ECE445

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Project Proposal

Automated Cat Laser Tower

Team #11
Elisabeth Tricou, Nour Sarikaya, Victor Liu
TA: Jialiang Zhang

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1 Introduction

1.1 Problem

Cat owners are sometimes busy or out of the house, and cats need stimulation. An automatic laser toy that interacts with them and reacts to them would be a useful way to keep them active and mentally stimulated in a safe and healthy way.

The automatic cat laser toys on the market don't really react to the cat, they just have pre-programmed or even random paths to follow. This results in a The area the laser dot occupies is limited by their motors, which results in either a small area for the cat and laser to be active in if the toy is placed on the ground, or they run the risk of leading cats onto furniture or into the wall if placed higher (say, on a table or shelf). A laser toy that can cover a larger area and map out the area to avoid furniture, as well as react to the motion of a cat would be much more effective at keeping a cat interested and active during times when the cat owner is not available.

1.2 Solution

Our solution is to create a cat laser toy that can use LiDAR to map out an area, designated by the cat owner, for furniture and to determine the space in which it can move. Mounting the toy on a cat scratching post allows for a larger range of choice for the cat owner to choose, and allows for a clever way for the cat to activate the laser themselves, via a pressure sensor, rather than merely wait on random activation. A motion sensor angled at the detection area will allow for the microcontroller to select different laser paths and speeds when the cat 'pounces' on the laser, and even 'catch' it.

1.2.1 Visual Aid

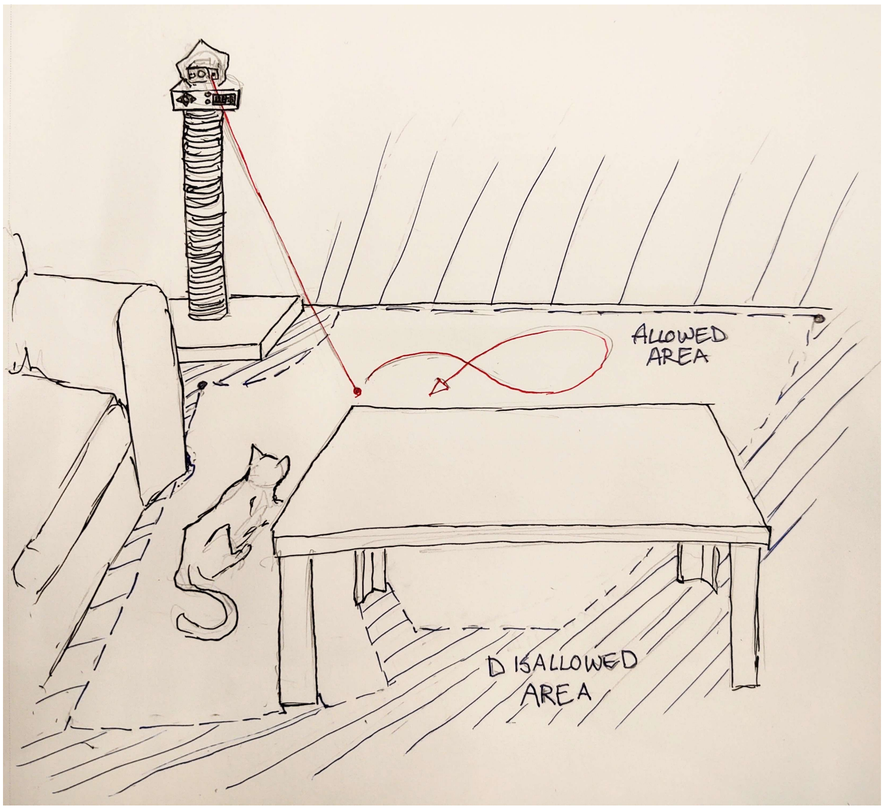

Figure 1: Automated Cat Laser Tower

1.3 High-Level Requirements

- The system's default state should be in low power mode until the pressure sensor triggers or random intervals during the time frame indicated during user set up; or via buttons on the user interface.
- The system should be able to create an area map on startup and once the area map is created, the laser module's range will be within the created area.
- The system should be able to detect fast motion and once detected, the control module should respond quickly by changing its pathing algorithm.

