Electromechanical Whole-Body Rotator for Cats

University of Wisconsin – Madison
College of Engineering – Biomedical Engineering
BME 301
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Team Members:
Leah Brandon – President
Adam Budde –Communicator
Kieran Sweeney –BSAC
Yik Ning Wong –BWIG

Client:
Prof. Tom C.T. Yin
University of Wisconsin – Madison
Department of Physiology

Advisor:
Willis Tompkins, Ph.D.
University of Wisconsin – Madison
Department of Biomedical Engineering

Abstract

A control experiment is required in research regarding the possible stimulation of the vestibular system of cats when localizing sounds. This project will design and implement an electromechanical device for a behavioral experiment with cats that are actively localizing sound sources. The design will passively rotate the animal under computer control via a stepper motor.

§ 1. Problem Statement

This project seeks to design an electromechanical device that will rotate cats to designated angles under computer control. The rotator will be used in a sound localization experiment with cats in order to test the influence of a vestibular reflex on ear movement. Generally, as a cat tracks an audio source, its ears and head can move relative to one another to maintain a lock on the source. If this is due to a vestibular reflex then passive movement, to be provided by the rotator, will elicit such a response.

§ 2. Background Information

§ 2.1 Client Research

Dr. Tom C.T. Yin's research primarily seeks to determine the neural mechanisms behind binaural hearing, *e.g.* hearing with two ears, and specifically sound localization. Sound localization has obvious implications for most animals as it may alert them to nearby predators, prey, threats, and food.

Cats have acute hearing and a strong ability to track even minute sound sources. When responding to a sound they first flick their ears to the source and then, as the head moves, reorient their ears to remain locked on the sound source. The regulation of the relative velocities of the head and ears is currently being explored. Dr. Yin believes that this may be due to an audio-vestibular reflex.

The vestibular system is a part of the inner ear that detects motion. The semicircular canals detect angular acceleration on multiple planes and the otolith organs, the utricle and saccule, detect linear acceleration. It is already known-and easily demonstrated by nystagmus- that the vestibular system controls the direction that eyes will gaze especially when their target is moving relative to the head (Coulter *et al.,* 2005).

The vestibular system responds to any motion, not just that initiated by the cat. Therefore an external, passive rotation should trigger the vestibular system. If the ears respond to vestibular input then it would support Dr. Yin's hypothesis.

§ 2.2 Client's Lab Setup

The main experiment area of the client's lab is an electrical and sound proofed chamber (Figure 1). The chamber has a speaker array circling its periphery. Each of these speakers has an LED light for visual stimulation and the whole array is typically hidden behind a semi-transparent black cloth. The cat is placed in a bag, which is strapped onto a mountable box, and the box is placed on top of two large pegs in the room's center. From here the cat is monitored as it responds to the various sound sources. The cat receives a treat via a peristaltic pump if it correctly tracks a sound source (Tollin, *et. al*).

