Auto-Docking Cat Toy

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Team 60 – Robert Malito, Yuhao Liu, Justin Li

TA: Soumithri Bala

Sponsor: Petronics, Inc.

I. Introduction

Objective:

The number of domestic pet cats in United States reached 94.2 Million in 20171/18[1], indicating a huge cat owner base. In the meantime, cats are mostly kept alone at home during the days. While cat owners start to think more of their feline companions' emotional well-being, since cats can feel lonely at home[2], but don't want to have multiple cats, a company called Petronics starts to come in and find a solution, building a fully automated cat toy that resembles a mouse and can "play" with the cat. The idea is well accepted by cat owners and the product they built is called Mousr[3] which has been release over a year and received APPA best new cat product for 2018 according to their website.

While buyers are mostly satisfied with the product, there is one problem that buyers address the most, the battery life. For now, the device's battery can only support around 2 hours of continuous operation, and buyers of this product would want to be able to leave the Mousr to entertain their cats for extended periods of time when they leave for work or vacation. However due to the size constraints, since cats' want to play with small objects, to increase the battery life from expanding the robot size is not a good way to solve the problem.

Therefore, Petronics came up with an idea to let the robot automatically go back to a charging dock when its battery level is low, and we purpose a feasible way to navigate the Mousr robot to identify and navigate to the dock station in order to recharge itself.

Our goal is to enable the robot to identify and navigate back to the docking station in a relatively simple room environment without too many obstacles and be able to achieve this by introducing as less cost as possible to the already built system.

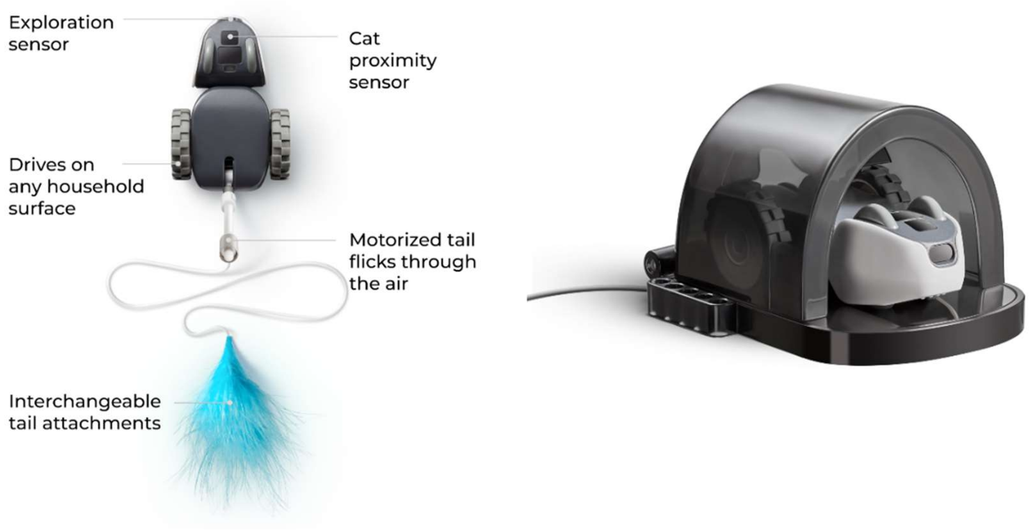

Figure 1. Mousr Overview and Current Charging Dock

Background:

There are a couple of self-docking commercial robot currently in the market, for example Roomba, and cleaning robot like iRobot. They all use multiple sensor complex and computational-heavy algorithm to map and navigate through the room. Some newer robots even utilize LiDAR to map the whole 3D environment in order to do the path planning precisely.

This is not suitable in our case since we need both the cost of the additional module we introduce to be within a reasonable range, as well as the additional size. So, the sensors we will be adding, and the additional processing unit must be cost-efficient, easy to plugin to the already existing software module, and as small as possible.

High-level Requirement List:

“Getting Home Safe on Empty”:

- The system must be able to locate and navigate to its charging dock in realistic test environments with a high degree of reliability (85%+ testing success rate) with its battery at a low charge (≈ 5-10% full).

“Load / Unload Compatibility”:

- The charging dock design should allow for reliable entry, secure charging, and easy undocking.

“A Petite Price Tag”:

- The additional production cost of the system should not exceed $10.

