Design Study

SEARCH: Smart Electronic Assistance and Retrieval Companion for Home

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Introduction

Brief Overview

Our design will be a rover-based device equipped with computer vision technologies that can be a powerful tool for locating misplaced items. The device can navigate autonomously through an environment on the ground while using its onboard cameras and advanced object recognition algorithms to identify and locate specific objects. Once an item has been located, the device can alert the user to its location through an application. This technology has the potential to save time and reduce frustration by quickly locating lost or misplaced items.

Problem

Over 40% of people will experience some form of memory loss by the time they turn 60 years old. While memory loss and mental impairments come in many forms, one of the most common symptoms includes misplacing important objects such as wallets, keys, hearing aids, and glasses. This significantly impacts the ability of elderly people to live independently. Coupled with declining eyesight and physical strength, searching through an entire living space for objects can be extremely strenuous for elderly people, and can often end up being unsuccessful. While current widespread solutions in production to track and locate missing objects, such as Air Tags and Tile Trackers, use Bluetooth transmitters, the resolution of these devices is limited to areas often larger than the entire house, making it unsuitable for isolating a specific area of the house for an elderly person to search.

In short, dementia, ADHD, and various other cognitive impairments often cause forgetfulness in the elderly population, especially in short-term memory function, and further cause a greater number of misplaced items.

Engineering Goal

The goal of our project is to develop a system or device that can address the problem of misplaced items in the elderly population, and consequently, increase independence in their day-to-day lives.

Target Audience

Although many elderly patients require care from caretakers or facilities, elderly patients typically have the desire to be independent and self-sufficient. A common association within the elderly care field is that greater independence for the elderly yields a higher quality of living. A strong measure for independence is characterized as the avoidance of visiting a care center for a period of time, such that the elderly will be able to remain in the comfort of their own homes.

Build and Testing

Design Study #1: ImageNet

Brief Overview

The first design study that we conducted was on the object recognition software on the Raspberry Pi hardware. We conducted this design study to determine the efficacy of the image processing software in real-life environments. It is important to analyze the efficiency of the image processing software as it is crucial to identify what objects the user may have misplaced. If the model does not work as necessary, the user's queries would not be able to be processed by the rover.

Build Steps

To run the ImageNet image processing model on the Raspberry Pi, we utilized PyTorch's torchvision utilities. To run ImageNet, we used a lightweight MobileNetV2 model that can detect objects from a list of 1,000 classes. We used pre-trained weights provided by PyTorch's library, and ran the script using jit-quantization to improve real-time performance. Outputs to the MobileNetV2 model were printed to the console to be monitored in real-time.

Variables

Independent Variables:

- Item
- Distance from camera
- Environment

Dependent Variables:

- State of detection
- Confidence level

Materials:

- Rover chassis
- Rover camera mount
- USB webcam
- Raspberry Pi
- Power Bank
- PyTorch image recognition utilities

Experiment #1: Item Detection

First, we varied the item or object to be detected and measured the state of detection and confidence level from the Rover. The script on the rover to be run will use the ImageNet object recognition model. The testing environment is as shown below, where we used

(a) (b) (c)

Figure 1: Varying objects for testing rover image recognition capabilities for Design Study #1 Experiment #1. Used a (a) laptop, (b) water bottle, and (c) wallet.

We followed the steps below to conduct this first experiment:

1. Place the rover on the ground in the respective environment.
2. Point the camera at the object within a 1 meter distance.
3. Run the image recognition script with a webcam attached, and return true/false with a confidence level.
4. Repeat steps 1-3 with a water bottle, wallet, and a laptop.

Experiment #2

Secondly, we varied the distance from the camera to a water bottle and measured the state of detection and confidence level from the Rover.

We followed the steps below to conduct this experiment:

1. Place the rover on the ground in the respective environment.
2. Point the camera at the water bottle from 1 meter away.
3. Run the image recognition script with a webcam attached, and return true/false with a confidence level.
4. Repeat the above steps from distances 0.5 meter, 1 meters, and 2 meters.

(a) (b) (c)

Figure 2: Varying distances for testing rover image recognition capabilities for Design Study #1 Experiment #2.

Experiment #3

Lastly, we varied the environment in the camera's view for a kitchen, living room, and bedroom, and measured the state of detection and confidence level for each detection.

We followed the steps below to conduct this experiment:

1. Place the rover on the ground in the respective environment (kitchen).
2. Point the camera at the water bottle from 1 meter away.
3. Run the image recognition script with the webcam attached, and return true/false with a confidence level.
4. Repeat the above steps in a living room and bedroom.

