Autonomous Alexa

Team FollowMe

Project Advisor: Professor Ahmet Enis Cetin

ft. Karim Eltahawy, Evan Gruzlewski, Kishan Patel, Michael Banasik

Date: May 8th, 2020

Table of Contents

I. Abstract

Home assistant devices, such as Amazon Echo and Google Home, are stationary devices that are intended to be used in a singular room. Users who wish to expand their voice control within their home are generally left to purchase several devices to distribute throughout their home. Our project was to build a rechargeable, easy-to-use robot with the ability to follow a user, providing power and, most importantly, mobility to users' home assistant devices. This is achieved by having a docking bay atop the robot that provides a stable platform to attach devices, while also acting as a power supply. The device, sporting dual USB ports and an AC outlet, provides broad device compatibility, including phones, speakers, and even laptops!

II. Overview

Project Goals

Home assistant devices are designed to be a stationary product. Typically, users will have their device set up in a common area of the house. But what if they're not in the common area, and they want to use their device? Our project, FollowMe, hopes to circumvent this core flaw of these devices by allowing users to use their product anywhere they go. By building a device with the ability to follow users around the house, users will have the benefit of always having their voice assistant with them, without the need for buying multiple devices to scatter throughout their homes; thereby meeting the needs of users who want to use their voice assistants anywhere they are, while retaining the use of only a singular device. That being said, however, this device will support a far larger range of devices than just voice assistants. Anything that can be powered off of either AC power or the standard usb format will be supported! This includes laptops, phones, raspberry pi projects, and even charging hubs! This project is different from all other products on the market, and it's pretty easy to explain why. Minimal convincing is necessary! Generally speaking, other products on the market are geared towards a very specific ideal. For example, we could have just designed a device that includes an voice assistant that is an embedded piece in our hardware implementation, thereby limiting the use of the product to fit to a certain ideal. Our project, however, is designed with openness in mind, such that users can utilize their device in any way that they see fit. In that regard, our device is very different from anything else on the market that utilizes the same school of thought.

Needs Statement

According to eMarketer, approximately 33% of the US population uses a voice assistant at least one time per month [9, Fig. 1]. The overall percentage of people who utilize voice assistants is growing every year. Currently, voice assistants are only used in one or two rooms of a household. As the technology grows and matures, so should the way that we use it. There is a need for a portable voice assistant that can be used all throughout a household.

Objective Statement

The objective of this project is to design and build a rechargeable, easy to use, portable voice assistant device that can follow users around their homes. The device will allow users to access their voice assistant no matter where they are, and will have sensors that allow it to seamlessly avoid obstacles.

Background

The Theory Behind Autonomous Robots

Before getting into the theory of autonomous robots, one should understand the definition of autonomy. According to Waypoint Robotics, autonomy is the ability to make your own decisions. Autonomous robots have the ability to make their own decisions and perform actions depending on certain situations [1]. The real world is constantly changing and unpredictable as even the most advanced technology in autonomy can come across many difficulties But when Aethon released its autonomous robot platform from the last decade, it revealed that achieving 100% autonomy was “impractical and intractable” [2]. Impracticality occurs from the costs needed to create such a sophisticated machine which would decrease the chances of producing affordable robots as achieving positive ROI (Return on Investment) is crucial. Intractability occurs from acknowledging the reality that autonomous robots can have difficulties deciphering reality as it comes across obstacles that are difficult to overcome, so according to autonomy purists, they suggest the best solution to this is to continue increasing the advancement of automation, sensing technology, and combining this technology together [2].

FollowMe offers the idea of Autonomous Alexa to provide users, who are already familiar with home assistance devices, the ability to have their home assistance device follow them on command to assist them in different, everyday tasks. This way, users do not have to be restricted to using their home assistant devices in limited locations since the devices are stationary. By implementing autonomy technology, the device relies on the following components: 1) sensors that help observe its environment such as objects in its path, avoid falling from high ground such as stairs, and detecting overhead falling objects to avoid damage; 2) person tracking via mobile application; 3) Distance measuring which determines the device's speed in certain situations.

Current Technology of Autonomous Robots

There are currently two different "versions," so to speak, of autonomy as we understand it today. There is artificial intelligence, more commonly known as just AI or machine learning, and its subset, cybernetics or control theory. AI is commonly defined as the simulation of human behavior and actions by machine, whereas cybernetics is the science behind the communication and control systems found within machines. Both have a firm standing in today's autonomous machines. Cybernetics is the physical manifestation of machine, whereas artificial intelligence is the programming and machine learning behind the machine. In other words, if cybernetics is a body, then artificial intelligence is the brain. Control theory and machine learning are thus complementary fields underpinning autonomy and are quite different in spirit, perhaps owing to their cultural roots in different thought communities [10].

Limitations of Current Designs/Technology

Advances in autonomy have been made at a steady pace throughout the years, no doubt at all about that, but the transition to systems that are capable of reacting to unexpected changes in the environment have not yet been developed, and don't seem to be nearing the horizon. With our current technology, we are faced with the inability to design systems that can react fast enough. Whether it is avoiding an obstacle, making a decision on the angle or trajectory of a turn, or something as simple as how fast the system can safely move, all of the decisions being made are done slowly. We simply can't provide the processing power necessary to truly harness the power that autonomy has to offer. That's not to say that we aren't making progress, however. Tesla recently released an update for their vehicles with a new feature entitled "Smart Summon." Using a smartphone, a person can now command a Tesla to turn itself on, back out of its parking space and drive to the smartphone holder's location [11]. Albeit slowly. There is definitive proof that progress is being made, and Tesla's ability to showcase a production, self driving vehicle is more proof than anything else we have ever seen. It does come with some stipulations, however. It's slow, some say unsafe, and the range isn't all that great. As with all autonomy, it has its limitations.

Similarities/Differences Between Concept and Current Systems

While our design is different from other designs in terms of its intended use, there are other similar devices that use the same technology. Our design relies on multiple sensors that assist in providing a pathway for our device. iRobot's Roomba has several sensors, including infrared, to detect walls and obstacles, as well as the Roomba slowing down when getting near them. It also has infrared sensors underneath the device to detect stairs/steep drops [3].

