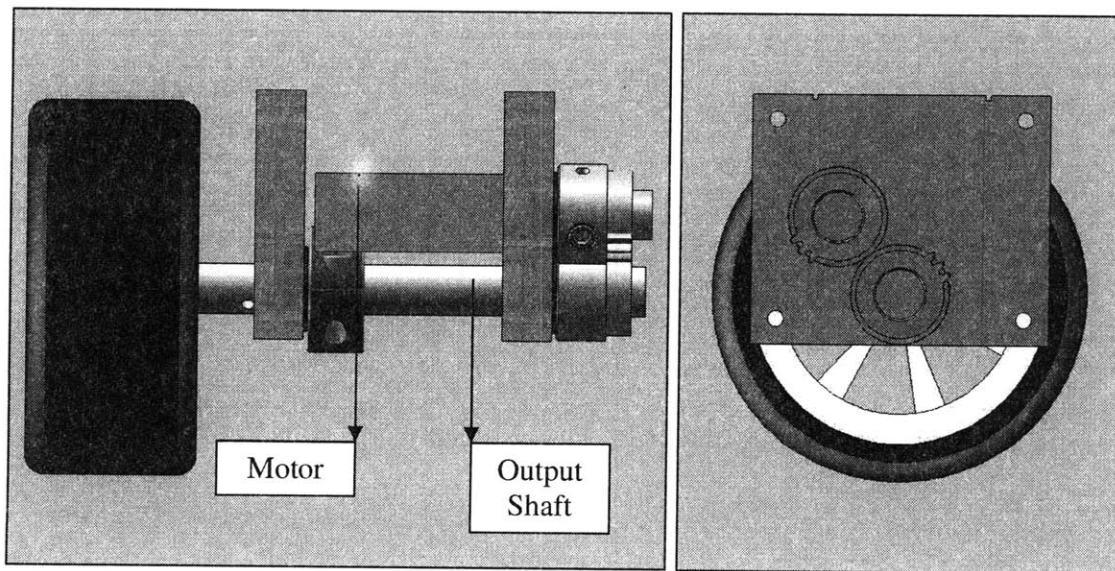


Figure 12 The motor drives one of the gears which in turn moves the other gear, which was set-screwed to the output shaft.

The motor was mounted on to the bearing plate farther away from the wheel, and the gears are fixed on to the shafts through set screws. The output shaft was also held in place with a clamp shaft collar fit for .25" shafts. The

distance between the two bearing plates were held with #4-40 female standoffs (not shown on the Figure).

3.2.2 Neck Module

Similar to the driving module, the neck module was also not altered very much in the second version of the robot. There was still a direct driving scheme with two gears at a gear ratio of 2:1. Also, the smaller gear would be driving the bigger gear in order to reduce the speed and increase the torque applied. This mechanism was also driven by the Sanyo NS4A motor, which transferred power into the output shaft, thus lift and lower the phone and its cradle through the brackets. Although, it was decided according to the feedback from v1.0 that the cradle of the phone should be built in a portrait orientation instead of a landscape orientation, as to yield to the activities of the added functionality from the arms. So the design of the cradle was changed accordingly. Figure 13 exhibits the assembly.