2 Design

2.1 Block Diagram

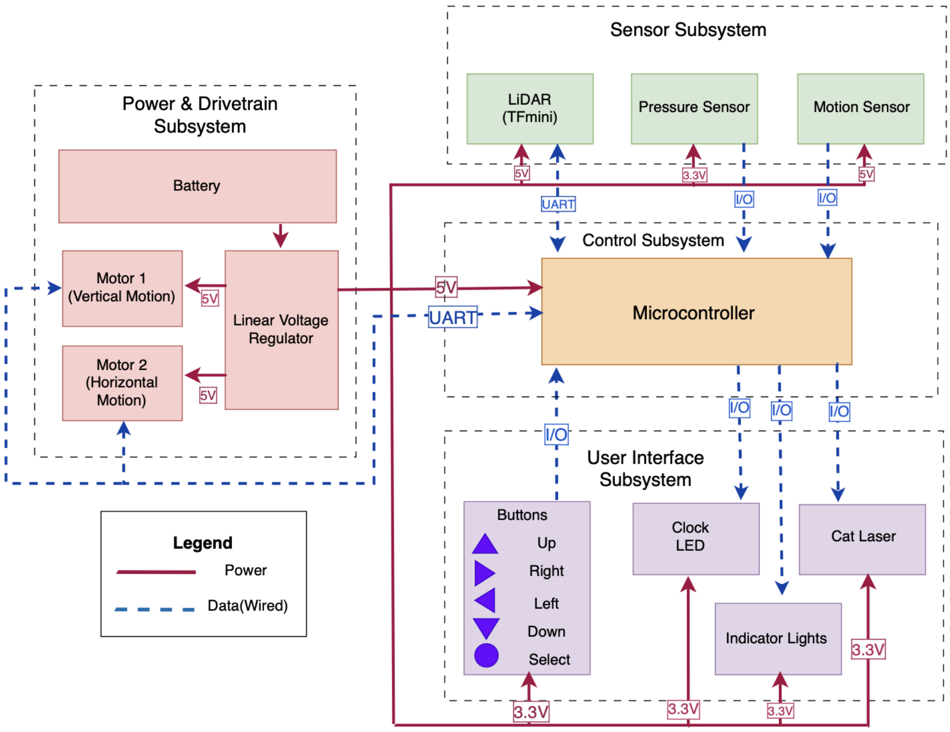

Figure 2: Project Block Diagram

2.2 Subsystem Overview

2.2.1 Power and Drive Train Subsystem

This distributes power to each of the Sensor, Control, and User Interface subsystems, and uses data from the Control Subsystem and pulse width modulation (PWM) to control the speed and direction of the motors and direct or divert power from the other Subsystems.

2.2.2 Sensor Subsystem

This subsystem includes the TFMini-S LiDAR module [1], which is used to map out a designated area for furniture; pressure sensors [2], which are wound around the scratching post so as the cat can turn the cat laser on and off; and a motion sensor, which allows the programming to react to the cat pouncing on the laser dot. These sensors send data to the Control Subsystem during their active cycles, and receive power from the electronic speed controller in the Power and Drive Train module.

2.2.3 Control Subsystem

The control system consists of an Arduino device, which power from the Electronic Speed Control modulation device in the Power and Drivetrain Subsystem and receives data from the Sensor and User Interface subsystems. It then uses this data and its programming to determine output, and sends data to the Sensor Subsystem, the User Interface Subsystem, and the Power and Drivetrain Subsystem.