Our design also relies on tracking the person via machine learning and a phone application, to be able to follow the user. According to a research article titled "A Tracking Robot Based on Wireless Beacon" from their book "Intelligent Robotics and Applications", the use of interferometry is used to make precise measurements of distance [4]. This method is used to track the target (in this case, the user) according to its location and distance information is gathered from an interferometric method depending on the wireless location of the receiver as well as a sonar system to measure distance [5].

Current Direct/Indirect Competitors

Currently, Amazon is working on a robot named “Vesta” which is being developed by Amazon Lab126 at Sunnyvale, California. Bloomberg reported last year that the robot would feature advanced cameras, computer vision, and navigation through homes. Vesta was set to enter the market in early 2019 but Bloomberg reports that it is not ready for mass production yet [6]. The disadvantage of this design compared to ours is the fact that it’s limited to using Alexa as its only device while our devices provide options for more devices that share similar connectability as Alexa (such as speakers, charging ports, ..etc).

Another competitor named the Temi Google Assistant Robot is currently on the market which launched in 2018. The device provides Google Assistant technology and can approach the user and follow while doing certain tasks. The device provides “fully-autonomous navigation” with AI features, 3D Mapping, and face recognition as well as a wireless charging station [7]. However, the base price for the Temi is currently for $1999 which is rather expensive [8]. Our design will provide similar features such as its autonomous system and charging station but its base price is aimed to be more affordable compared to the Temi.

User Survey Summary

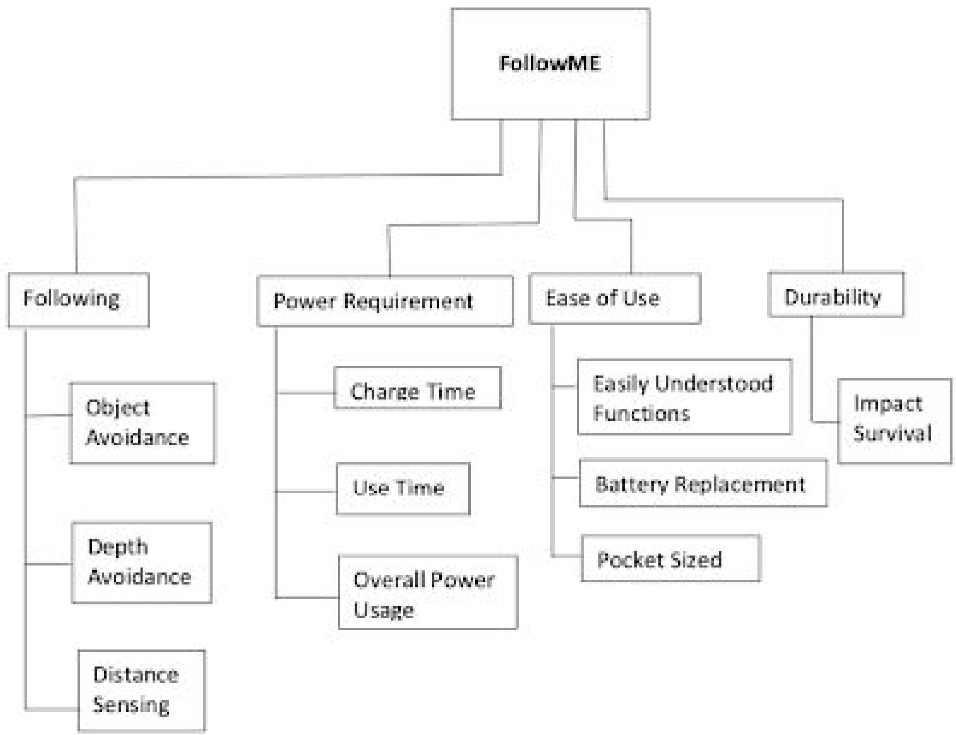
We conducted a User Survey to see what users would expect at specific price points in terms of cost, functionality, appearance, user interface, reliability, power requirements, and expected product lifetime. The survey was sent to people who currently use, have previously used, or look forward to using a personal home assistant to collect reliable and dependable data from people who would use our product. We asked participants to choose if they wanted an all in one package or a docking system and results showed that opinions and wants were split almost even between the two. Aside from having a controllable distance of following, potential consumers wanted the robot to follow them at a five foot distance. We asked for concerns and expectations for the product at the price they chose and being durable stuck out at all price points. As the device would be powered through a portable battery, we asked questions about usage to expect how much power it would need to last. An interesting note is that after sharing our ideas, people note that they would be willing to pay more for our product. A link to raw data will be in the appendix

Marketing Requirements

1. The device should be easy to use.
2. The device should have a long battery life.
3. The device should have a low charge time.
4. The device should not consume excess power.
5. The device should be able to survive getting stepped on.
6. The device should be able to follow users via machine learning
7. The device should not fall down the stairs if it is following a user.
8. The device should be able to move regardless of the surface it is on.
9. The device should be able to get around without crashing into objects.
10. The device should be able to back up out of a space when it detects that it is stuck.
11. The device should be able to avoid an object that is potentially about to fall on top of it.
12. The device should be dust and water resistant as well as having a cooling system.

Objective Tree

Figure 1: Objective Tree



III. Engineering Requirements

Table 1: Engineering Requirements

#	Marketing Requirement	Engineering Requirement	Justification
1	Easy to use	The device should have an intuitive interface, such that there is little to no learning required to use the device.	https://standards.ieee.org/content/ieee-standards/en/standard/82079-1-2019.html (Setting up device)
2	Long battery life	The device should have enough battery life to last 8-12 hours of use to match user needs.	https://standards.ieee.org/standard/1625-2008.html
3	Low charge time	The device should be able to charge up to 50% in around 3-4 hours.	https://standards.ieee.org/standard/1625-2008.html
4	Highly durable	The device should be able to survive drops and getting stepped on (0.57kN) .	https://standards.ieee.org/content/ieee-standards/en/standard/693-2018.html
5	Depth perception	It can detect cliffs such as stairs or high ground.	https://standards.ieee.org/project/3141.html
6	All home terrain	The device should be able to travel on all common terrain typically found within homes.	(No standard required)
7	Obstacle avoidance	Able to detect the object and prevent crashing into them.	https://standards.ieee.org/content/dam/ieee-standards/standards/web/documents/other/ead_v2.pdf

