TOWARDS ACCESSIBLE SMART HOMES FOR SENIOR CITIZENS

An Undergraduate Research Scholars Thesis

by

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Approved by
Faculty Research Advisor: Jeeeun Kim

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Major: Computer Science

RESEARCH COMPLIANCE CERTIFICATION

Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

I, Rush Hoelscher, certify that all research compliance requirements related to this Undergraduate Research Scholars thesis have been addressed with my Research Faculty Advisor prior to the collection of any data used in this final thesis submission.

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ABSTRACT

TOWARDS ACCESSIBLE SMART HOMES FOR SENIOR CITIZENS

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Will aging individuals accept the convenience and safety features of Smart Home technology? According to the U.S. Census Bureau Population Projections, there are currently 52 million people categorized as aging individuals with an age over 65. Almost a third of these individuals do not have internet connection. A majority prefer to maintain their independence, but many will likely encounter health issues that limit their abilities to continue to live on their own without support. Something as convenient as voice command lights, phone calls, or entertainment could assist these individuals in staying safe, even with limited mobility. This is where the problem arises. Most seniors do not accept life changing smart home technology for many reasons. In this work, I introduce an offline system and preferred command-device that can be used to control a house. In addition, pairing with Alexa is possible with internet access.

DEDICATION

Dedicated to my Great-Aunt Rosa Lee Hoelscher 1931-2021.

ACKNOWLEDGEMENTS

Contributors

I would like to thank my faculty advisor, Dr. Jeeeun Kim, and user testing advisor Elaine Yi-Lien Liang for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University an engaging and educational experience.

Finally, thanks to my parents, Stephen and Gwynetta, and my fiancée Aynsley (as seen in video) for their encouragement.

All other work conducted for the thesis was completed by the student independently.

Funding Sources

This work is not supported through any funding agencies.

NOMENCLATURE

B/CS	Bryan/College Station
nodeMCU	The firmware that ESP chips run on.
ESP	The family of chips from Espressif Systems
ESP 12	Also referred to as 8266 (the chipset) and nodeMCU (the firmware) in documentation.
ESP 01	The first and smaller iteration
TAMU	Texas A&M University
C	A popular and very strong programming language
Arduino C	A reduced version of C to function on lightweight hardware
DNA	Did Not Answer - This is used to make figures more readable.

1. INTRODUCTION

1.1 Introduction to Smart Homes/Businesses

Throughout time, humankind has made strides to create products used in our daily lives easier, safer, and more reliable. One of the most obvious advancements is the light system, starting with open fires and moving to candles, lanterns, and eventually electric lights. These advancements have saved countless work hours in both installation, activation, and upkeep. Currently, we are making the next step to reduce all these again; this will be done through the Smart Home/Business.

The idea of the smart home is to connect the user's needs to the control system and act accordingly. This is done using a network of sensors and controlled devices. However, this innovation has not spread to all segments of the population. In fact, there are major gaps in rural communities as well as aging individuals. This paper focuses on the elderly with poor internet connection who would likely benefit tremendously from such an innovation and how smart homes can better apply to their lives.

1.1.1 The Modern Smart Home

Current smart home designs typically rely on devices such as Google Home or Amazon Alexa, with some users opting for more advanced "hubs" that can connect more devices over different control frequencies. However, there is a common trend here, that almost all of these devices require always-online cloud services. Considering a cost perspective, according to market research (Home Depot and Amazon), in the spring of 2021 the cost of a basic light switch is around $0.50 whereas the least expensive consumer smart home switch is closer to $8.00.

1.1.2 The Problem with the Modern Smart Home

This online cloud system works well enough for many users to accept its shortcomings; however, there is a large sector of people who find an always online system impossible for their internet situation and many others worry about the privacy risks involved with that kind of conductivity. This is a major problem since “27% of seniors do not use the internet at all.” ("U.S. internet reach by age group 2019.") Out of those who do have the internet, there are many others who worry about “planning for the eventuality of their computer ‘blowing up’” and find general usage “quite frightening.” (Hanson, Bran, Knowles, Vicki L.) Even in everyday tasks “older adults are considerably less likely than their younger counterparts with a disability to adopt assistive tools designed specifically for them” (Hanson, Bran, Knowles, Vicki L.) These barriers to early adoption keep these tools out of the hands of seniors who would benefit from them, because the tools are compatible with their needs, but not with their adoption processes.