Results

From the three above experiments, the results can be found below.

Table 1: Experiment #1 Results.

Object	Detection (Y/N)	Confidence Level (%)
Wallet	N	N/A
Water bottle	Y	57.68
Laptop	Y	57.25

Note. The detection and confidence levels were measured by running the 1000-class ImageNet image recognition model on the Raspberry Pi in real-time.

Table 2: Experiment #2 Results.

Distance of Rover from Object (m)	Detection (Y/N)	Confidence Level (%)

0.5	Y	40.24
1	Y	10.30
2	N	N/A

Note. The detection and confidence levels were measured by running the 1000-class ImageNet image recognition model on the Raspberry Pi in real-time for a water bottle.

Table 3: Experiment #3 Results.

Environment	Detection (Y/N)	Confidence Level (%)
Living Room	Y	20.47
Bedroom	Y	30.83
Kitchen	Y	18.41

Note. The detection and confidence levels were measured by running the 1000-class ImageNet image recognition model on the Raspberry Pi in real-time.

Analysis

From these results, we determined that ImageNet worked only as a preliminary software for object recognition. One limitation of this software is that the classes are limited to the 1,000 classes of objects that the model can recognize. Many of these classes, such as animals or other large objects, are irrelevant in the case of commonly found home items. Therefore, it is advisable for the final prototype to develop a novel image recognition algorithm or image processing software that is trained specifically for common household items.

One issue with the MobileNet model is the presence of noise in our testing images. Since backpacks, laptops, and other objects were also detected along with the water bottle, the confidence level for water bottles went down. This issue would naturally be addressed in a home-setting where the more objects detected, the better.

Furthermore, the camera mount on the rover was shaky, and proved to be difficult to capture clear still-frames because of the rover's movement. Thus, we are to add more support for the final prototype to improve the camera mount.

One component that performed strong from our initial experiments were the detection capabilities for many different objects. In our experiment of varying the objects to be detected by the ImageNet algorithm, it performed well and was able to differentiate between different objects. Therefore, we are to include this model in our final prototype to differentiate objects. This model performs up to standard with our Level 1 requirements, and thus, satisfies our clients needs for a reliable object recognition software.

Design Study #2: Database and Mobile Application Testing

Brief Overview

The mobile application component of our project serves to communicate between the front and hardware ends of the project. When a user desires to order the SEARCH bot to execute a task or to find previously logged items, the mobile application can be used. Furthermore, documents are stored per user in Firebase Firestore for later use.

Variables

Independent Variables:

- User input
- Function calls

Dependent Variables:

- Response from application
- Feedback loop of functions
- User feedback

Materials:

- Flutter
- Firebase Firestore
- Ios simulator
- Cloud functions
- Flutter image packages

Experiment #1

In order to test functionality, we tried our application under a few different use cases as noted below. These cases only included user-specific functions such as being able to sign-in.

1. Provide random user with credentials
2. User registers with new account
3. User attempts to enter the app with login credentials
4. User signs-out
5. All feedback is reported back to Joe & Sons

Experiment #2

Secondly, we tested the core features such as speech recognition. These features are crucial in order to provide our client with the desired functionality.

1. Resume testing with user from *Experiment #1*
2. Request user to try core features of application
    a. Speech recognition
    b. Item queries
    c. Item log menu
    d. Image output
    e. Deleting items
3. User provides feedback on functionality to team