IV. Design Alternatives

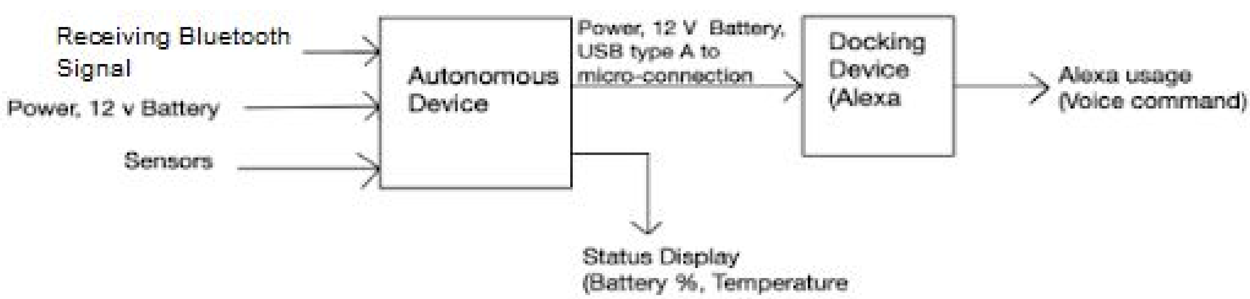
Design Alternative 1:

Table 2: Components Table for Design Alternative 1

Wireless Signals	User Interface	Display	Power	Sensors (Collision Avoidance)	Cooling System	Casing Materials	Ports
Wifi	Touch Screen	7 segment LED	Rechargable (12V)	Ultrasound	Fan	Acrylic	USB type C
Bluetooth	Buttons	*LCD	Replaceable (12V)	Infrared	Water Cooling	PLA	AC Port
Low frequency radio waves	App	LED light indicator	Disposable (12V)		Ventilation	ABS	USB type A

*Note: The display was not implemented in the final design due to a lack of resource availability.

Figure 2: Level 0 Circuit for Design Alternative 1

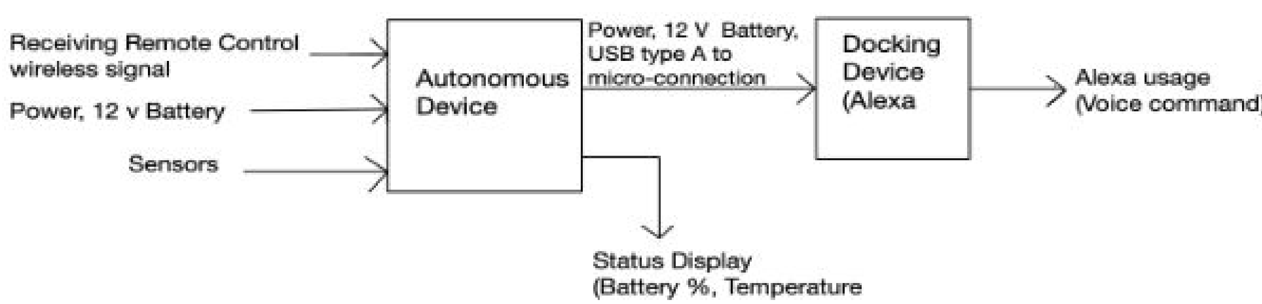


Design Alternative 2:

Table 3: Components Table for Design Alternative 2

Wireless Signals	User Interface	Display	Power	Sensors (Collision Avoidance)	Cooling System	Casing Materials	Ports
Wifi	Touch Screen	7 segment LED	Rechargable (12V)	Ultrasound	Fan	Acrylic	USB type C
Bluetooth	Buttons	LCD	Replaceable (12V)	Infrared	Water Cooling	PLA	AC Port
Low frequency radio waves	App	LED light indicator	Disposable (12V)		Ventilation	ABS	USB type A

Figure 3: Level 0 Circuit for Design Alternative 2

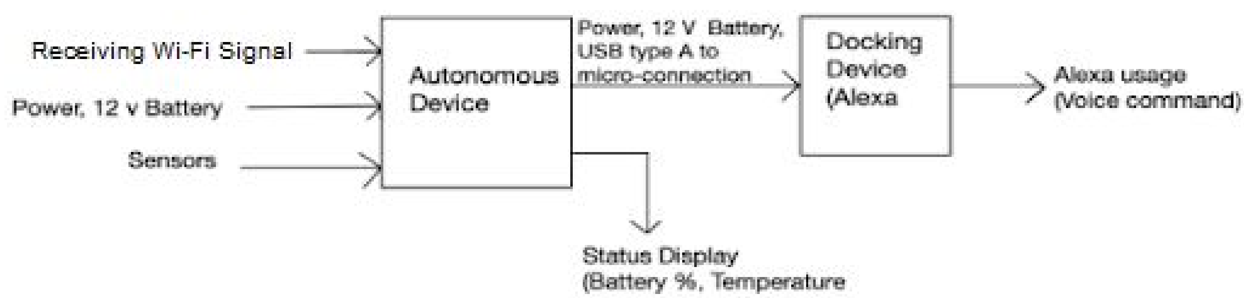


Design Alternative 3:

Table 4: Components Table for Design Alternative 3

Wireless Signals	User Interface	Display	Power	Sensors (Collision Avoidance)	Cooling System	Casing Materials	Ports
Wifi	Touch Screen	7 segment LED	Rechargable (12V)	Ultrasound	Fan	Acrylic	USB type C
Bluetooth	Buttons	LCD	Replaceable (12V)	Infrared	Water Cooling	PLA	AC Port
Low frequency radio waves	App	LED light indicator	Disposable (12V)		Ventilation	ABS	USB type A

Figure 4: Level 0 Circuit for Design Alternative 3



V. Best Design Alternative and Justification

Selection Criteria:

Table 5: Selection Criteria and Justification Table

Criteria	Justification
Manufacturing Cost	We have a strict budget, and to develop a potentially competitive product, the cost of manufacturing the device is important; the lower the cost can be while retaining standard features, the better.
Time to Develop	Given that we only have a single semester to develop the product, we do not have the time to develop a needlessly complicated system. The amount of time that something takes to develop is important; the quicker we can implement features, the better.
Ability to Develop	Our ability to combine our knowledge from an ECE background as well as having expectations of learning new topics needed for the project (research, references, ..etc).
Ability to Manufacture	Working with the limitations that we have, and the equipment that we have available to us, how feasible is the manufacturing process for the parts we choose?
Ease of Use	Making sure to make the product as consumer-friendly as possible and welcoming to any age group.