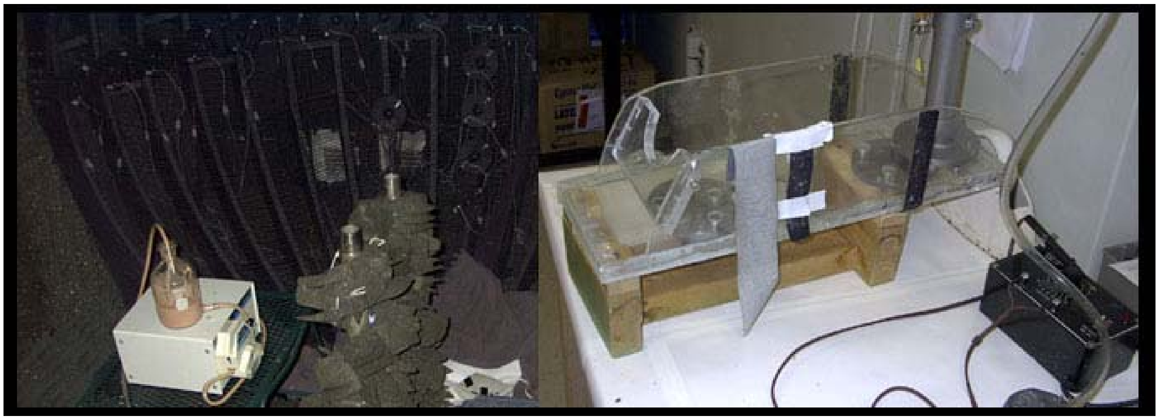


Figure 1: Left: The cat's box. Right: Photo of the testing chamber

The cat's ears and gaze are detected using a brilliant mix of physics. An electromagnetic field is generated and aimed towards the head of the cat. Wires are sutured into the eyeballs and attach to signal devices. When the eyes move there is a change in magnetic flux through the subcutaneous wires and, by Lenz's law, a current is generated in the wires. The current is then received and interpreted by computers. The head and ears can be tracked via cameras and specially marked reference points on the cat.

Faraday's/ Lenz's Law

$$\mathbf{EMF= -N \frac{d\Phi}{dt}}$$

This team must ensure any new implementations to the lab do not interfere with current lab components. This will maintain consistency with current results and avoid future inaccuracies.

§ 2.3 Stepper Motors

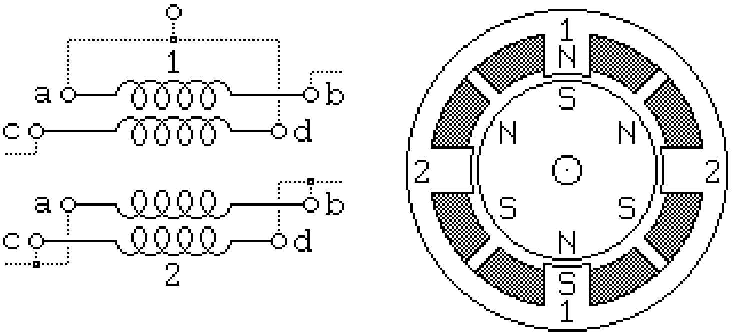
According to client request, a stepper motor should be the source of rotation of the device. This modified electric motor can make incremental angular steps according to an electrical input signal it receives. This allows for precise control that can be easily logged for experimental purposes by knowing the input signal.

Physically, a stepper motor functions much the same way as a normal electric motor. However, a stepper motor lacks a commutator, a circuit setup attached to the rotating axle that regulates current and accordingly magnetic field direction. Instead, a stepper motor has a magnetic axle with definite poles. Commutation is handled externally and under the control of the input signal. Wires coiled into toroids are placed at points surrounding the magnetic axle and current flows through the coils. The current produces a magnetic field by the relationship described in Ampere's law and Biot Savart's law. The reverse of this relationship can be seen in Lenz's and Faraday's law. (Jones)

Ampere's Law

$$\oint_S \mathbf{B} \cdot d\mathbf{s} = \mu_0 I_{\text{enc}}$$

The magnetic field produced can push and pull the poled axle into the desired position. The direction of current flow will determine the magnetic field direction, essentially whether it acts as a north or a south pole. By varying this current one can cause the axle to rotate (Brain). This is made even more efficient by having arrays of coiled wires surrounding the axle, their effects being pulsed and varied through time.



Such a setup is illustrated in the following picture (Figure 2).

Figure 2: A Bifilar Stepper Motor setup

Control of a stepper motor can be very precise since commutation is under the direct control of the input signals. The axel spins incrementally from pole to pole, which makes precision proportional to the number of poles which the motor has. An added benefit of stepper motors is that techniques such as microstepping can stop the spinning midstep, adding resolution and smoothing out the motion. Common step sizes are 1.8 degrees, 3.6 degrees, and generally angles that sum to 360 degrees (Jones). Motor controllers can be integrated or separate from the motor and will interface with computers like those in the client's lab.   Also, the use of a stepper motor should not greatly affect the magnetic field in the experimental setup (Lee).