II. Design

The design scheme our team has developed to achieve the addition of autonomous docking to Mousr’s current specifications involves three main subsections: the sensing hardware, environmental data algorithms, and wireless communication hardware. The sensors serve as an input to the environmental data algorithms, which in turn output navigation commands to the Mousr over Bluetooth Low Energy technology. The sensors consist of 950nm IR emitters, 950nm IR receivers, and a high accuracy Time-of-Flight laser distance calculator. Laser distance data is classified by the “Floor Type” algorithm. IR receiver data is interpreted by the “Return to Dock” algorithm. One BLE module will be fixed onto the Mousr and the other will be fixed to the dock. The Mousr BLE module will have connections to the dock, and the internal system of the Mousr.

Block Diagram:

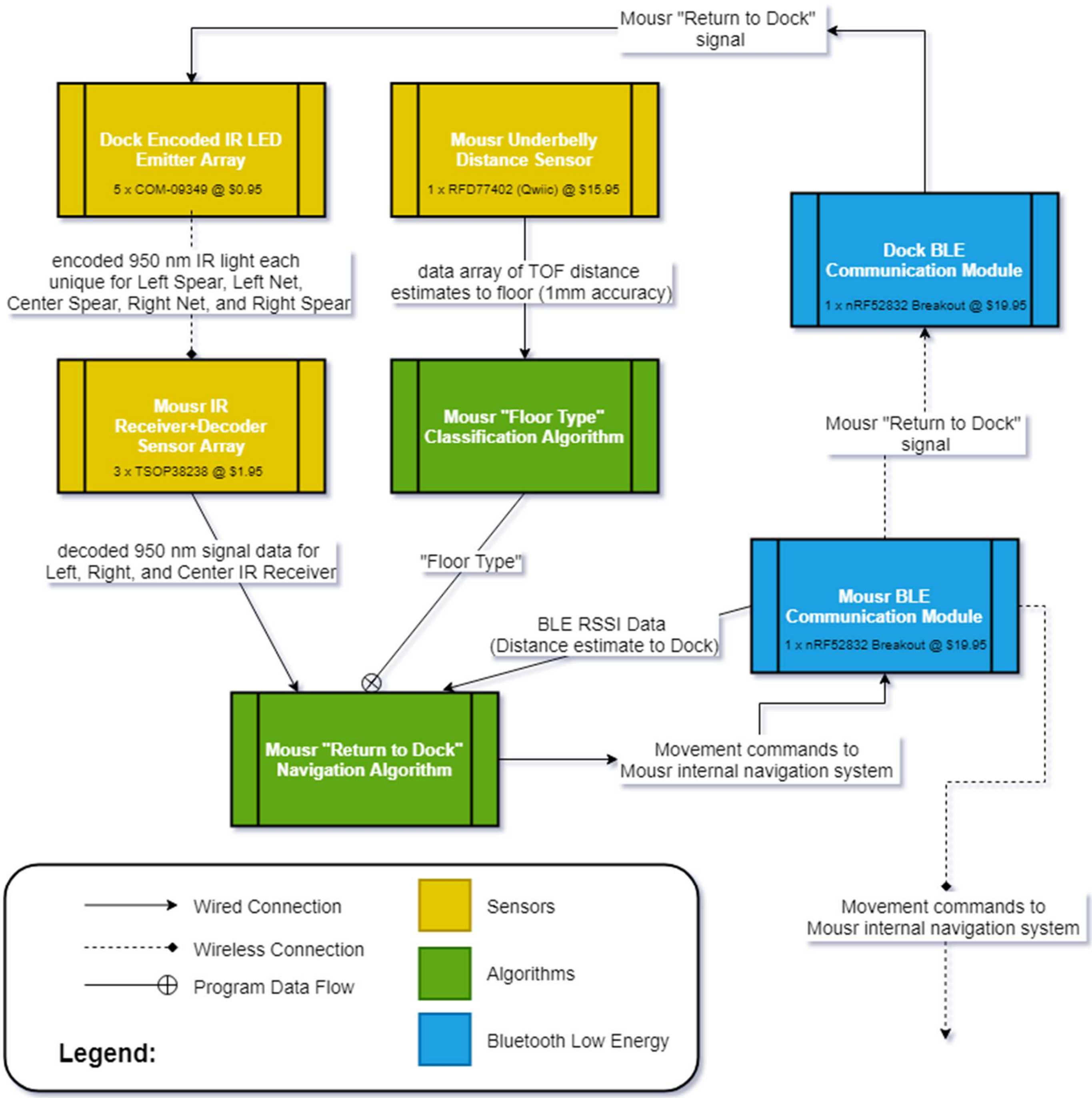

Figure 2. Block Diagram

Functional Overview:

II – 1 Charging Dock Sensing

This sub-section handles the transformation of real-world environment measurements to informative and processable data. Sensors were chosen to be affordable, reliable, and to fit the individual design constraints they face.