Pair-wise Comparison of Selection Criteria:

Rating: 1 = equal, 3 = moderate, 5 = strong, 7 = very strong, 9 = extreme

Table 6: Final Results of Selection Criteria

	Manufac-turing Cost	Time to Develop	Ability to Develop	Ability to Manufac-ture	Ease of Use	Geo-metric Mean	Weights
Manufac-turing Cost	1	0.20	0.25	0.23	2.83	0.50	0.08
Time to Develop	6	1	1	4	4	2.49	0.40
Ability to Develop	4.50	0.63	1	2.33	2.33	1.73	0.28
Ability to Manufacture	4.50	0.23	0.33	1	3.83	1.06	0.17
Ease of Use	0.97	0.16	0.39	0.25	1	0.43	0.07

Table 7: Evan’s Selection Criteria

	Manufacturing Cost	Time to Develop	Ability to Develop	Ability to Manufacture	Ease of Use
Manufacturing Cost	1	1/7	1/3	1/5	3
Time to Develop	7	1	3	5	9
Ability to Develop	3	1/3	1	3	5
Ability to Manufacture	5	1/5	1/3	1	3
Ease of Use	1/3	1/9	1/5	1/3	1

Table 8: Kishan's Selection Criteria

	Manufacturing Cost	Time to Develop	Ability to Develop	Ability to Manufacture	Ease of Use
Manufacturing Cost	1	1/3	1/7	1/5	3
Time to Develop	3	1	1	5	5
Ability to Develop	7	1	1	3	7
Ability to Manufacture	5	1/5	1/3	1	7
Ease of Use	1/3	1/5	1/7	1/7	1

Table 9: Karim's Selection Criteria

	Manufacturing Cost	Time to Develop	Ability to Develop	Ability to Manufacture	Ease of Use
Manufacturing Cost	1	1/5	1/5	1/3	5
Time to Develop	5	1	1	3	7
Ability to Develop	5	1	1	3	5
Ability to Manufacture	3	1/3	1/3	1	5
Ease of Use	1/5	1/7	1/5	1/5	1

Table 10: Michael's Selection Criteria

	Manufacturing Cost	Time to Develop	Ability to Develop	Ability to Manufacture	Ease of Use
Manufacturing Cost	1	1/9	1/3	1/5	1/3
Time to Develop	9	1	5	3	5
Ability to Develop	3	1/5	1	1/3	1
Ability to Manufacture	5	1/5	1/3	1	1/3
Ease of Use	3	1/5	1	1/3	1

Rating of each Design Alternative Relative to the Selection Criteria:

Table 11: Design Alternative Rating to Selection Criteria

	Manufacturing Cost	Time to Develop	Ability to Develop	Ability to Manufacture	Ease of Use
Design 1	3	3	3	3	3
Design 2	5	5	5	5	3
Design 3	7	7	7	5	1

Decision Matrix:

Table 12: Decision Matrix Table

		Design 1	Design 2	Design 3
Manufacturing Cost	0.08	3	5	7
Time to Develop	0.40	3	5	7
Ability to Develop	0.28	3	5	7
Ability to Manufacture	0.17	3	5	5
Ease of Use	0.07	3	3	1
Score		3	4.86	6.24

Final Decision:

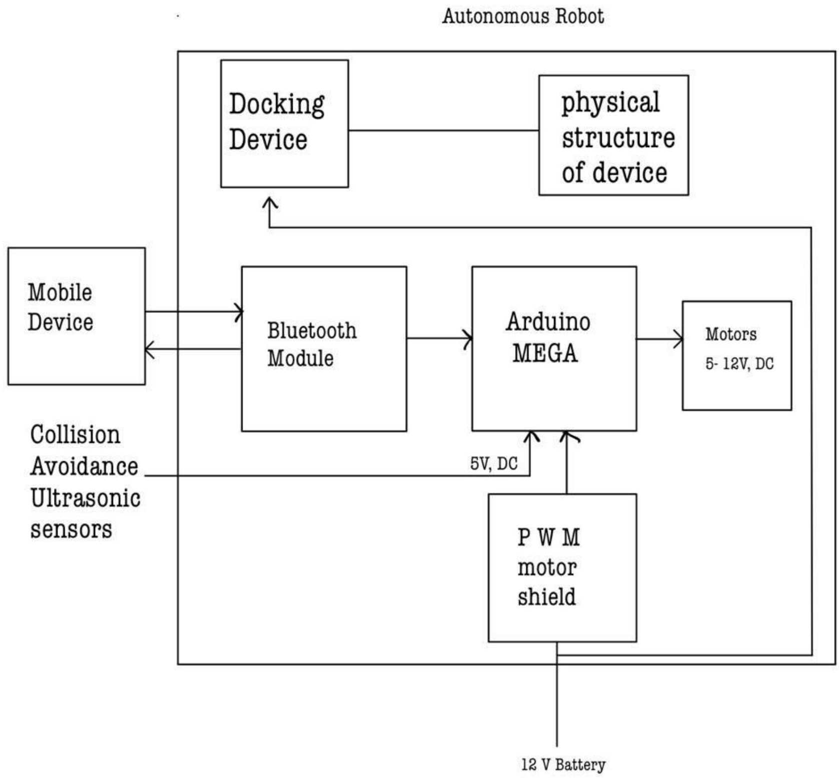
Looking at the table above and comparing the weights of the various criteria, time to develop and ability to develop are clearly main priorities, as they make up for well over half of the total weight. Design 1 meets these categories the best, staying well rounded all throughout. Design 2, while also well rounded, would take too long to develop. Design 3 is very difficult to develop and would have a high manufacturing cost, although it would have a very good consumer ease of use.

Given the data above, Design 1 seems to be the most suitable alternative to meet the needs of the project. This design affords us the time necessary to complete all of the objectives while maintaining a low cost, and it will be relatively easy to develop and manufacture when compared to the other designs.