§3. Design Constraints

The Electromechanical Whole-Body Rotator will be designed for holding and rotating the cats under computer control. Since the experiments are performed in a magnetic field, minimal use of metal and electricity is required to minimize the electromagnetic interference. Non-metal or diamagnetic materials are preferred to minimize disruption inside the magnetic field.

The rotation of the cats will be controlled by computer thus the rotator must be able to integrate into the client's existing computer program. The box being rotated should be light, easily sterilized and strong enough to withstand repeated trials

For the operation of the rotator, the center of rotation must be about the center of the cat's head. The position of the cat's head can deviate, at most, 20cm from the center of the magnetic field to ensure linearity in experiments. A maximum of 90 degrees rotation, 45 degrees to the left or right of the initial position of the cat, in the horizontal direction is required. The speed of rotation must be less than 3-4 hertz.

The rotator should minimize noise in order to avoid distraction to cat during the experiments. Also, the design must be able to integrate two existing pegs as support and be able to move the weight of cat (2-3kg). The design should also be able to endure repeated use, around 100 trials per day, during the work day.

Compliance with the standards from the Institutional Review Board (IRB) and the Institutional Animal Care and Use Committee (IACUC) is required.

Additional design constraints are in the Product Design Specification (Appendix B).

§4. Competing Designs

A literature search of competing designs and motors shows that there are currently no similar systems. However several forms of computerized rotational systems exist. Many are hand-built systems using stepper motors in conjunction with telescopes. Others include rotational systems for antennas from companies such as Antenna Products, United States Antenna Products, and R.A.Mayes. U.S. patents for computerized rotational systems and similar products include patent numbers 6,976,821; 6,023,247; 5,671,648; and 4,920,350. The products previously mentioned do not directly compete with this project because the use of the rotational system differs and the integration of a containment box is not seen in any design.

§5. Alternative Designs

Two design alternatives will be discussed in detail with their advantages and disadvantages addressed. These are the pneumatic mechanism design, and the direct drive design. Our final design, the belt drive design, will be discussed in detail in section §6. The use of a design matrix (see Appendix B) compares the differences in each design with respect to categories such as control, amount of electromagnetic interference, safety, speed, implementation and cost.

§5.1 Pneumatic Powered Rotator

Description

The first design is the pneumatic powered rotator (Figure 3). A pneumatic pressure pump is used as the main component to rotate the platform. In order to obtain 90° of rotation, two plastic air pipes are attached to the left and right from the initial position of the cat. Each air pipe controls 45° of rotation. Mechanical arms which are made of plastic are attached to the pipes for providing force to rotate the platform. Wheels are added to the bottom of the platform to facilitate mobility.

Figure 3: Schematic of a possible set-up using pneumatic pump.

Advantages

The advantages of the pneumatic powered rotator design are that no metal or magnetic materials are used so there will be no electromagnetic interference inside the magnetic field. In addition, a pressure generator can be easily computerized so our client can control the rotation of the platform. Flexible air pipes are also used and be easily adapted to the experimental environment.

Disadvantages

The disadvantages of the design include the amount of noise from the pneumatic pump and mechanical arms that may distract the cats from performing the experiment. The pressure generator is also space consuming and there is not enough space to install the mechanical arm and air pipes under the cat-containing box. In addition, since the mechanical arms are made of plastic, the strength needs to be tested to see if the arms are strong enough to rotate the platform.