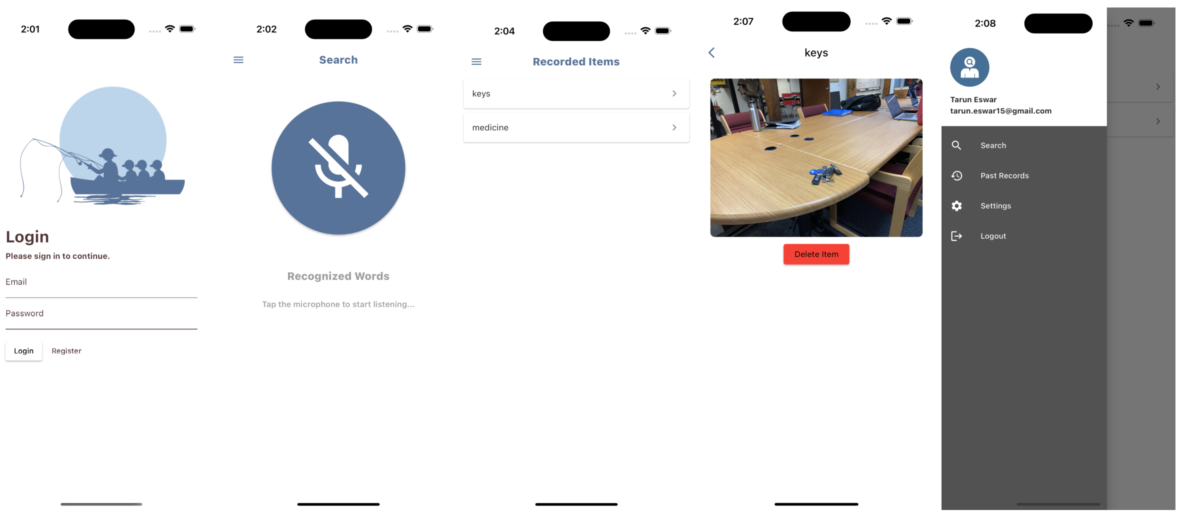


Figure 4: Mobile Application screenshots for command recognition. *Note. The UI allows our client(s) to speak words and it will search the Firebase database for items found within the household by the rover.*

Results

The results from the mobile application tests are shown below.

Table 4: Experiment #1 Results.

Test	**Result**	**Response Time (in seconds)**
Login capability	Functional	0.0 < t < 1.0
Registration capability	Functional	0.0 < t < 1.0
Sign-out ability	Functional	0.0 < t < 1.0

Table 5: Experiment #2 Results.

Test	**Result**	**Response Time (in seconds)**
Speech recognition	Functional	3.0 < t < 4.0
Item query	Functional	0.0 < t < 1.0
Item log menu	Functional	0.0 < t < 1.0
Image output	Functional	2.0 < t < 3.0
Delete items	Functional	0.0 < t < 1.0

Analysis

After conducting these experiments, we found that the application is fully functional and prepared for full-scale deployment. This application satisfies the requirements for being able to recognize voice commands, and also passes the requirement of being aesthetic in design and functional.

For the final design, larger text may be necessary for our clients, who may have vision impairments. In terms of our project requirements, the functions of the application currently meet all required needs. Items are able to be viewed, tracked, and searched through the application.

Additionally, the user-based design enables multiple patients to use our application. Documents are unique per user and each user is able to access the application independent of other users. Thus, we are able to provide support for hundreds of users if necessary. In this sense, the application was able to go above and beyond the requirements to provide the most functionality for those that require assistance.

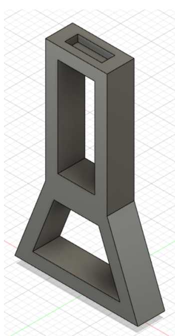
Design Study #3: Rover Hardware

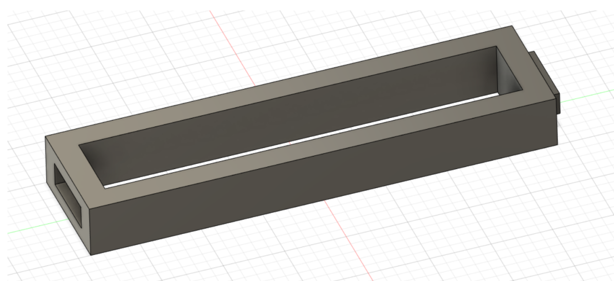
Brief Overview

The third design study was conducted on the rover's hardware components to test for usability, strength of the rover design, and the strength of the camera mount. It is necessary that the rover does not tip over during movement so that the client, who may have limited mobility, does not need to reset the rover. Furthermore, any tipping or falling of the rover could damage property or capture any unauthorized media.

Build Steps

To construct the camera mount, we 3D printed four stilts that would be attached using screws and super-glue. The camera mounts were attached to the rover body using screws and superglue, with a wider base and a more narrow top. Finally, the camera was attached to the top of the mount and the USB cable was wired through the stilts. The CAD designs for the 3D printed camera mounts can be found below, which were printed at 50% infill.





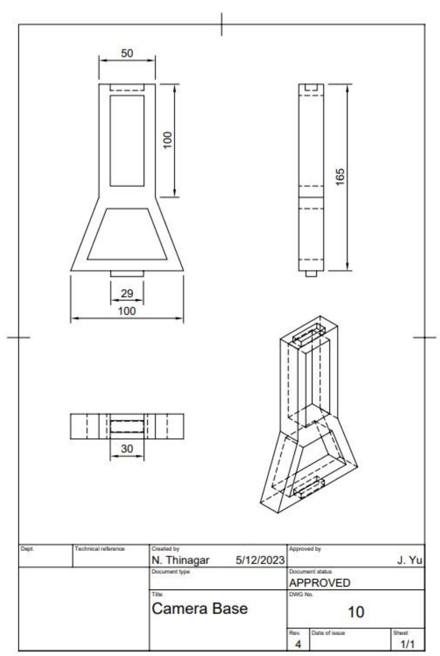


Figure 5: Camera mount CAD design. The left design is for the base of the camera mount and the right is for raising the height.