VI. Preliminary Design

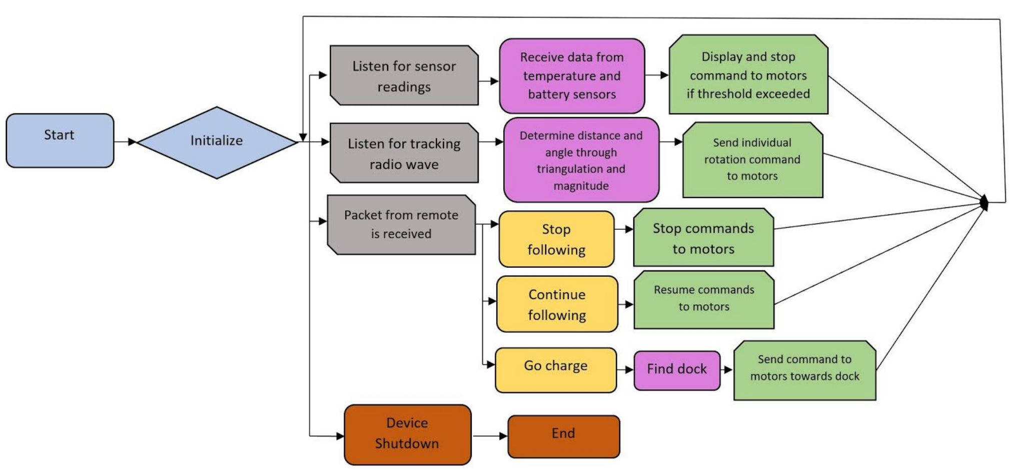
Level 1 Design:

Figure 5: Level 1 Circuit for Best Design Alternative



Software Design:

Figure 6: Autonomous Robot Software Level Diagram



Circuit Design:

Figure 7: Boost Converter Schematic

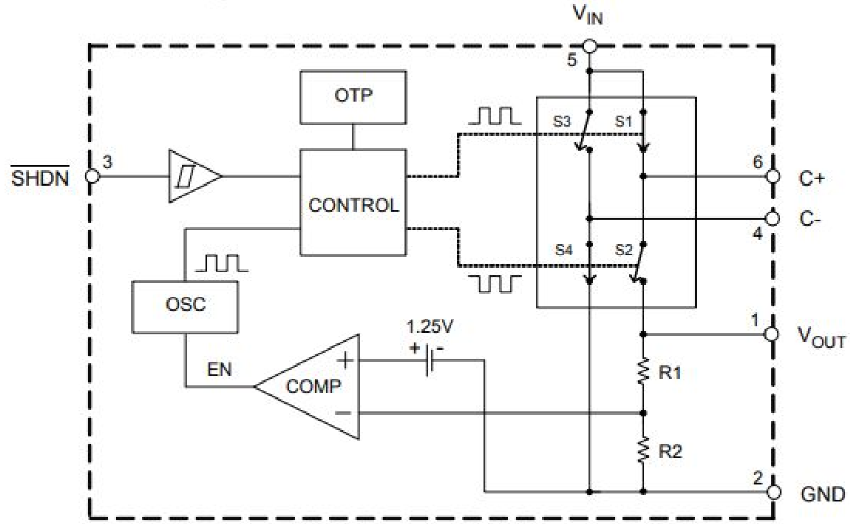


Figure 8: Buck Converter Schematic

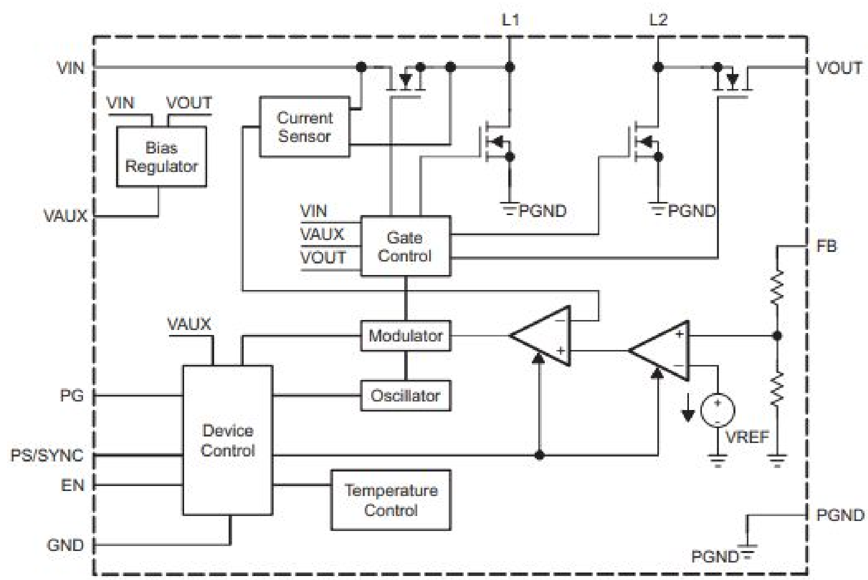


Figure 9: Arduino Mega 2560 Schematic

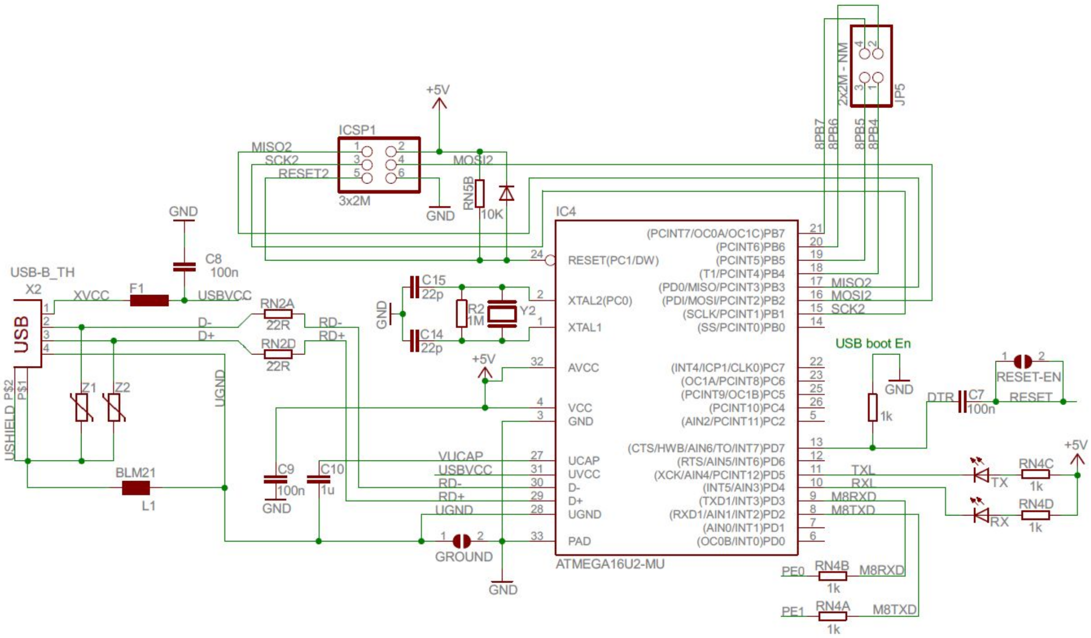
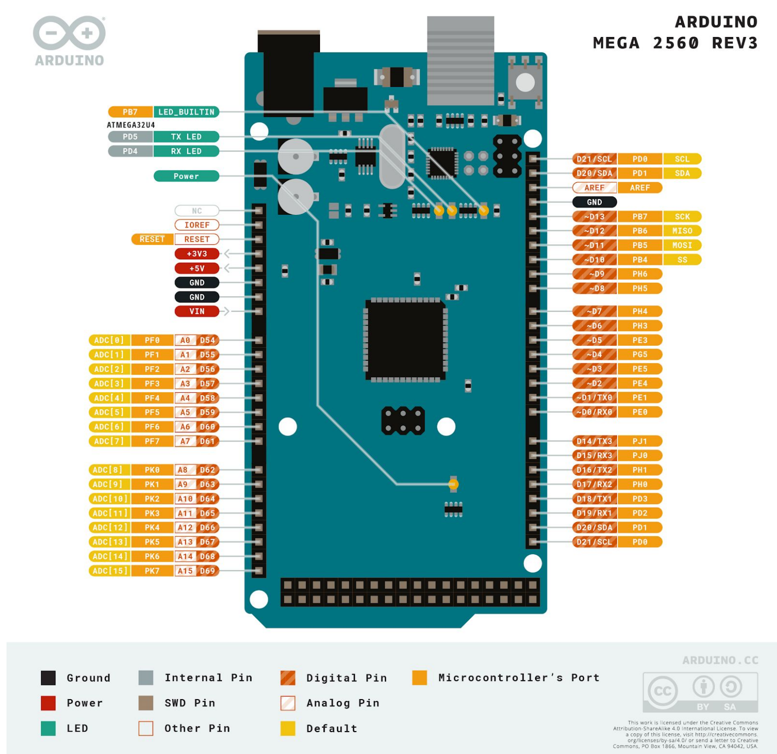


Figure 10: Arduino Mega 2560 Pin Layout



VII. Final Design

Figure 11: Block Diagram

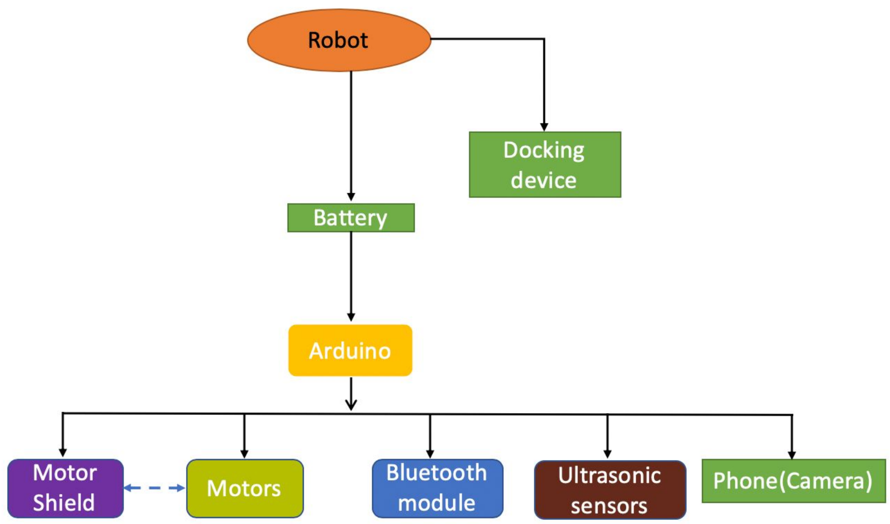


Table 13: Bill of Materials

Part	Link	Cost	Quantity	Total
Ultrasonic Sensor	https://cutt.ly/7rWxn6w	$9.59	2	$19.18
*OLED Screen	https://cutt.ly/DrWxUK1	$6.99	1	$6.99
Arduino Mega	https://cutt.ly/OrIA1Za	$14.99	1	$14.99
Cooling Fan	https://cutt.ly/5rIA8ih	$7.37	1	$7.37
Heatsinks	https://cutt.ly/vyxUO9m	$9.99	1	$9.99
Motors/Controllers/ Wheels	https://cutt.ly/kyxUAin	$14.99	1	$14.99
BlueTooth Module	https://cutt.ly/MyxUDcO	$9.99	1	$9.99
Wire Crimp Set	https://cutt.ly/5yxUVZ9	$12.99	1	$12.99
18 Gauge Wire	https://cutt.ly/gyxUMyG	$14.99	1	$14.99
Battery	https://cutt.ly/fyxUHoH	$99.99	1	$99.99
*7 Segment Displays	https://cutt.ly/syxUKjm	$5.49	1	$5.49
Terminal Blocks	https://cutt.ly/1yxUZbR	$12.49	1	$12.49
			Cost:	$229.45
*Not implemented in final design			Budget:	$20.55

VIII. Task Allocation and Timeline

Table 14: Task Allocation and Timeline

Week	Task	Description	Leader
1/24/20 - 1/29/20	1	Ordering of parts and early design stages	Evan
1/29/20 - 2/5/20	2	Part testing and research stage	Karim
2/5/20 - 2/12/20	3	Setting up connection of parts and software	Kishan
2/12/20 - 2/19/20	4	Redesigning autonomous features of robot	Michael
2/19/20 - 2/27/20	5	Looked into power requirements and code debugging	Evan
3/11/20 - 3/18/20	6	Finished the prototype and continued code debugging	Kishan
4/3/20 - 4/10/20	7	Building of the robot and testing autonomy functionality	Evan
4/10/20 - 4/17/20	8	Robot Testing	Michael
4/17/20 - 4/24/20	9	Expo Slides and Demonstration	Karim

IX. Testing and Results

Testing is an extremely important step in any developing products lifecycle. For each step taken forward on a project, one must ensure to test the product and ensure proper functionality before continuing onwards. Failure to properly test any individual component could lead to less than desirable results.