§5.2 Direct Drive Rotator

Description

The direct drive design (Figure 4 and 5) uses a stepper motor as its source of torque. The stepper motor is placed directly underneath the client defined point of rotation. The front end of the cat box is then connected to the stepper motor. The rear of the cat box rests on a platform via a ball pivot which will allow for smooth rotation of the device. Since the motor is place directly under the pivot point, the removal of a

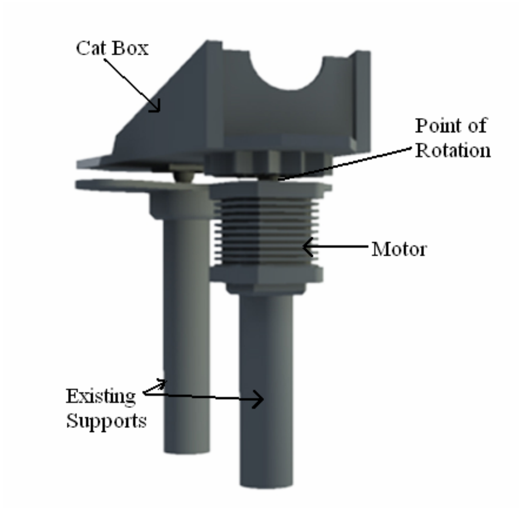


Figure 4: Front view of direct drive design

portion of the existing support pegs would be required.

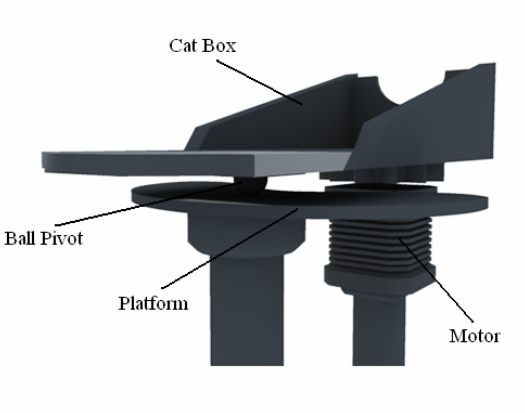


Figure 5: Back view of direct drive design

Advantages

Placing the stepper motor directly underneath the desired point of rotation allows increased accuracy, control, and response time. This design also decreases the amount of additional elevation which will decrease deviation of the cat's head from the center of the magnetic field.

Disadvantages

Installation of this device may become more problematic than desired. Since the motor is placed directly under the point of rotation, the current support peg that is directly under the front of the cat box will need to be shortened. This may not be ideal since the client has previously had difficulty installing the pegs. Also, shortening the front peg may inhibit future experimental designs.

The amount of noise and vibrations, that may be distracting to the subject, should also be a concern with this design. Again, since the motor is placed directly under the cat box, more noise and vibrations from the movements of the motor will be experienced by the cat than if the motor is placed at a distance.

Electromagnetic interference may also be an issue. Placing the motor inside the magnetic field increases the amount of metal in the field and may result in skewed data. Also, the stepper motor operates by creating a small magnetic field within itself.