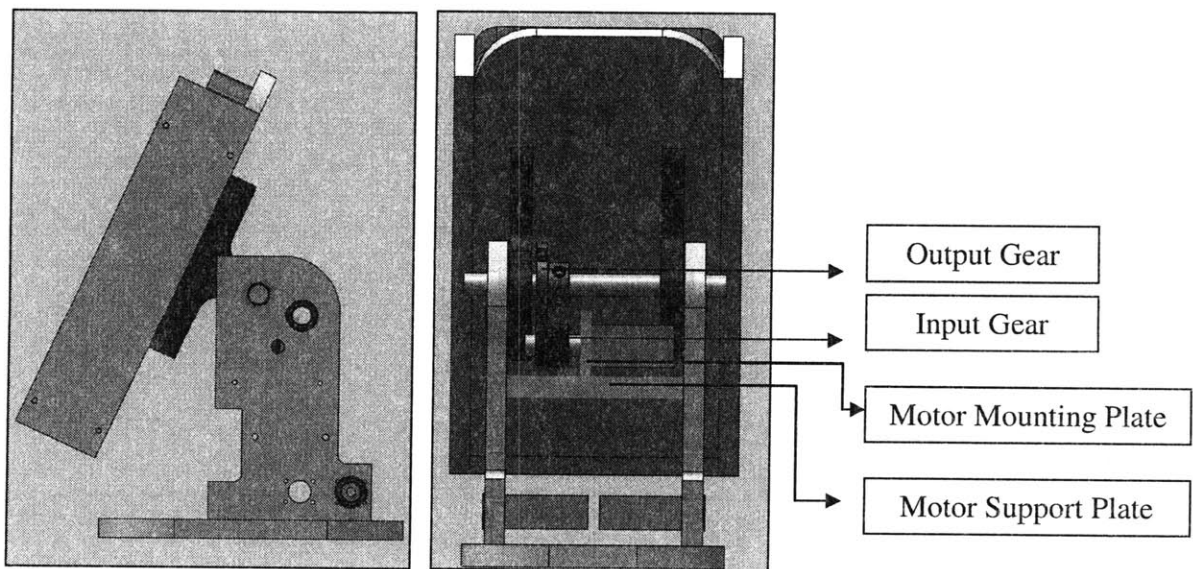


Figure 13 The phone and cradle were pivoted at an axis behind them, which was driven by a motor fitted in between the two standing bearing plates.

The Sanyo NS4A, unlike the servo motor used in the first version, mounts to a plate from the face plate of the motor. This meant that if the NA4A was mounted the same way as the servo motor was, the entire body of the motor would be sticking to the one side of the support structure, thus making a very unstable design. In order to position the motor in a more centered location while having full contact with the output gear, a horizontal plate was made to support the motor. A vertical plate was made to stand on top of the supporting plate for the motor to mount on. To add stability, the distances between the left standing structure and the vertical mounting plate, and between the vertical mounting plate and the right standing structure, were maintained by inserted standoffs.

3.2.3 Rotating Mechanism

As suggested by the feedback from v1.0, the robot needed to be able to turn the upper portion of its body, including the neck and the two arms, independent of the movement of the wheels. It was decided that an independent moving upper body would give the robot more range and natural movement while it's trying to use its arms to point and gesture.

The first step into implementing this degree of freedom was to separate the upper section of the robot from its base. Thus, the original one layer of base plate was separated into two, with the upper base plate taking on the supporting structure for arms and neck and the lower base plate only connected to the wheel modules. The two base plates needed to be connected while giving them freedom to turn independent to each other. In order to fulfill this design requirement, it was decided to use a needle thrust bearing. The bearing would be put in between the two base plates so that one could rotate on top of the other. Figure 14 shows the mechanism in whole.