II – 1.1 Dock Encoded IR LED Emitter Array

The dock's IR LED array will consist of 5 directionally pointing 950nm emitters (5 x COM-09349 IR LED @ $0.95)[8]. Each LED will be emitting a different code, and all will be encoded using the same method (encoding method TBD). The dock's LEDs from left to right will be referred to as "Left Spear", "Left Net", "Center Spear", "Right Net", and "Right Spear". Their names are referring to their shape and signaling technique (see Figure 4. below in Physical Design section). Their purpose is to signal the Mousr's receivers to facilitate a return to dock when Mousr indicates it is low on battery or idle.

Requirements: Must be able to transmit encoded IR @ 950nm that receiver can detect and decode at realistic ranges.

II – 1.2 Mousr IR Receiver + Decoder Sensor Array

The Mousr's IR decoder array will consist of 3 directionally aligned 950nm IR receivers (3 x TSOP38238 @ $1.95)[8]. One will face forward, one left, one right. These will be the most crucial element of Mousr's "Return to Dock" strategy. Their purpose is to help Mousr figure out where it is located in relation to the dock. Their data will be used continuously to make real time decisions during the Mousr's "Return to Dock".

Requirements: Must be able to decode IR @ 950nm into useful data.

II – 1.3 Mousr Underbelly Distance Sensor

A Time of Flight laser distance sensor bounces light off a target and measures the elapsed time to determine distance. The RFD77402 (Qwiic breakout) provides millimeter accuracy in an ideal range of 100mm – 2000mm [9]. This is compatible with the clearance under the Mousr and can be used to take a burst of measurements of the distance from the toy to the ground. This data is processed by the "Floor Type" classification algorithm which is trained to detect how data from common *flat* surfaces (wood, metal, rubber, cement) deviate from common *rougher* surfaces (carpet, tile).

Requirements: Must be able to quickly and seamlessly take a burst of mm-accuracy distance measurements without sticking too far out from the chassis.

II – 2 Environment Data Algorithms

This sub-section is fundamental to solving the problems and obstacles associated with autonomous docking. It processes the data output from the sensor arrays to provide movement commands to be sent wirelessly to the Mousr. The strategies we use to get Mousr to locate and navigate to its dock are based upon use-space assumptions, and our physical design/sensor layout.

II – 2.1 Mousr "Floor Type" Classification Algorithm

The current floor type Mousr is on can help it make decisions if it knows the floor type the dock is on. This algorithm could be trained to detect if a burst of measurements from the underbelly sensor represent a flat (wood) or rough (shag carpet) surface. It gives its output to the "Return to Dock" algorithm.

Requirements: Must be able to return prediction on floor type quickly based on possibly erratic input data.

II – 2.2 Mousr "Return to Dock" Navigation Algorithm

This algorithm is the central logic behind the Mousr's ability to locate and navigate to its dock. When Mousr is in range of the dock's IR signal data from the 3 direction IR decoder array (forward, left, right) tell the Mousr how it is situated based on what code the receivers are getting (Left Spear, Right Net etc. see Figure 4). When Mousr is out of range or obstructed from the dock's IR it can improve the robustness of its decision-making process by taking into account the current floor type from "Floor Type" classification, and BLE Received Signal Strength Indication (RSSI) from its connection to the dock (accurate to around 2m in some indoor scenarios)[11]. This algorithm outputs the current movement instructions to be delivered to the internal Mousr system over wireless BLE.

Requirements: Must be able to guide Mousr to dock when in range with a high degree of reliability (85%+ success rate in testing).

II – 3 Wireless Communications

This sub-section is responsible for interfacing with the current Mousr specifications and keeping all aspects of the design in synchronization. Bluetooth Low Energy technology is to be used for communication between with dock, the external autonomous docking system on the Mousr, and the internal Mousr navigation system.