§6 The Belt Driven Rotator

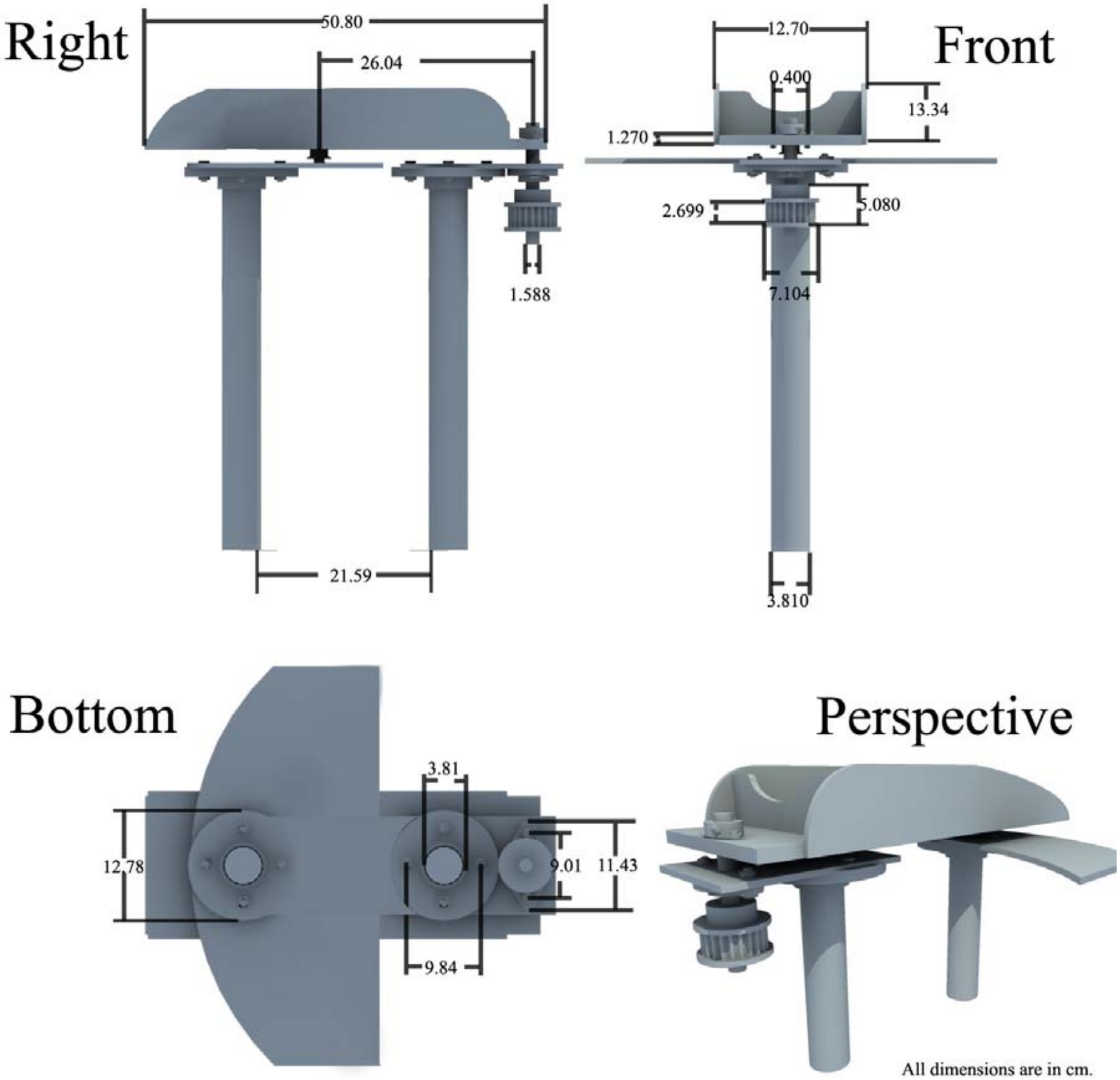
Description

Our final design, a belt driven rotator, operates under much the same concept as the second design, with the major distinction of moving the stepper motor from underneath the experimental box to outside of the electromagnetic field. A picture of this design can be seen in Figure 6.

Figure 6. A computer generated image of the Belt Driven Rotator design, which rotates the experimental box, through a chain or belt, by a stepper motor which is placed outside of the electromagnetic field.

Under this design, the experimental box is entirely supported by a single shaft that will be attached rigidly to the bottom of the experimental box, underneath the center of the feline's head. This will ensure that the cat's head is the center of rotation. The back end of the experimental box moves via two ball transfers. This allows the back end of the box to move unopposed along the platform during rotation.

The shaft is attached via a bearing to the mounting plate that will be attached to the two pegs in the current experimental setup. On the shaft there is drive pulley which is connected by a timer belt to another drive pulley on the stepper motor. The stepper motor will be rigidly attached to the wall of the experimental setup.



All dimensions are in cm.

Figure 7: A computer generated scale model of the belt driven motor.

Design Materials

The first step in the design process was to construct an experimental box. It needed to be made out of a material that is lightweight, easily sterilized, and strong enough to withstand the high rotational acceleration we will impose on it. The current box is made out of Lucite and has a very high moment of inertia, which we wished to minimize in the new box to maximize angular acceleration. Because of this, the new box is made out of ultra-high molecular weight polyethylene (UHMW). UHMW is lightweight, easy to sterilize, has excellent wear properties, a high tensile strength and so was a good fit. The new box was built with the same dimensions as the original box, to ensure experimental uniformity.