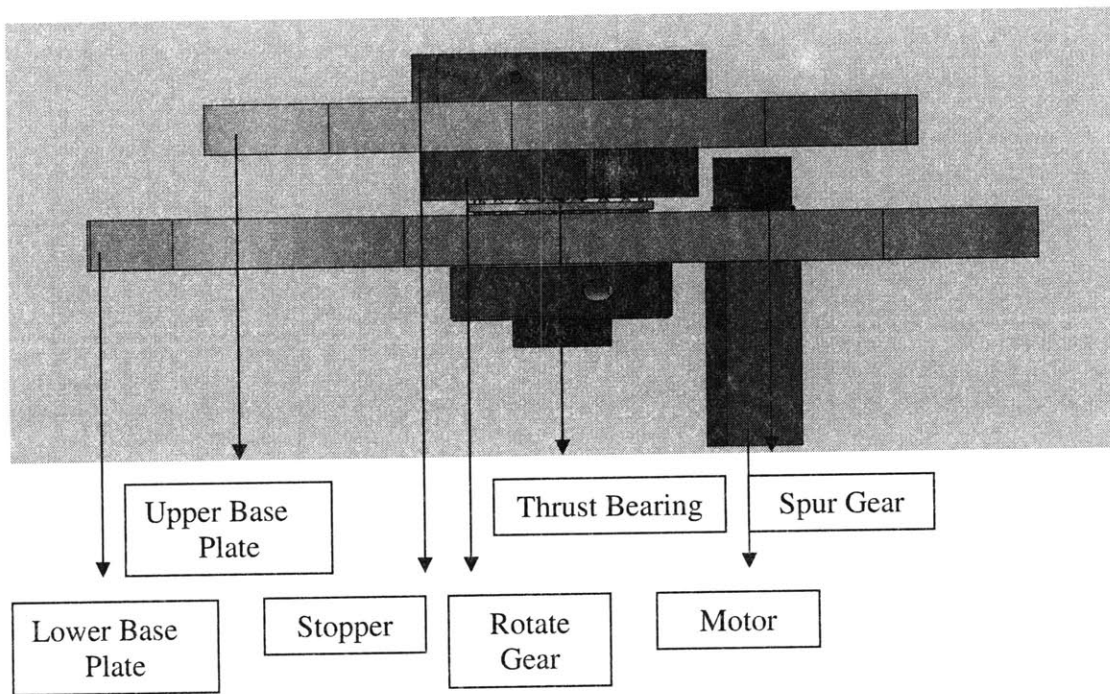


Figure 14 The two base plates were separated by the thrust bearing so that they could rotate independent of each other. The rotate gear was fixed to the axel, which was fixed to the upper base plate. The motor was mounted onto the lower base plate and outputted to the spur gear, which drove the rotate gear, and thus turned everything above the upper base plate.

As the spur gear turned, it pushed against the big rotate gear, which was sitting on top of the needle thrust bearing. With the help of the bearing, the upper base plate did not cause the lower base plate to move even though they were fixed to the same axel. A stopper was put on top of the upper base plate to fix the axel to the upper base plate and to prevent it from rotating with respect to the upper base plate. The stopper was screwed onto the upper base plate. A longer screw was to be inserted from the side of the stopper and to be plugged through the axel and to be screwed into the other side of the stopper. Thus, the whole upper base plate would turn as the axel turned.

3.2.4 Arm

For the second version, arms were added in order to make the robot more expressive through gesturing and pointing. This way, the robot would be more efficient as a better embodiment of the caller on the remote end. Along the same vane, it was also decided that the two arms would move independently.

The motion of the two arms was made possible by a belt-pulley system with the motor being fixed to a base plate and transferring the motion through a belt to the joint of the arm. Even though the pulley system would be slightly more expensive than a regular gear-driven system, it was still used in this situation because of its ability to move at a high speed with fluency and a low noise level, which would be very beneficial since the arms were expected to move at very high speed very frequently. Figure 15 shows the mechanism.