II – 3.1 Dock BLE Communication Module

This module uses one Nordic Semiconductor nRF52832 BLE hardware to communicate with Mousr. Gets sent "Returning to Dock" signal from Mousr to activate IR LED emitters. (nRF52 chosen by Petronics) [10]

Requirements: Must be cheap and able to communicate with Mousr successfully in standard indoor BLE range.

II – 3.2 Mousr BLE Communication Module

This module uses one Nordic Semiconductor nRF52832 BLE hardware to communicate with the dock and the Mousr internal system. It sends the movement command output from the "Return to Dock" algorithm to the Mousr internals. It also should notify the dock when its low on battery. It supplies the RSSI value to estimate distance to the "Return to Dock" algorithm.

Requirements: Must be cheap and able to communicate with Mousr internals successfully in standard indoor BLE range. (nRF52 chosen by Petronics) [10]

Physical Design:

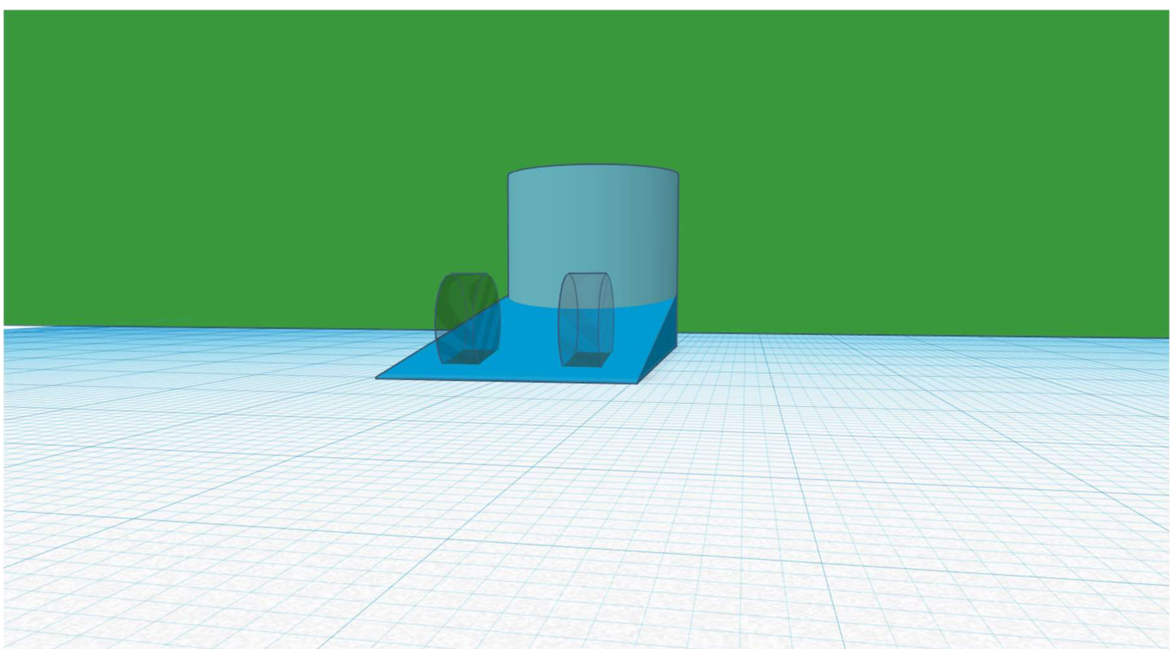

Figure 3. 3D concept for improved Mousr charging dock, designed for autonomous docking compatibility. Low incline ramp. Wheel wells for secure fit. Rounded face for radial IR spread.