Upon completion of the box, parts were chosen that would connect it to our stepper motor. When choosing these parts, our goals were to minimize noise produced, moment of inertia, and metal inside the chamber while at the same time maximizing rotational control and ease of sterilization. The belting selected was a good example of this. We chose an H series timing belt, which allowed for quieter operation while maintaining experimental control, compared to other belts. The belt is made out of urethane, which runs more quietly than rubber belts and is FDA compliant.

Torque

Once all of the parts were chosen, the moment of inertia for all of the parts about the center of rotation was calculated to be 8.84 N-m. This calculation was performed from measurements and weights of the materials, using basic moment of inertia formulas, and then the application of the parallel axis theorem. Since our parts were not available yet, we could not measure moment of inertia directly, and so this calculation allowed us to choose a suitable torque on our stepper motor.

The Motor

The stepper motor we choose, which includes a built-in controller, produces up to 22.6 N-m of torque. The motor is from Excitron , model number FTFc15-110-150. We chose a motor with a torque that was over twice as large as the calculated need because a stepper motor can be programmed to produce less torque, but not more. This ensures that the motor would be functional even if there were changes to the experimental design.

Integrating the control of the stepper motor into the experimental set-up is being left to Prof. Yin's programmer, as per his instructions. The programmer was contacted to guarantee that the stepper motor could be integrated into the experimental control before was purchased.

Mounting System

To mount the stepper motor, a wooden shelf was purchased from Home Depot. It will be attached to the diagonal supports that are present in the experimental chamber behind the foam padding of the walls. So that there was control over the amount of tension on the belt, slots were machined into the shelf so that the stepper motor itself can be moved in the direction of the belt when its bolts are loosened. In addition to tension control, this also allows for the initial placement of the belt and for its easy removal.

The shelf will be the only difficult portion of our design to install into the experimental chamber, due to the required removal of some acoustic foam and mounting of the brackets to hold the shelf. The rest of our design will simply slide onto the current pegs mounted on the floor of the chamber. This will allow our design to be installed and removed fairly quickly by Prof. Yin's lab.

Advantages

The biggest advantage to this design is that it places all electrical and magnetic components outside of the experimental magnetic field, which minimizes interference. Since this design includes a stepper motor, it will be very accurate, and so experimental fidelity should be maintained.

The stepper motor, in addition, can be integrated into the current experimental control without excessive changes. Another feature of this design is that by varying the size of the belt wheels, any gearing ratio can be used. This expands the range of possible steps that can be taken from the standard 3.6 and 1.8 degrees of stepper motors, to anything that would fit the experimenter's wishes.

A previous concern with this design was the possibility of the mounting plate raising the height of the cat which would distort linearity. This is no longer a concern since the mounting plate adds significantly less than 10cm to the height of the cat's head.

Disadvantages

As with the Direct Drive Rotator design, disadvantages of using a stepper motor remain. Even though the motor may be outside of the magnetic field producing box, it is still within the chamber and may introduce some amount of electromagnetic interference. This interference should be small, however. Also, when operating, the box will produce noise, which could interfere with the feline's especially sensitive hearing. In one of the few instances when it is easier to work with live animals, this problem should be avoidable through training of the felines to ignore the motor noise and treat it as 'white noise'.

§ 7. Cost Analysis

The materials used in construction of the design and their cost are summarized in Table A. The costs described in table A do not include shipping costs. Since the design team was not directly in charge of ordering parts, shipping costs were not available for this report.

All materials were obtained from McMaster Carr and Home Depot with the exception of the stepper motor which was purchased from Excitron.