1.1.3 Other Groups That Can Benefit

Currently, research continues in multiuser smart homes. As knowledge increases, it sets precedent as to how roommates and family can assist each other and increase the level of care for all involved. This becomes a problem with roommates because “there is often one person to whom the device belongs, and there is less of an assumption of shared access and control rights as there may be between partners.” (Geeng and Roesner 1-13) Although relatively straight forward in areas where one of the residents purchased the hardware, there are also cases when “Some smart home fixtures may remain physically with a home when people move, such as smart outlets or thermostats.” (Geeng and Roesner 1-13) As with all technology, smart home technology needs an end-of-life plan. Some of these devices, specifically security cameras, can become permanently locked to one account. In the case of selling a device to another user, this

transfer process can be a hassle at best or impossible at worst. This presents a scenario where much of this new, expensive technology can actually end up in a landfill instead of being used for years, if not decades to come. If offline smart home systems progress, both of these topics will eventually require consideration as the technology reaches maturity.

1.2 The Current Offline Smart Home

Currently, the fully offline smart home is nothing more than the occasional remote controlled or temperature-controlled device such as a ceiling fan or HVAC system. As with most emerging technology, this presents an important junction point where unity can actually occur. Today, we can see that anytime a standard does not emerge quickly enough, such as in some of Europe's mixed directional roads and Japan's electric grid, these unnecessary differences reduce efficiency when interacting with each other and make life more difficult for everyone involved. Without true compatibility, devices can still be added to the system, but compatibility issues will result in frustration even if they still mostly work most of the time. In something like a smart home, once the complexity and frustration increase, its negatives can quickly outweigh its benefits and cause the user to prefer traditional methods of control, thus harming the user in the long term.

Clearly, remote control solutions are primitive, and better solutions exist with online connections. This leaves the question of whether we can find a middle ground with the ease of use of the always-online systems while maintaining a level of perceived privacy and security.

1.3 The Semi-Offline Smart Home

An advanced control system that smart home enthusiasts use is a system called Home Assistant. This works largely offline but connects to many online services and requires internet conductivity to operate fully. This system works very well but does not fulfill the needs of the seniors who have absolutely no internet access at home. Additionally, it requires hardware including a Raspberry Pi and administration controls on a router to operate. This requirement also raises the barriers to entry since people living in apartments may not be permitted to use their own routers. These downsides are negated by some clear advantages such as easy home automation with both visual and scripted linkages and user-friendly interfaces (Figure 1.1). This interface can be viewed, controlled, and edited on computers, tablets, and phones. Although Home Assistant is a very powerful system, its high barrier to entry and lack of resources for non-technical users puts it out of range for many seniors to use and create a smart home on their own.