2.2.4 User Interface Subsystem

The User Interface Subsystem is the vector by which the end user interacts with the system during calibration. It also includes the cat laser as an output, a digital clock system screen and LEDs to broadcast the state of the device while in operation. Four direction buttons are included for user navigation, and a 'confirm' button to confirm selections. The User Interface receives power from the Power and Drive Train Subsystem and sends and receives data from the Control Subsystem.

2.3 Subsystem Requirements

2.3.1 Power and Drive Train Subsystem

This subsystem's purpose is to point the LiDAR and cat laser, and distribute power to the rest of the system. Without this subsystem, we could not ensure the device could run for an extended period of time, and the 'play area' could not be mapped due to a lack of ability to move the LiDAR for scanning purposes.

The battery will need to be 12V, with 3000 mAh. This will be brought down to 5V and a 3.3 V using linear regulators. In total, this battery can provide 36 Wh of power, which combined with our average power consumption of 200 mA, provides roughly one week of power.

The motors which drive the robotic arm needs to be able to move to a designated position while sending data to our control system of its position. This is needed to map the area, and the motors must have precision to ensure we can properly map the area. We are planning on using Dynamixel XL-330-M288-T motors [3], which have position feedback and a position mode to direct the motors.

Our power system needs to have an idling mode as to be able to save power during operation. This idling mode should be using less current throughout the entire system compared to in active mode, verifiable by using an ammeter.

2.3.2 Sensor Subsystem

The sensor subsytem takes in data from the LiDAR, PIR motion sensors, and the pressure sensors and feeds it to the control system. Without the Sensor subsystem, the device would not be able to react to its environment.

The LiDAR is to primarily allow for mapping of furniture while the device is in calibration, and must provide accurate distance measurement within 5 meters and detect objects that are at least a foot wide. This is so we can be sure to locate any surfaces of furniture, even if we might not be able to detect table and chair legs.

The PIR motion detector is to allow for indicating whether or not there is activity near to the pointed location of the laser within 5 meters. It needs to be able to detect motion at cat height.

Ideally, it should not detect motion outside of 6m, which we hope to achieve by positioning the lidar so that it points at the mapped area. The performance of the LiDAR and the motion detection systems can be verified with independent testing.

The pressure sensors, which are pressure controlled resistors, are to be mounted on the tower itself, and would inform the Control Subsystem to exit low power consumption mode when activated. The exact characteristics of the pressure sensor are controlled by resistors and will have to be adjusted to account for rope being wrapped around them in actual operation to perform optimally.

2.3.3 Control Subsystem

The control system ties the entirety of the system together. It takes data from the sensors and motors and user interface input, and interprets them via software programming to then direct the motors, and the laser and LiDAR.

The microprocessor needs to be capable of communicating over UART serial protocols and have . There needs to be space to store 650 bytes in the EEPROM for the boolean map, and then space for the clock times. It also needs a minimum of 22 I/O pins for all proposed motors, sensors, inputs and outputs.

2.3.4 User Interface Subsystem

This user interface subsystem allows the user to set the time for the device as so to enter in times in which the device would activate during the day to the Microcontroller. Without the user interface, the end user would not be able to set up the device.

The 4 arrow keys and the confirm button setup would allow the user to set the limits of the furniture mapping so as to be within wanted parameters (IE only a certain part of a room). This also allows the user to input the current time, and the timeframe they want the device to be active in. The LEDs would provide information to the user to inform them on the current state of the Cat Laser Tower and what data they need to input next. Since it's important to process user input and display current state information, the user interface must be responsive ideally with a lag of under 100ms.

The cat laser pointer is also a part of the UI subsystem and we need to make sure that it is petsafe. The power used by the pointer must be lower than 5mW.