Table A: List of Materials and Costs

Serial Number	Description	Cost (per unit)	Quantity
8752K213	UHMW sheet-1/4 x 24 x 12 in.	$12.78	1
8752K215	UHMW sheet-1/2 x 24 x 12 in.	$21.88	2
95000A247	Nylon screws	$5.85	1
6460K21	Ball mount transfer	$5.80	1
4881K216	PVC pipe fittings	$7.48	2
62645K39	Rigid shaft support	$19.36	1
6253K55	5/8” Stainless steel shaft	$11.74	1
6357K34	Flange mount ball bearing	$31.49	1
6495K44	Timing belt pulley-2.97” diameter	$33.08	1
6495K47	Timing belt pulley-4.01” diameter	$48.19	1
1840K6	Belting	$6.09/ft	10 ft.
2553K92	End plate	$48.75	1
8992K411	Stainless steel plate	$17.38	1
590796	Lock washer	$0.10	4
655414	Hex nut	$0.04	4
077355004922	11’’ Bracket	$4.97	2
718793152478	Wood Shelf 3/4 x 12 x 24in	$3.57	1
AME	HBLT 3/8 x 11/2	$0.18	2
ADC	HBLT 1/4 x 1	$0.09	4
ABV	HBLT 1/2 x 11/2	$0.40	8
655465	Hexnutuss 1/2	$0.14	1
030699267019	Screws(packs of 4)	$0.98	4
FTFc15-110-150	Stepper Motor and Controller	$529.00	1
6460K11	Nylon ball transfer	$10.70	2
	Total Cost	$926.49	

Since no specific monetary budget was placed on the design, parts were chosen based upon their ability to suit the needs of the design. Price was considered after several options of suitable materials were comprised. In no case was a design component chosen for low cost unless it met all the requirements the team desired from the component.

§ 8. Ethics

The Electromechanical Whole-Body Rotator is designed and constructed with full consideration for the safety and well-being of the cats which are performing the experiment. Care was taken to ensure that any failure of the system would not result in harm to the cats.

In addition, the comfort of the cats should be ensured. For example, the box should not be rotating too fast and the experimental box should be spacious for the cats.

The standards from the Institutional Review Board (IRB) and the Institutional Animal Care and Use Committee (IACUC) should be followed.

§9. Future Work

In order to make the rotator design complete and functional, there is some additional work which must be completed. Further testing for using the rotator in practical environment should be done before actual conduction of experiments.

After constructing the experimental box, it will be fit on the pegs in the experimental room. It will then be connected to the mounting system for the stepper motor on the wall and a timing belt will be attaching the motor to the experimental box.

Once this is set up, the rotating system, through the integrated stepper motor and controller, will be integrated in the existing computer in lab by the software programmer.

Practical use of the design is needed to be use by the client for ensuring the functioning of the design.

§10. Conclusion

The belt driven design adheres to the client requirements. The choice of stepper motor and driver should provide the desired experimental controls such as speed of rotation and accuracy. The design places the motor outside of the magnetic field and should therefore interfere minimally.

Also, considerable time was put in to ensuring the safety and accuracy of the design. This ensures uniformity of previous experiments with those to be done with the new equipment, and maintains and safe and healthy environment for the test subjects.

The design team will install the rotator system in the Dr. Yin’s lab. However, since this team is not versed in programming, integration of the design to the current computer system will be completed by the programmer in Dr. Yin’s lab.

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Appendix A

Design Matrix

Category	Pneumatic Mechanism	Direct Rotation	Belt Driven Rotation
Control/Accuracy (10)	7	10	9
EM Interference (10)	10	7	9
Safety (10)	6	8	8
Speed/Response (8)	6	8	7
Range of Motion (8)	4	8	8
Feasibility/ Practicality (6)	2	3	6
Cost (5)	2	5	4
Total	**37**	**49**	**51**

A design matrix proves useful in determining the most effective design proposal. The matrix is weighted according to the design constraints and the desires of the client and scored. A higher score indicates that the design meets the specific characteristic better. The most important constraints that of maintaining experimental accuracy through accurate control and minimization of electromagnetic interference and safety, were scored on a scale out of 10. Speed and range of motion were scored out of 8, as they were also integral to the design. Implementation and cost were scored out of 6 and 5, respectively, as they were the lesser important considerations of our design.

