Electromechanical Whole-Body Rotator for Cats

University of Wisconsin – Madison
College of Engineering – Biomedical Engineering
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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. 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 it 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 evidenced 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, the bag 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*)

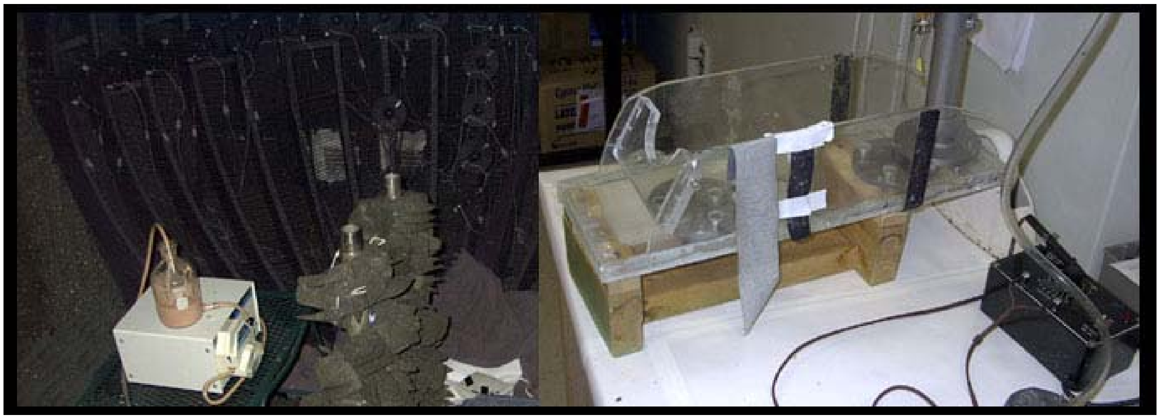

Figure 1: Left: The cat's box. Right: Photo of the testing chamber

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.

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

Faraday's/ Lenz's Law

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 Motor Information.

According to the client's request a stepper motor should be the means 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)

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

Ampere's Law

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 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).

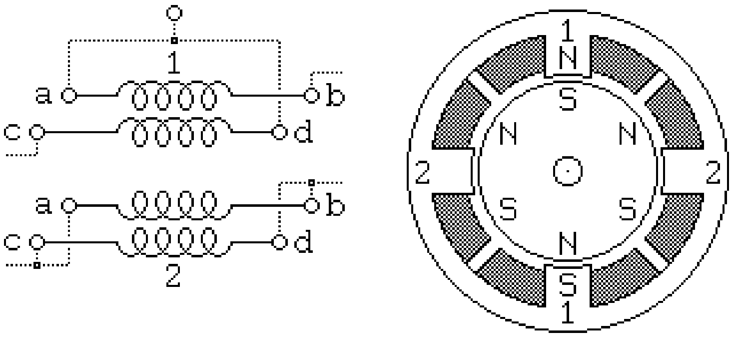

Figure 2: A Bifilar Stepper Motor setup (Jones).

Control of a stepper motor can be very precise since commutation is under the direct control of the input signals. The axel can spin incrementally from pole to pole. This implies that the precision is proportional to the number of poles which the motor has. This is true, but techniques such as microstepping can stop 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 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.

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 pre-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

Three design alternatives will be discussed in detail. These are the pneumatic powered rotator, the direct drive design, and the belt drive design. Also, advantages and disadvantages for each of these are addressed. 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 portion of the existing support pegs is required.