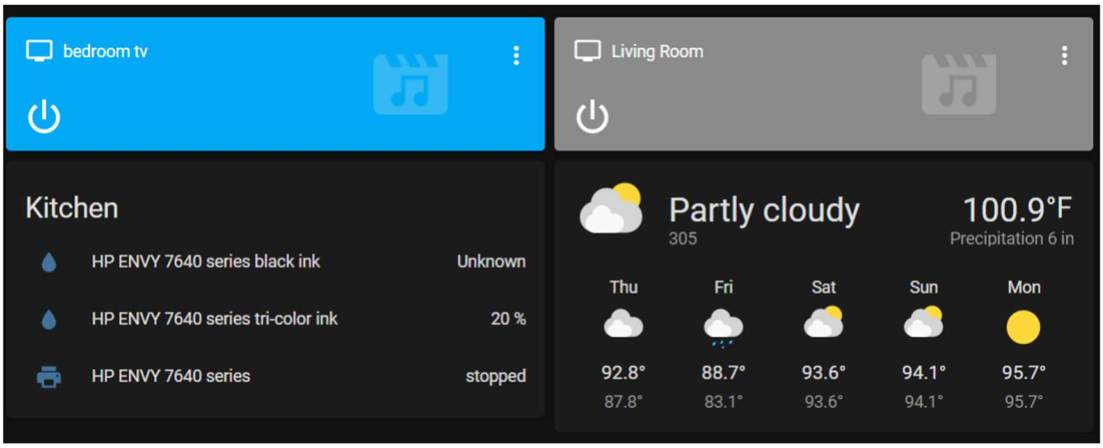

Figure 1.1: Home Assistant User Interface

1.4 Proposal of Offline Smart Home

I will be creating this middle ground solution where no current option exists. I will be using ESP 01 and ESP 12 chips for networking and control. The ESP 12 chips will be paired with sensors and the ESP 01s will pair with relays to control other devices. This has created a system that is visually secure to the users since it does not allow or require any outside connection while maintaining an actual state of security since there will be no saved data that could even be breached. These advancements should make this offline method more acceptable for users while maintaining much of the usability of always online systems.

2. METHODS

In this section, I detail the creation processes for the hardware and software, the processes that the projected user surveys and interviews will follow, and the results from the user surveys.

2.1 Hardware Implementation

The design rationale used in choosing hardware systems is to support the most cost-effective microchip series. This eventually came to the ESP 01 and 12 as other options that were heavily considered were Raspberry Pi s and the ESP 32 series; however, these were much less cost effective. Once this was determined, I investigated which pins were safe to attach using Figure 2.1 with the best options being pin D1, D2, D5, D6 and D7 as these can act as both input and output while not being pulled in any direction during boot or controlling the boot process of the micro controller.

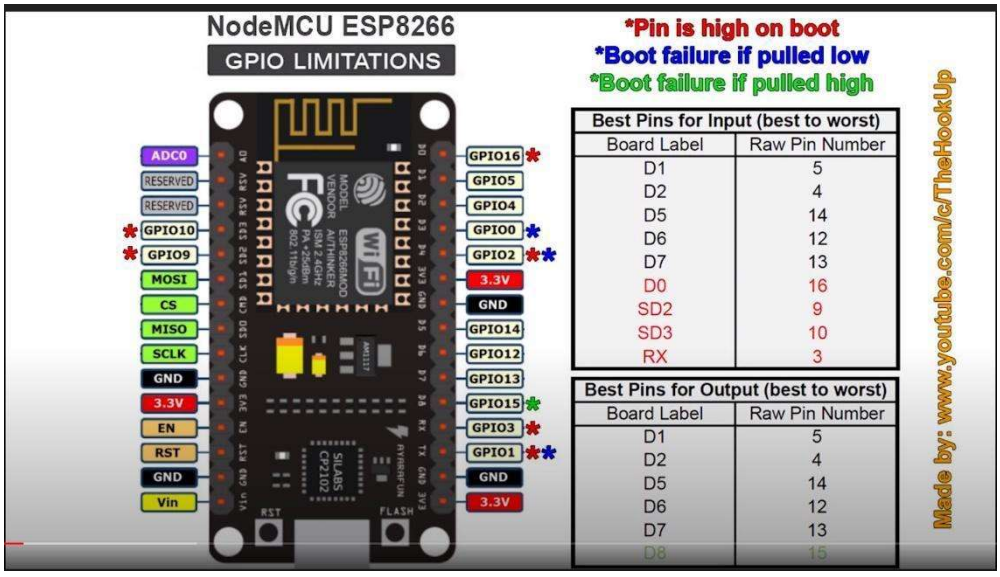

Figure 2.1: ESP 12 pinout

2.2 Software Implementation

The ESP system is an Arduino based system, so it runs on a variant of C. From here, I was able to use ESP Painless Mesh to create a local mesh network that allows any number of ESP systems to connect to each other. Beyond this, I set up protocols that allow for varying commands to be sent across the network to control different rooms and give access to measurements. From here, I went about implementing the programing for the different control methods setting the options for the IR controllers and integrating the motion sensors into the control units. For further technical information please reference Appendix B.1 or at https://github.tamu.edu/rushhoelscher1/SmartHomesForSeniors.