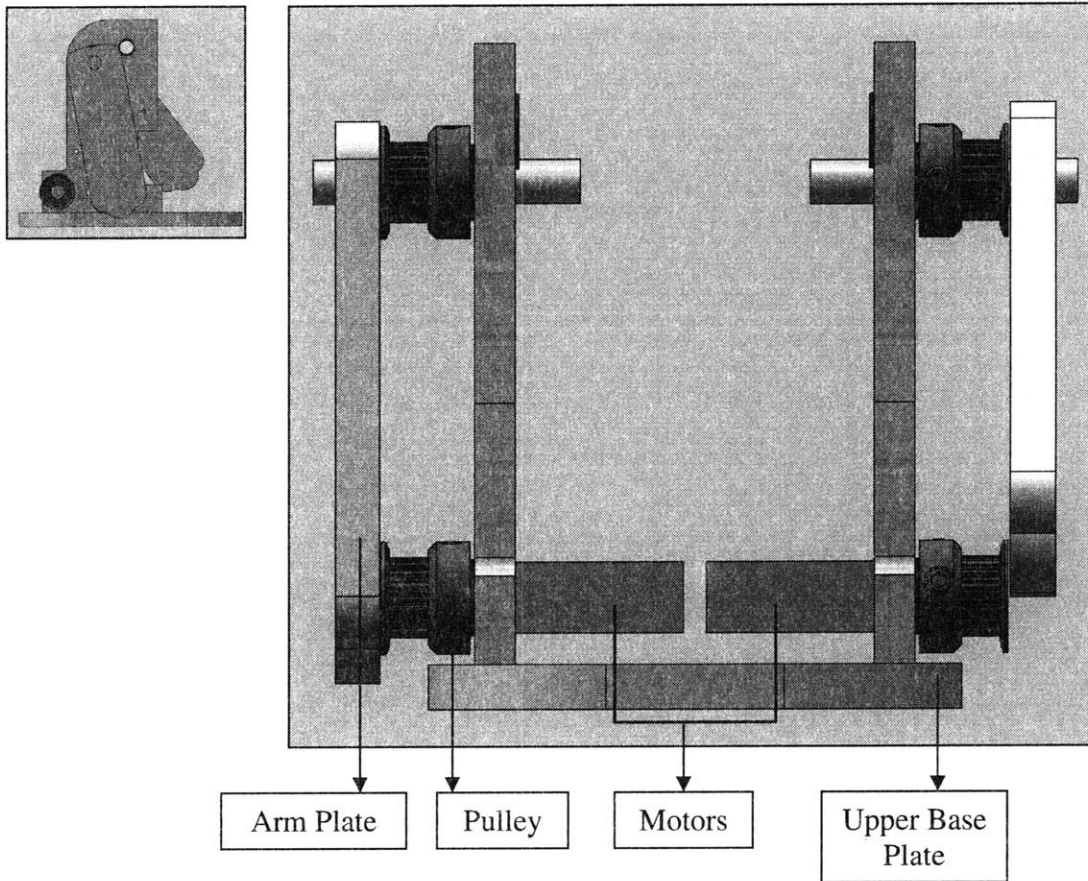


Figure 15 For each arm, there were two pulleys, one was an output from the motor and one was living and lowering the arm plate. The two pulleys for each arm were connected by a timing belt (not shown on the diagram).

In order to conserve space, there was no special supporting bearing plates built for the arm mechanism, and it was designed that the arm mechanism would be sharing the same bearing plate with the neck module.

3.2.5 MeBot v2.0

With the six degrees of freedom put together, the robot stood 8.5" tall, 1.5" wide and 4" deep, which was a slight improvement from the first version. The Mebot v2.0 would be more expressive than the first version due to the

added functionality of the arms. Also the added degree of upper body rotate would also provide the arm more range of motion while giving the whole robot a more natural movement. Figure 16 shows the MeBot v2.0 from different perspectives.