2.4 Tolerance Analysis

2.4.1 Data Storage

The system needs to map an area with a radius of, at maximum 5m, and we are limiting it's horizontal rotation to 180°. We are limiting our points to measure to ever 10 cm. Putting this in a matrix, we have a 10m x 5m, or a total of 5000 points to put into a boolean map. The standard bool is 1 byte, so we would need 5k SRAM and EEPROM to ensure data storage or manipulation of the boolean map alone. If we compress the data into one bit per bool, we can put the array into 625 bytes, or 650 bytes in practice. Our proposed microcontroller has 2k SRAM and 1k EEPROM, so this fits the data requirements.

2.4.2 Distance Calculation Error

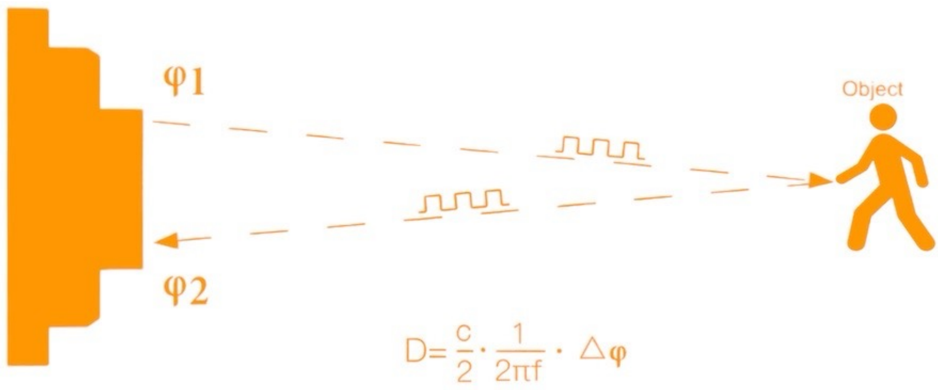

Figure 3: Schematics of Time of Flight Principle

LiDAR detects objects and measures distances by obtaining the time of flight by measuring round-trip phase difference and then calculating relative range between itself and the detection object.

The LiDAR module we have chosen for this project, TFmini-S, has an operating range from 0.1 meters to 12 meters. The accuracy of the LiDAR varies depending on the distance and it's accurate to ±6 cm within 6 meters and ±1 cm within 12 meters.

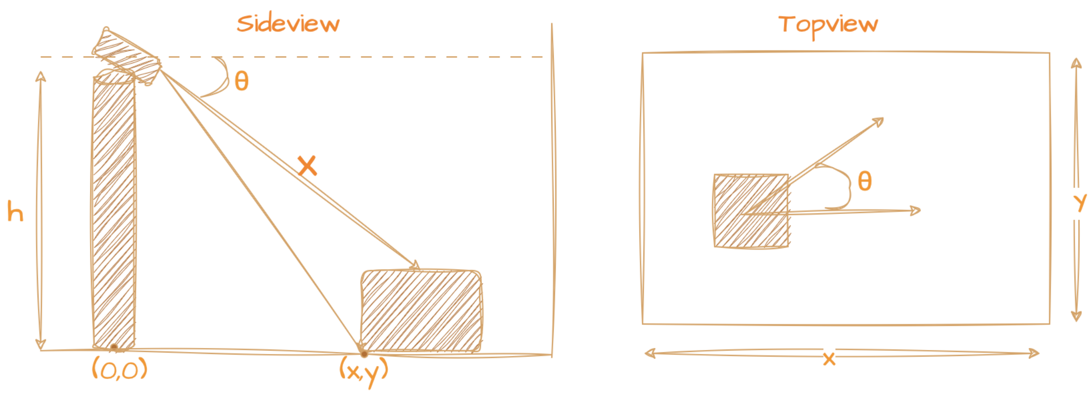

Figure 4: Laser Angle Side and Top View

We will use the following formula to obtain the Cartesian coordinates:

$$\hat{x} = h * cos(\theta)$$

where $\hat{x}$ is the distance measured by the LiDAR, h is the height of the scratching post, and θ is the angle at which the LiDAR is positioned relative to the ground. The height of the scratching post, h, is fixed and theta can be obtained from the motor controlling vertical motion.

$$f(x) = \begin{cases} 1 & \text{if } |\hat{x} - x| < \epsilon \\ 0 & \text{if } |\hat{x} - x| \geq \epsilon \end{cases} \tag{1}$$

As the LiDAR has an error component of ± 6 cm [1], $\epsilon = 0.06$ m.