2.3 Design of User Testing

Originally, the trial was planned to be an in-home, user-testing experience to find the optimal option for aging users. However, with the onset of COVID at the time this research has been conducted (Fall 2020-Spring 2021), in-home user testing became unnecessarily risky to this vulnerable portion of the population. Since these users present a completely different understanding of and experiences with technology, they require special considerations.

The new testing plan will result in a videoed user test involving people in my circle of contact interacting with the system. These videos will show the differences between remote control systems, motion-controlled systems, and voice operated (Alexa) systems of smart home control. This video can be viewed through this link https://www.youtube.com/watch?v=EzGrcS5-Y7k. The videos of that test will be presented to a larger group of seniors as well as others after they fill out a consent form, as seen in Figure A.1. This will result in a much broader cast than the previous plan could achieve. This will be followed up with questionnaire Figure A.2 to collect clear results; however, the live experiences

would have been preferred, but a phone interview follow up can still allow for an in-depth conversation about how participants would envision themselves using the system while maintaining a testing environment.

This testing will include 15-30 second demonstrations of each system plan. (Table 2.1)

Table 2.1: User Options

Type	Remote Control	Motion	Local wireless control	Amazon Alexa
Description	Based in IR signals, similarly to a television remote	Based on sensors that detect the presence of movement	Based on a locally contained intranet network, this will be used to set alarms	Voice based control that relies on a constant internet connection

These are the examples that the subjects are provided with.

2.4 User Survey with Videos in Three Conditions

2.4.1 Disclaimer

It is important to note that, due to the distribution method (Facebook sharing), everyone in the sample space will have access to the internet and will be at least competent in its use. I was hoping that we could pursue a different test path but due to COVID, meeting with seniors would be unwise to say the least. Even with these disclaimers, some of these subjects still may not have in home internet access but instead have access via another means such as a phone data plan, local connection points (libraries and restaurants), or through friends or family, so the survey still has the potential to reach some of that population; however, an in-person option would better reach this age group as the oldest person surveyed was 75.

2.4.2 Hypothesis

Through this study I seek to establish the need for an offline smart home system through the survey. Once this need has been established, the phone interviews will attempt to confirm if the surveyed individuals feel that the created system provides a benefit over current online systems.

2.4.3 Procedure

The participants process started with a Facebook post and video to capture their attention followed by the consent to participate. After this, the participants were expected to complete a questionnaire reporting how they felt about the different smart home options and advances in technology. At this point, some of the participants did not want to receive a call back, but out of those who did wish to receive the call back and were over 50. 18 calls were attempted. 7 participants answered their phones to continue with the interviews. These interview participants were asked to explain their reasoning further and discuss where the technology is going and where they would like it to go. At this point, all of the respondents would have completed the study.

2.4.4 Survey Results: Perception Towards Internet and Connected Devices

The introduction survey, as outlined in Figure A.1 and A.2, has yielded some very interesting results. Through this survey, we can see how the age of the user can impact many of the users' experiences such as the frequency of Internet outages does impact the over 50 population slightly more than the overall population. This likely contributes to the general distrust of internet conductivity as any unreliable resource. A major limitation of the standard smart house set is the requirement of a constant internet connection. In this surveyed population, half had monthly or more frequent issues (Figure 2.2).