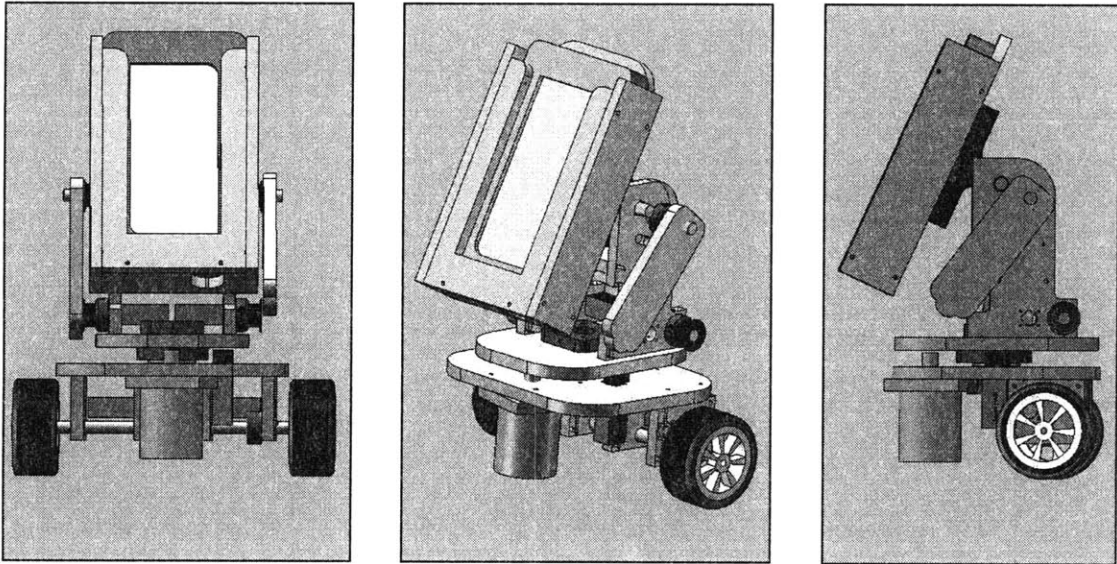


Figure 16 MeBot v2.0 was designed to have six degrees of freedom, two in the arms, one in the neck, one in the upper body and two in the wheels.

4. Conclusion and Future Works

After the testing of MeBot v1.0 and the preliminary design of MeBot v2.0, it was determined that the six degrees of freedom would afford the robot with ability to be express enough for now. All the modules were designed to be as compact as possible with direct driving method, and only one kind was motor was used for all degrees of freedom so to reduce the chance of complications in the circuit board. Four out of the six degrees of freedom were driven by gears, which also contributed to the compactness. The design requirement of being able to be mass produced was satisfied by using hobby components such as lower-cost motors and RC plastic wheel. With improvements implemented and design requirements satisfied, the design MeBot v2.0 is being built and tested.

In future versions, effort could be put into making the current design more robust and autonomous. As more and more degrees of freedom are added to the robot, controlling from the other end of the conversation would start to be challenging. In order to ensure ease of use, it should be also considered to build in more autonomy into the robot. Moreover, as a whole, the robot could enjoy lighter weight and smaller size through better designs of the custom made plates.

In detail, the following key improvements are suggested:

For More Robustness

1) Torsion Spring

It was found that keeping the phone at a certain tilted position for a long period of time was very straining on the motor. In order to assist the motor at keeping the phone at the position, it is suggested that a torsion spring be used to share the torque load from supporting the phone with the motor.

2) Redesign the bracket for strength

In the neck module, there are two brackets designed to transfer motion from the driving shaft to the phone and cradle. Currently, the brackets are connected to the shaft through the use of set screws. It was observed that the heavy load put on the junction tended to break the brackets. Thus, it is suggested that either brackets be made with material stronger than acrylic, such as delrin, or the brackets be re-designed to clamp on onto the shaft rather than just a press fit.

For More Autonomy

3) Navigation

With the current design and control system, the user would have to control the movement of the robot from the basic elements of forward, backward and turn. This becomes rather troublesome once more degrees of freedom are added and need to be controlled. Thus it would be better if an on-board navigation system consisted of sensors or cameras were added to the robot so that it could move to a certain point without detailed instructions from the user.

For More Compactness

4) Lighter elements

The current design employs all metal gears and plates designed only for functionalities, and it weighs over 1kg. In order to make it more of an accessory to cellular phones, the robot would need to be much lighter. Suggestions to solve this problem include using plastic gears in joints that don't take too much load and cut speed holes into the plates.

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