Appendix B

Electromechanical Whole-Body Rotator for Cats:
Project Design Specification (PDS)

Team Members: Leah Brandon, Adam Budde, Kieran Sweeney,
Yik Ning Wong (Jacqueline)
Client: Professor Tom C.T. Yin

Last updated: 4/28/06

Function:

This project will design and implement an electromechanical device for a behavioral experiment with cats that are actively localizing sound sources. We need a control experiment in which the cat is passively rotated under computer control (rather than actively moving its head) to see if the same reflex is elicited by stimulation of the vestibular system.

Client Requirements:

The client requires the design to:

- Center of rotation must be about the center of the cat's head.
- Maximum 90 degrees rotation in the horizontal direction
- Minimize electromagnetic interference inside magnetic field
  - Metal use
  - Electricity
  - Competing magnetic fields
- Speed of rotation less than 3-4 hertz
- Minimize noise and vibrations
- Design must integrate two existing pegs as support
- Motor must be computer controlled (stepper motor)
- Allow integration into existing computer program
- Be able to move weight of cat (2-3kg)

1. Physical and Operational Characteristics

a. *Performance requirements*: The design must endure repeated use during the work day. Experiments include approximately 100 trials per day and possibly over several months. Loading on the design will vary with the weight of the cat; generally 2-3kg.

b. *Safety*: There should not be any exposed wires or sharp edges that may pose health risks to the cats. Also, amount of control and rotational speed of the motor should be adequate enough to prevent unnecessary distress to the subject.

c. *Accuracy and Reliability*: Position of the cats head can deviate ~ 20cm from the center of the magnetic field to ensure linearity in experiments. Rotation of the cat cannot exceed 45 degrees to the left or right of the initial (centered) position of the cat.

d. *Life in Service*: See performance requirements.

e. *Shelf Life*: Device should be operable over several years.

f. *Operating Environment*: Operation of the device may occur directly in a magnetic field. The design should be away from sensors and disrupt the magnetic field as little as possible

g. *Ergonomics:* Design should facilitate experiment preparation including cat placement and removal. The device should not cause any unnecessary discomfort to the cats including rotational speeds not exceeding 3-4 hertz.

h. *Size*: No definite size requirements exist for the motor setup; though it should not take up an excessive amount of space nor deviate the cats head more that 20cm from the center of the magnetic field. Cat box size requirements assuming current support peg height of 75cm are as follows:

- 50.5 x 17.5 cm x 12.7cm
- Base elevation ≤ 2.5cm
- Empty rear space ~ 12.7cm
- Velcro spaced 12.7cm from back and 12.4cm apart

i. *Weight:* Optimal weight should be less than the current weight of the box (approx. 15lbs.)

j. *Materials:* Non-metal or diamagnetic materials are preferred to minimize disruption inside the magnetic field. Outside the magnetic field may allow for more metal components.

k. *Aesthetics, Appearance, and Finish*: Secondary to safety and functionality.

2. Production Characteristics

a. *Quantity*: Only one unit is required for the experiments.

b. *Target Product Cost*: Funded by research grants, any reasonable cost is acceptable.

3. Miscellaneous

a. *Standards and Specifications:* This project must adhere to all relevant animal testing protocol as stated by the IRB and the IACUC.

b. *Customer*: The current weight of the cat box is a concern. It would be optimal to reduce the overall weight of the finished box.

c. *Patient-related concerns*: Components of the design in direct contact with the cats should allow of easy clean-up and maintenance.

d. C*ompetition*: U.S. patents for computerized rotational systems and similar products include patent numbers 6,976,821; 6,023,247; 5,671,648; and 4,920,350. The products previously mentioned do not directly compete with this project because the use of the rotational system differs and the integration of a containment box is not seen in any design.