2.4.3 Power Consumption

Components	Voltage Draw	Current Draw	Power Draw
ATmega328P [4]	5V	200 mA max	1 W
Motors (x2) [3]	5V	17 mA	170 mW
Laser Pointer [5]	3V	1 mA	3 mW
LiDAR [1]	5V	140 mA	700 mW
IR sensor [6]	5V	50 uA	250 uW
Analog Display [7]	5V	30 mA	150 mW
Max7219[8]	5V	330 mA max	1.65 W

Table 1: Power Requirement per Project Component Analysis

We would like the Cat Tower to be able to operate without human intervention for more than a week on average playtime for a cat. A battery will be used to supply power to all our components. One of our concerns is the battery life. Having to change the battery every so often will be an inconvenience to the user, we want our cat laser tower to be able to supply enough power to all of our subsystems for at least a week.

We are assuming a cat to play with the cat laser tower 3 times a day and 15 minutes each time. So, we expect our device to be active for 45 minutes a day. During the times where the device is inactive, the two motors will be in idle state where they will consume less power.

In idle mode all nonessential components, meaning motors, buttons, laser pointers, and transistors, will be electrically ungrounded through the use of an NMOS powered by a signal from the microcontroller. This means while in idle mode, there will be minimal power consumption, with the only significant power loads being micro-controllers and the pressure sensor, which has a signal to switch the device from idle mode. Even in active mode, assuming that the largest draws of power are components, the maximum possible power draw (probably not achievable with our device, since that assumes maximum power consumption on our micro-controllers) would be approaching 4 W, which with a 36 Wh battery as planned would allow 9 hours of active use. Assuming that the motors and analog display would use 50% of the power in the system while non-idle, the average non-idle power draw would be 640 mW, providing roughly 56 hours of cat play time. Assuming in idle mode the Analog display is both on and consumes 75% of the power, the device would have 180 hours of idle use, or roughly 7.5 days of idling time. Thus we can achieve a week of operation with our device.

This calculations are done for the period after the calibration process. The calibration process will consume more power because of the use of the LiDAR. The LiDAR will be in an inactive state after the calibration is completed.

3 Ethics and Safety

In accordance with the standards of the IEEE [9], we promise to uphold high standards of integrity, responsible behavior, and ethical conduct during the course and production of our project.

We seek to design safe systems for the use of the public, and to that end, the Cat Laser Tower must be safe and not cause significant harm to the health of cats or humans. All wires will be internal or tucked away safely, and all components will be safely stored within the device so as not to be easily accessed by cats.

The cat laser will be a class IIIa laser, which is low powered and not dangerous if one does not stare into the laser for more than a moment. The LiDAR will only be active during the calibration period, during which no cat or human should be looking into the laser. Both laser and LiDAR will have warning labels appropriate for the laser type. [10]

The battery we plan on using is a Lithium-ion battery, which can be a fire hazard if stored improperly. We intend to ensure we only use the proper charger and not overcharge the battery, as well as include any information to this effect in the instructions. This can prevent the fault of overcharging. The device will not be stored near fire, and is intended to be used indoors[11].

We seek to be transparent in the capabilities and usage of our device. Any shortcomings or flaws of our final device will be addressed, whether by informing end users or finding ethical workarounds.

While working on this project, we seek to be open and cooperate with each other and to not engage with harassment or discrimination of any form. To do this, our group members will seek to hold each other accountable and ensure everyone follow the IEEE code of ethics in both letter and spirit. [9]

References

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