During the building and implementation of our project, components were tested at each stage to ensure proper functionality. Initial testing results per component are outlined below:

Table 15: Component Testing and Results

Component	**Testing Methodology**	**Results**
Arduino Mega 2560	Plug in various components, hook up to the computer, flash example.	Compiles with no errors
Battery	Use the device from full to no charge, charge back up to full, calculate capacity.	Works as advertised, calculated capacity was 82Wh vs. advertised capacity of 88Wh.
Motors	Hook up directly to power supply and ensure each motor works and runs at correct speed.	One of the motors runs slightly lower at the same voltage supply.
Motor Controllers	Hook up motors to the controllers, power the motors through them, and power the controllers with the battery.	Accurately provides PWM to motors via Arduino. Powers motors perfectly fine.
Ultrasonic Sensors	Hook up to Arduino, program, ensure proper distance measurement.	All of the sensors received gave consistent results when tested individually.
OLED Display	Print output of sensors	Crisp image, fast refresh rate.

X. Lessons Learned

Throughout any project, regardless of difficulty, it is important to treat the process as a learning experience. Analyzing each and every step, criticizing constructively, and formulating new, creative ideas is the ground floor in terms of knowledge and experience acquisition. It is in this way that humans grow and develop, and only by expressing a true passion, a thirst for knowledge, can individuals find themselves in a state of success.

During the implementation of our project we faced many difficulties. The two that come to mind immediately are planning and time. Throughout the semester, our project changed a lot. The base methodology of how we would actually track and follow the user was constantly evolving. We learned quickly that had we spent more time planning and doing research, we probably would have been able to come up with a better solution to the problem. If we were to do this entire project all over, from the beginning, knowing what we know now, things would be a lot different. We likely would not shy away from machine learning, but rather meet it head on. An Nvidia Jetson paired with a webcam would have been an insanely competent build for the job.

The second thing that we really learned was how to manage our time. Having an entire semester to build a robot sounds extremely feasible...until it isn't. There are a multitude of reasons why time was an issue, but what it really boils down to is the lack thereof. Whether it be due to personal issues or time conflicts, not everyone was available to always be working on the project. We severely underestimated the amount of time that we would be spending working on the robot, both in physically building it and in programming it. While all of the components were tested individually, there were still issues and complications when it came to integrating the components into one seamless system. The amount of time spent programming was insurmountable, and was by no means an easy task. We were extremely close to having a finished project just days before it needed to be completed, and we hit some major roadblocks. Time is not something to take lightly, as had we not pulled a couple all-nighters to debug the program, everything could have fallen apart, and we would not have been able to recover.

XI. Conclusions

In conclusion, there were many things that we did right, and many that we did wrong. As stated above, if we were to start all over, given what we know now, things would be different. While we would still be using machine learning, our component choice would have changed drastically. Instead of using the user's phone and an application to actually do the tracking, we would be using an Nvidia Jetson Nano microcontroller paired with a camera, such that no user device would be necessary. Other things we would have changed would probably be giving Alexa custom voice commands, such as "follow me" or "stop following" telling the robot what to do. The final thing that we would likely do differently, under the scrutiny of conformity, would be to focus on Alexa being the primary target for devices. Broad compatibility for multiple devices was not originally in the plan, hence the name, but was brought about simply due to convenience. A more proprietary device, although removing features, would give the device a much larger sense of purpose.

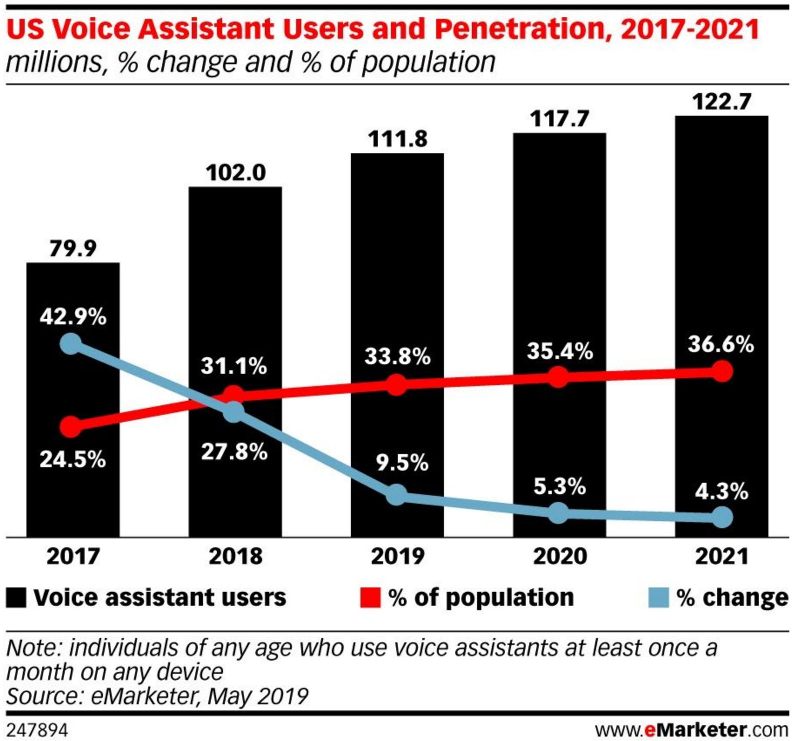
XII. Appendix

Appendix A: Final User Manual

The user can begin using the robot by first powering up the robot's battery, then starting up their phone app that allows the robot to start following them. Although the robot is connected to an Amazon Echo by default, the user can replace it with another device that is powered similarly (via USB/AC). Afterwards, the user can command the robot to follow them through the phone app and can go on with their day as the robot follows them autonomously and can avoid objects in the way of its following path.