Figure 6: Camera mount on the rover chassis. This picture was taken after stabilization features were added to the camera mount (i.e. steel plates and tape).

Variables

Independent Variables:

- Direction of force applied
- Height of force applied to the camera mount
- Speed of the rover

Dependent Variables:

- Minimum force necessary to be able to tip over the rover
- Maximum speed to keep the rover components stable

Materials:

- Rover chassis
- Rover camera mount
- Raspberry Pi
- Power Bank
- Newton Force Meter Spring

Experiment #1

The steps that we followed for the first experiment are listed below.

1. Place the rover on a flat surface (i.e. a table).
2. Hook the Newton Force Meter Spring to the rover camera mount at 1 meter high.
3. Pull in the direction of the front of the rover.
4. Record the maximum Newton force applied without the rover falling over.
5. Repeat the above steps for the other three sides of the rover.
6. Repeat the above steps for hooking the Newton Force Meter Spring to the rover camera mount at 0.5 meters and 0.1 meters high.

Figure 7: Photos of the experiment of the force tests on the Camera Mount. The left picture is the force test near the top of the mount, while the right picture displays the experiment at 0.5 meters above the base.

Experiment #2

The steps for the second experiment are listed below.

1. Place the rover on a flat surface (i.e. a floor).
2. Progressively increase the rover's speed until it falls/tips over.
3. Record the max speed of the rover.
4. If the rover falls over, repeat with a power output of 10% less.

Figure 8: Photos of the experiment of the rover moving along a carpeted surface. The rover was attached via cable to a monitor to display the results.

Results

In our first experiment, we quantified the amount of force the rover can withstand without typing over. Using a spring Newton Force Meter Spring, we were able to measure the maximum force necessary to

Table 6: Experiment #1 Results.

Direction of Force Applied	Height of Force Applied (m)	Minimum Horizontal Force Necessary to Tip the Rover (N)
North	1	0.60
East	1	0.50
West	1	0.55
South	1	0.35
North	0.5	0.92
East	0.5	0.98
West	0.5	1.12
South	0.5	0.73
North	0.1	4.83
East	0.1	4.45
West	0.1	5.20
South	0.1	3.20

Note. The North, West, East, and South directions are in relation to the rover frame, where North is the front of the rover, West/East are the side, and South is the rear of the rover.

Table 7: Experiment #2 Results.

Power Output (%)	Speed (mph)	Tipped? (Y/N)
10	0.2	Y

20	0.4	Y
30	0.6	Y
40	0.8	Y
50	1	Y
60	1.2	N
70	1.4	N
80	1.6	N
90	1.8	N
100	2	N

Note. The speed was modified from the navigation script on-board.

Analysis

The first experiment showed that the camera mount was sometimes unstable at more extreme conditions. This made us revise our design and add exterior aluminum supports and super glue between the beams in the mount to improve the design. Qualitatively, the strength seems to have improved much more. It is also observed that the minimum force applied to tip the rover from the rear side is much lower, signifying that additional supports near the rear of the rover or increased weight distribution near the rear is necessary.

In order to address this issue, we increased support on the bottom of the rover by strapping the battery pack to the bottom and adding 500 grams of weight to the chassis. This lowers the center of mass and also improves stability of the rover. The new results from the decreased center of mass showed that the rover can move without falling at 100% power output. Without the stabilized bottom, the rover could only move up to 50% power output without falling over. However, we could also address the issue of a max speed with a lower acceleration. Furthermore, from observational analysis, it can be seen that the rover board was flexing during movement. An improvement that would be necessary for our final design would be to add more weight to decrease the center of mass and make the base rover larger or longer.

The new prototype now satisfies the requirement of being able to move around the house without falling or damaging other components. Furthermore, the wheel materials are made of rubber, which prevents leaving marks on wooden floors. From qualitative tests, we also determined that the rover can navigate on hardwood and carpeted floor. For the final prototype more structural changes are necessary to lower the center of mass and/or also increase stability of the camera mount.