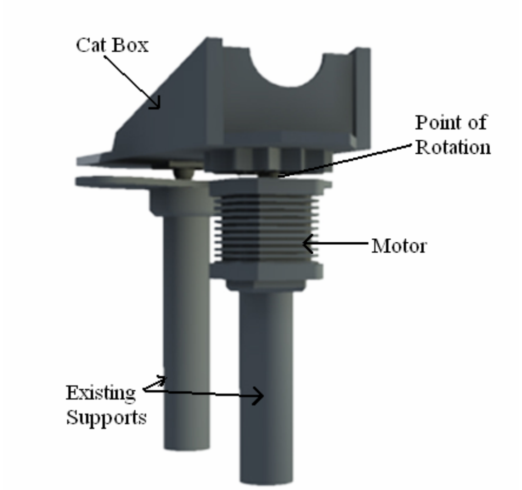

Figure 4: Front view of direct drive design

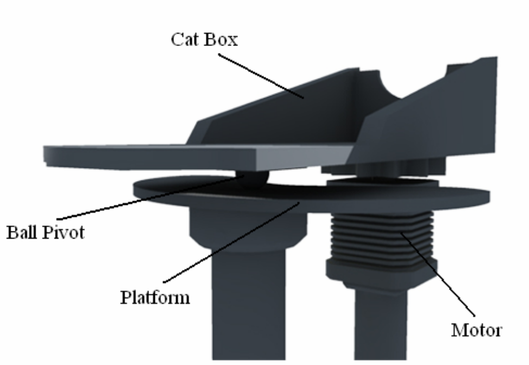

Figure 5: Back view of direct drive design

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. The extent to which this will affect the existing magnetic field is unknown.

§5.3 The Belt Driven Rotator

Description

Our third design option, 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 Design 3, 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 rod 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 center of rotation is the cats head. This rod will be attached, using a bearing, to mounting plate that will attach to the two pegs that are part of the current experimental setup. On the rod there will be a wheel which is connected by either the chain or belt to the stepper motor. The stepper motor will be rigidly attached to the wall of the experimental setup.

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.

As in Design 2, the stepper motor 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.

Disadvantages

This design does introduce several difficulties. First is the fact that the mounting plate will raise the height of the cat. This must be kept to a minimum, as the position data from the cat's head is only guaranteed to be linear if it is within 10 cm of the center of the experimental setup. Concern must be shown, but it should be possible to design a mounting plate that is sufficiently thin. Also, a suitable belt or chain must be found for the design to work as intended. It should contain minimal metal and yet be strong enough to accurately rotate the box. It must stretch very minimally, as any stretch would result in an overshoot and snap back of the experimental box upon completion of the rotation of the stepper motor. This effect would lead to a decrease in experimental accuracy, and so is very important to minimize.

As with Design 2, 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 so 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.

§6. Design Matrix

A design matrix, as seen in Appendix A, 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.

Upon evaluation of the design matrix, the chain drive design idea emerges as the highest scorer and best option for us to pursue. This design does well in all design constraints, with no large drawbacks. The matrix reflects this, as the chain drive won because it scored very evenly on all constraints.

§7. Potential Problems

Outside of the design constraints, there remain many large hurdles before this project can be successfully implemented. First, an experimental box must be constructed to hold the cats in our design. The box will need 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. Currently, there is a box, but it is made out of Lucite and is very heavy, which would tax the motor that we purchase.

A suitable belt or chain is also required for the design to work as intended. It must contain minimal metal and yet be strong enough to accurately rotate the box. It must stretch very minimally, as any stretch would result in an overshoot and snap back of the experimental box upon completion of the rotation of the stepper motor. This effect would lead to a decrease in experimental accuracy.

Also to be solved is the problem of integrating the stepper motor into the current experimental control system. The lab had an external expert programmer to design the computer system, and so this step may be too complex for this group's limited programming experience. In order to solve this problem, way may be able to contact the programmer directly, and receive their input on the proper method of installing this new addition into the experimental setup.

§8. Future Work

The first step for us in completing this design will be to build and complete an experimental box. As discussed earlier, it needs to be lightweight, easily sterilized, and strong enough to withstand a high rotational acceleration. When this portion of the design is finalized, a proper stepper motor can be chosen and purchased. Significant research has already been completed regarding individual stepper motors, but a decision must be finalized.

Specifications then need to be created and a design made for all other material components of the design. This is an extensive list that includes a mounting system for the stepper motor on the wall, the mounting plate that will attach the experimental box to the pegs, and the belt or chain and its attachment to the motor and box. After this, all materials related to the design need to be bought. These items will need to be prepared as thoroughly as possible, so that their installation will be quick and will not interfere with the current experiments being conducted at the laboratory.

While these material designs are being completed, integration of the stepper motor into the experiment will have to occur. To accomplish this, we will have to research and buy a proper driver for the stepper that will operate within the current laboratory system. All of these steps will require extensive time and effort, and so progress must be made on strict timetable in order to implement this design before the end of the semester.

§9. References

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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**

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: 2/26/06

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.