Appendix B: Research Survey

Figure 12: Research Survey Graph



Appendix C: User Survey Results

https://docs.google.com/spreadsheets/d/1JMO7NmUos2oyvnFPjCx3p-8Ny-_08AZlB4qpafahW1g/edit?usp=sharing

Appendix D: Work Distribution on Final Report

Table 16: Work Distribution on Final Report

Karim Eltahawy	Worked on the autonomous features and participated in the design stages of the robot.
Evan Gruzlewski	Worked on the programming of the Arduino and the components connected to it and participated in building/testing the robot.
Kishan Patel	Worked on designing the body of the robot, was in charge of the 3D-printing, and managing the parts needed.
Michael Banasik	Worked on the power distribution and participated in the building/testing of the robot.

Appendix E: Source Code

https://github.com/egruzl2/FollowMeAutonomousAlexa/

Appendix F: Slides and Video

Slides:https://docs.google.com/presentation/d/1D7koh7q1Qo3JnRhW7tCW0pLHRZhWV05ekbCOTMy20gY/edit?usp=sharing

Video: https://youtu.be/LSVruoDa8z4

XIII. References

[1] “What Are Autonomous Robots?”, Waypoint Robotics. [Online] Available: https://waypointrobotics.com/blog/what-autonomous-robots/ [Accessed:06-Oct-2019].

[2] T. Melanson, “Augmented Autonomy – The Future of Autonomous Machines”, Robotics Online, 2018. [Online] Available: https://www.robotics.org/blog-article.cfm/Augmented-Autonomy-The-Future-of-Autonomous-Machines/86 [Accessed:06-Oct-2019].

[3] C. Woodford, “Roomba® robot vacuum cleaners”, ExplainThatStuff, 2018. [Online] Available: https://www.explainthatstuff.com/how-roomba-works.html [Accessed:06-Oct-2019].

[4] “Interferometer“,howstuffworks, 2009. [Online] Available: https://science.howstuffworks.com/dictionary/astronomy-terms/interferometer-info.htm [Accessed:06-Oct-2019].

[5] Z. Fang, L. Deng, Y. Ou, and X. Wu, “A Tracking Robot Based on Wireless Beacon

“, ResearchGate, 2010. [Online] Available: https://www.researchgate.net/publication/221105377_A_Tracking_Robot_Based_on_Wireless_Beacon [Accessed:06-Oct-2019].

[6] V. Song, “Are You Ready For an Alexa Robot to Follow You Around?

“, Gizmodo, 2019. [Online] Available:
https://gizmodo.com/are-you-ready-for-an-alexa-robot-to-follow-you-around-1836306499
[Accessed:06-Oct-2019].

[7] A. Li, “Temi’s personal home robot adding ‘Ok Google’ & Assistant, launching this year for $1,499“, 9to5Google, 2018. [Online] Available:
https://9to5google.com/2018/07/11/temis-personal-home-robot-ok-google/
[Accessed:06-Oct-2019].

[8] “The Personal Robot”, Temi.com, 2019. [Online] Available:
https://www.robotemi.com/product/temi/ [Accessed:06-Oct-2019].

[9] V. Petrock, “US Voice Assistant Users 2019 Who, What, When, Where and Why“, eMarketer, 2019. [Online] Available:
https://www.emarketer.com/content/us-voice-assistant-users-2019 [Accessed:06-Oct-2019].

[10] B. Martin, “Advancing Autonomous Systems: An Analysis of Current and Future Technology”, rand, 2019. [Online] Available:
https://www.rand.org/content/dam/rand/pubs/research_reports/RR2700/RR2751/RAND_RR2751.pdf [Accessed:06-Oct-2019].

[11] R.Mitchell, “Now your Tesla can come pick you up”, Los Angeles Times, 2019. [Online] Available:
https://www.latimes.com/business/story/2019-10-04/tesla-puts-driverless-cars-on-public-byways-controlled-by-humans-with-smartphones-abuse-is-rsafety-regulators-shrug
[Accessed:06-Oct-2019].

[12] “TPS61045 Digitally Adjustable Boost Converter", Texas Instruments, 2014. [Online] Available: https://www.ti.com/lit/ds/symlink/tps61045.pdf [Accessed:02-Dec-2019]

[13] "HC-SR04 Ultrasonic Sonar Distance Sensor + 2 x 10K resistors", Adafruit.com, 2019. [Online]. Available: https://www.adafruit.com/product/3942 . [Accessed:02-Dec-2019].

[14] "Adafruit Motor/Stepper/Servo Shield for Arduino v2 Kit - v2.3", Adafruit.com, 2019. [Online]. Available: https://www.adafruit.com/product/1438 . [Accessed:02-Dec-2019].

[15] "Monochrome 128x32 I2C OLED graphic display", Adafruit.com, 2019. [Online]. Available: https://www.adafruit.com/product/931 . [Accessed:02-Dec-2019].

[16] "VERTER 5V USB Buck-Boost - 500mA from 3V-5V / 1000ma from 5V-12V", Adafruit.com, 2019. [Online]. Available: https://www.adafruit.com/product/2190 . [Accessed:02-Dec-2019].

[17] "Adafruit MiniBoost 5V @ 100mA Charge Pump - AP3602A", Adafruit.com, 2019. [Online]. Available: https://www.adafruit.com/product/3661 . [Accessed:02-Dec-2019].

[18] "Adafruit Metro Mini 328 - Arduino-Compatible - 5V 16MHz", Adafruit.com, 2019. [Online]. Available: https://www.adafruit.com/product/2590 . [Accessed:02-Dec-2019].

[19] “Arduino Mega 2560 Rev. 3”, Digikey.com, 2020. [Online]. Available: https://www.digikey.com/reference-designs/en/open-source-mcu-platforms/2546 [Accessed: 07-May-2020]

[20] “Arduino Mega 2560 Rev. 3”, arduino.cc, 2020.[Online]. Available: https://store.arduino.cc/usa/mega-2560-r3 [Accessed: 07-May-2020]

Digital Signatures

Michael Banasik

Michael Banasik

Evan Gruzlewski

Evan Gruzlewski

Kishan Patel

Kishan Patel

Karim Eltahawy

Karim Eltahawy