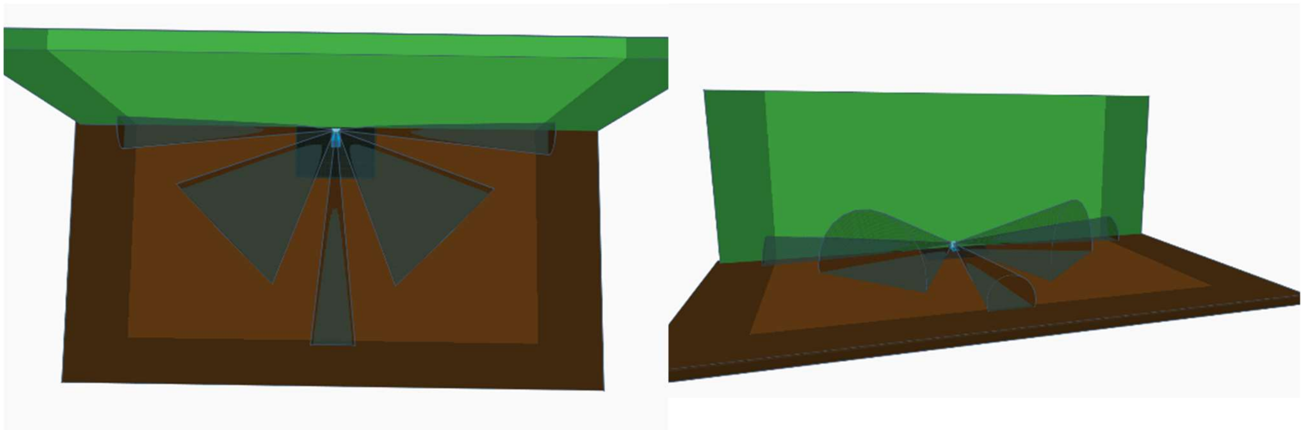

Figure 4. IR emitter array field layout: Left Spear, Left Net, Center Spear, Right Net, Right Spear

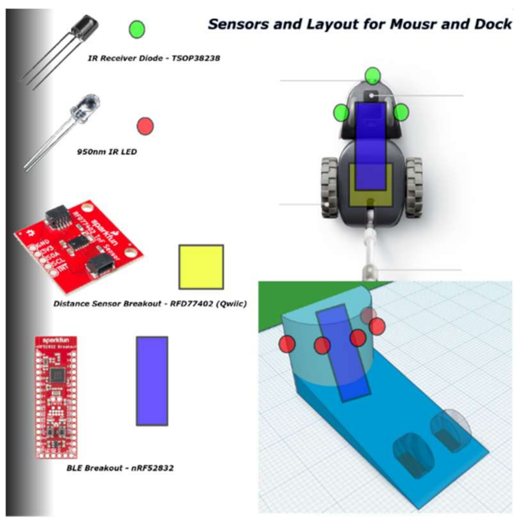

Figure 5. Prototype Hardware Layout

Risk Analysis

The main risk present is how accurate can the robot identify the target signal[4]. We all know that many appliances have some inherit infrared signals, such as remote controls and fridges. So, to be able to distinguish between the target signal and the “noise” signal is one challenge, we may need to encode the infrared signal so that when the robot senses a typical pattern of infrared signal, it will decode and recognize it as the target to go to.

The other risk is the integration of system, since we are to build new module for some existing system that has multiple components, being able to integrate fully into the system is of great importance. This directly affect how well it will behave as a product.

The risk of successfully control the robot to enter the charging dock can’t be neglected as well, since the robot does not have many sensors, and will not be allowed to add much more, we will be having limited sensor resources to do a rather delicate control.

Final risk is cost and power constraint, for we are not allowed to use many additional parts to either increase its cost by a non-neglectable margin, and to drain too much power by the additionally introduced parts.

III. Safety and Ethics

There are several safety and ethics issues that are relevant to our project. Pertaining to point #1 of the IEEE Code of Ethics [4], we must ensure that the materials we use to build the Mousr is non-toxic to pets, as cats tend to hold things in their mouths and such the cat may accidentally ingest the material. A thing that must also be taken into consideration is the product’s impact on the environment, whether the materials it is made of can be potential pollutants such as the outer shell and battery.

According to the user guide for Mousr [5], the device uses a lithium-ion polymer battery which contains hazardous materials. To avoid harm, the battery must not be overcharged and must not be exposed to extreme temperatures. The battery must also not be left to charge overnight because of issues that can be caused from overcharging. We should figure out a way to program the device so that it becomes active and leaves the charging station when it has detected that it is at full battery.

The sensor of the Mousr could also pose a potential privacy issue to the end-user. We must ensure that the data that the Mousr collects in order to navigate will not be used for malicious means, such as making sure the data cannot be transmitted from the device and that it cannot be used by third parties.

According to OSHA safety standards for robots, we must also account for safety issues that can possibly be caused by the electrical system [6]. Exposed wiring can be potentially dangerous as even a low voltage wire can be dangerous. A similar concern would be making sure that there aren't exposed moving parts that can cause potential harm to any users (such as gears catching hair). To ensure the user's safety we must make sure that the outer shell of the Mousr doesn't expose any of these moving parts or electrics.

IV. References

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