Final Design

Executive Summary

Our final design consists of a base rover plate with a Raspberry Pi secured onto the board. The 1 meter camera mount is attached to the center of the base rover plate with a camera wired at the top of the camera mount. The camera mount is stabilized with aluminum plates and duct tape. The four wheels of the rover each have their own DC motor's with independent power output. Furthermore, the battery bank is attached to the bottom of the rover for a better weight distribution.

The final prototype is detailed below.

Final Requirements Matrix

Table 9: Final Requirements Matrix.

Problem/Need	Dementia, ADHD, and various other cognitive impairments often cause forgetfulness in the elderly population, especially in short-term memory function, and further cause a greater number of misplaced items.			
#	*Level*	*Requirement Type*	*Requirement Statement*	***Prototype #3 (Final)***
1	1	Functional	The device shall identify the locations of items within an area with at least 50% accuracy.	Yes
2	1	Functional	The device shall reduce the frequency of searching for lost items by at least 50%.	Yes
3	1	Functional	The device shall respond to client requests for	Yes

			misplaced items within 10 seconds.	
4	1	Safety	The device shall not cause injury to the client(s).	Yes
5	2	Safety	The device shall not significantly impede the ability of the client to navigate their house.	Maybe
6	2	Functional	The device shall conduct searches at least once a day.	No
7	2	Cost	The device shall not be greater than a total of $300.00 in cost.	Yes
8	2	Functional	The device shall sustain movement and data collection for at least 30 minutes.	Maybe
9	2	Functional	The device shall accept commands from natural language	Yes
10	2	Physical	The output device should be secured properly.	Yes
11	2	Appearance	The user interface should be aesthetically	Maybe

			pleasing.	
12	2	Functional	The device shall not store recordings for more than 10 minutes.	Yes
13	2	Physical	The device shall not take more than 1 cubic yard of space.	Yes
14	2	Functional	The device shall not cause damage to any property on the household.	Maybe
15	2	Appearan ce	The device should have a display for showing lost items.	Yes
16	2	Functional	The device shall not capture unauthorized media of any private property without explicit permission by the client.	Maybe
17	2	User	The user shall be able to use a basic application on a mobile phone or computer.	Yes
18	2	User	The user shall be able to pick up the device.	Yes
19	2	Physical	The device shall	Yes

			be less than 10 pounds.	
20	2	Documentation	The device shall include a training manual.	Maybe
21	3	Physical	The device shall be able to maintain functionality autonomously	Yes
22	3	Functional	The device shall have a product lifespan of at least 1 year.	Yes
23	3	Functional	The device shall report any unresolvable errors to the client	Maybe
24	3	Physical	The device shall not obstruct the view of the client.	Maybe
25	3	Functional	The output should be customizable to suit the client.	No
26	3	Cost	The cost of maintenance and upkeeping sholuld be less than $100.00 per year.	Yes
27	3	Physical	The device shall have a strap for carrying.	No
28	3	Physical	The device shall be aesthetically	No

			pleasing.	
29	3	Physical	The charging port shall be grounded and secure.	Yes
30	3	User	The user shall be able to navigate their house and avoid the device in motion.	Maybe
31	3	Documentation	The device shall have a software API.	Yes

Note. These requirements are derived from the design studies above.

Future Work

Some future work for this project would be to improve the movement of the camera on the camera mount. This would include using a scissor lift or a rotating camera in order to change the camera angle. Furthermore, additional extensions to this project would include: turning axle for the wheels for tighter angle turns, voice recognition on board the rover for faster command recognition, and a faster mini-computer (Jetson Nano).

These additional costs are summarized below.

Table 10: Future materials and costs.

Item	Cost
Jetson Nano	$175.00
Voice Recognition API	$24.00
Scissor Lift	-
Wheel axle and improved chassis	$50.00
Total Costs	$249.00

Note. These are projected costs and are subject to change.

Appendix

Bill of Materials

Table 11: Final Project Budget.

FINAL Project Budget		
Team Name	Joe & Sons, Inc.	
	Proposed Grant	This Project
Income Sources		
Individual In-Kind Contributions		$120.00
External Funding		
Received Grant	$200.00	$200.00
Other Income		$0.00
Total Income		$320.00
Expenditures		
This Project: SEARCH		-
Hardware Costs		
Rover Chasis		$25.00
Web Cam		$30.00
3D Printing Filament		$20.00
Ultrasound Detector		$10.00
Raspberry Pi	$200.00	$90.00
*Software Costs**		
Website Hosting / Domain		$20.00
Total Expenses		$195.00
Surplus/Deficit		$125.00
Footnotes		

*Software costs are projected for multiple years of hosting and maintenance