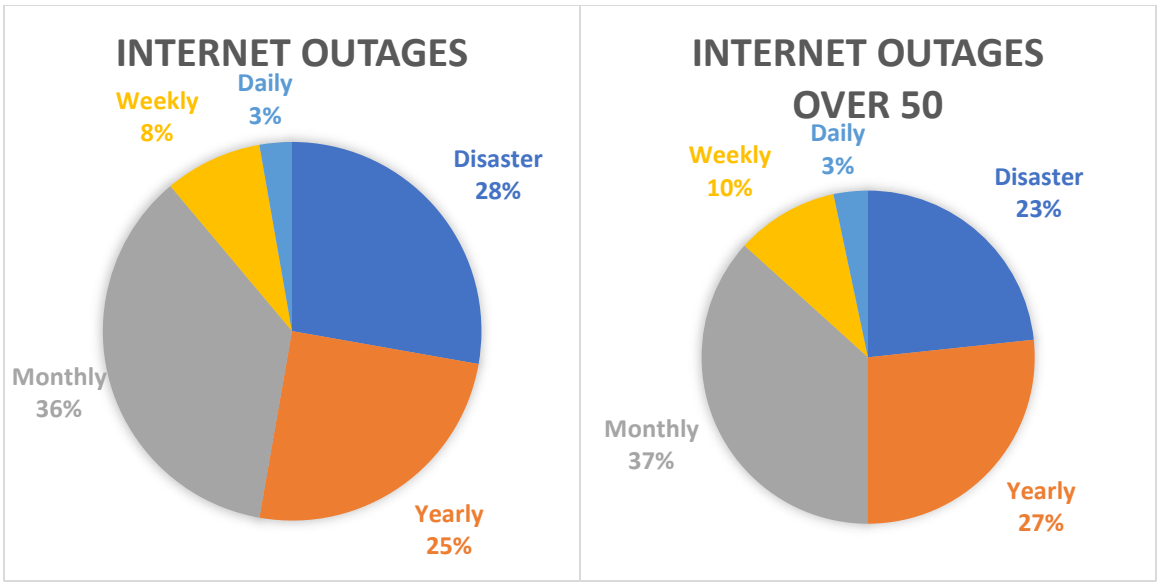

Figure 2.2: Internet Outages

Interestingly, only 30% of the survey participants reported that they have no concerns about online devices such as Amazon Alexa, phones, or computers listening to their private conversations, as seen in Figure 2.3.

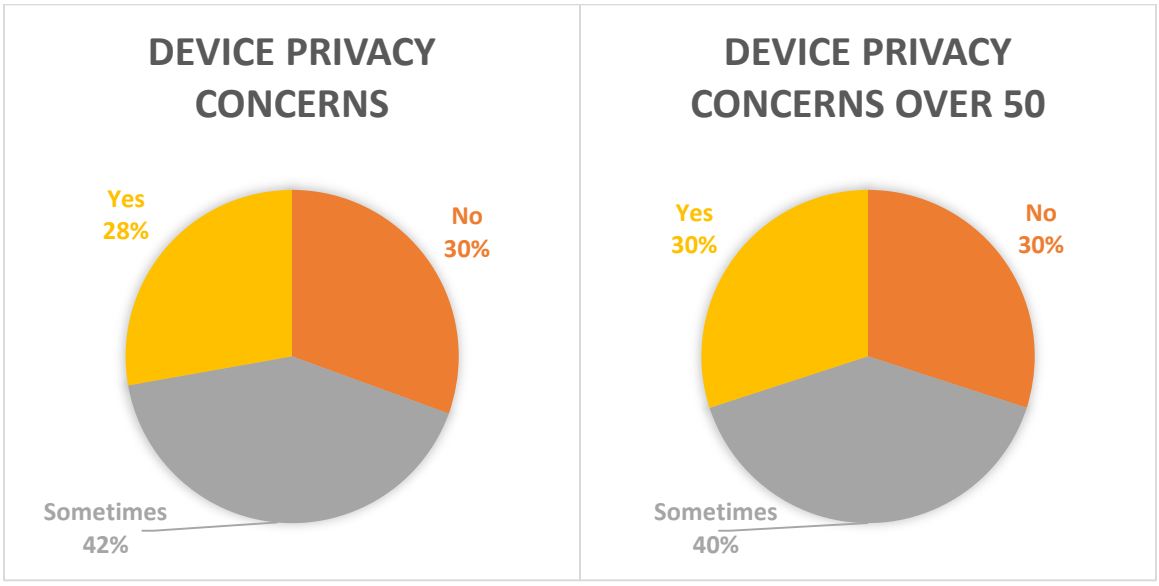

Figure 2.3: Device Privacy Concerns

However, greater concerns emerge when discussing general internet privacy. Participants tend to fear corporations and hackers; however, 4.7% of respondents had no privacy concerns and personally that is still too many, as depicted in Figure 2.4.

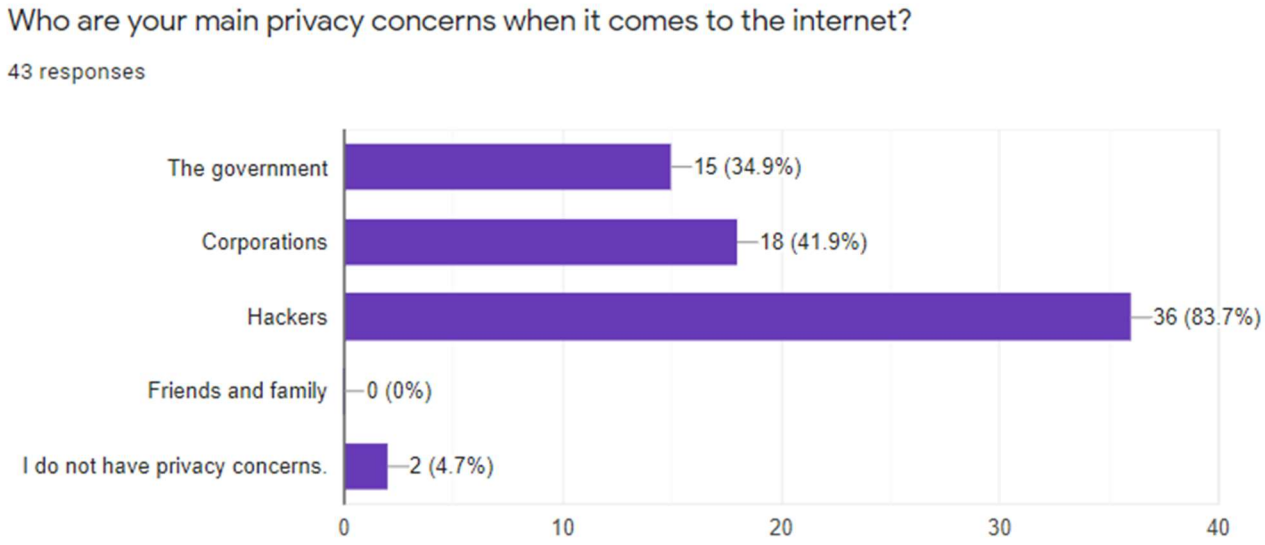

Figure 2.4: Privacy Concerns

The survey revealed that 36% of people are currently afraid of an online Smart Home device compromising their privacy, as shown in Figure 2.5.

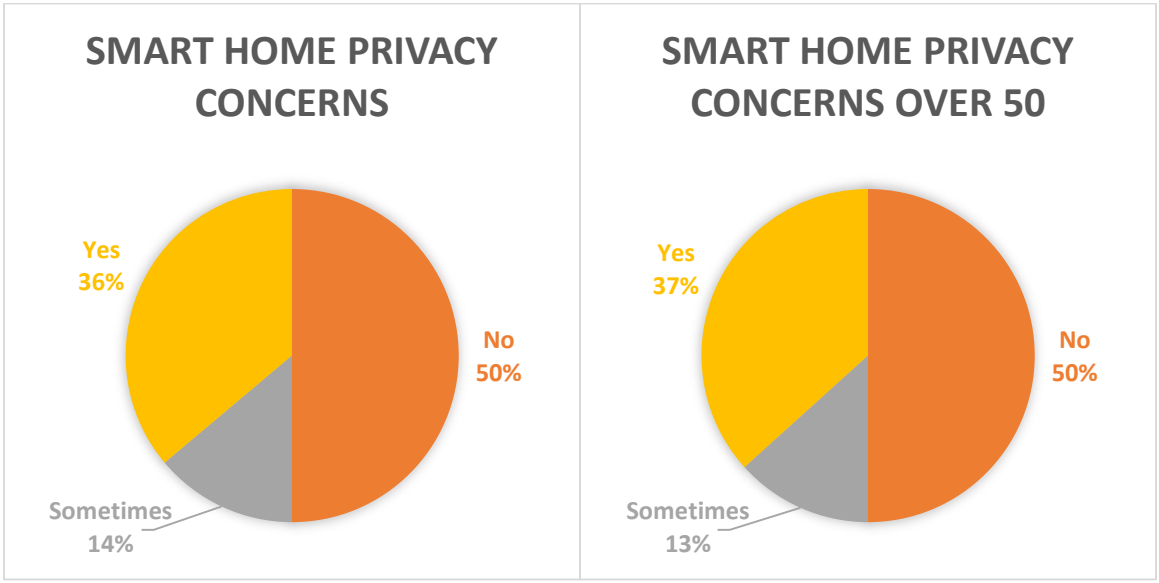

Figure 2.5: Smart Home Privacy Concerns

This can be solved by switching to an offline variety where over 75% (Figure 2.6) of the survey population would prefer a version of a Smart Home that does not communicate over the internet, as well as 73% of the population over 50. When the remaining 11% were asked why they preferred online systems, they said it had to do with cost concerns, which is a valid concern as consumer grade smart switches are roughly 10 times the cost of traditional switches. Other participants simply wanted features that would not be possible ever on offline devices such as music streaming.

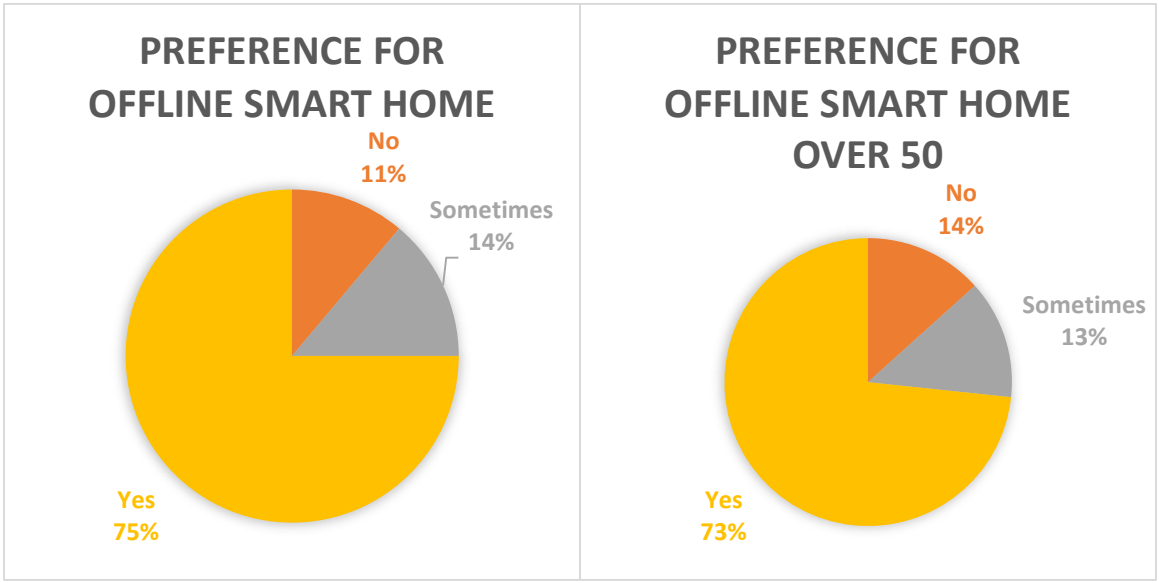

Figure 2.6: Offline Preference

Moving on to how this impacts the elderly more specifically, 17% of the overall population surveyed admitted to have fallen before and 20% of the over 50 population have fallen because it was dark in their home as seen in Figure 2.7. This is a surprising result as in today's society, lights are a staple of modern living and almost everyone carries a flashlight via their cell phones. This is a significant portion of the population that has been put in an

completely unnecessary danger. This proves that this project could advance further and prevent these future falls. Out of the section of the population that has fallen, 67% would prefer a version of a smart home that does not connect. If this were implemented this would be a significant portion that would never have been put in the position to fall in the first place.

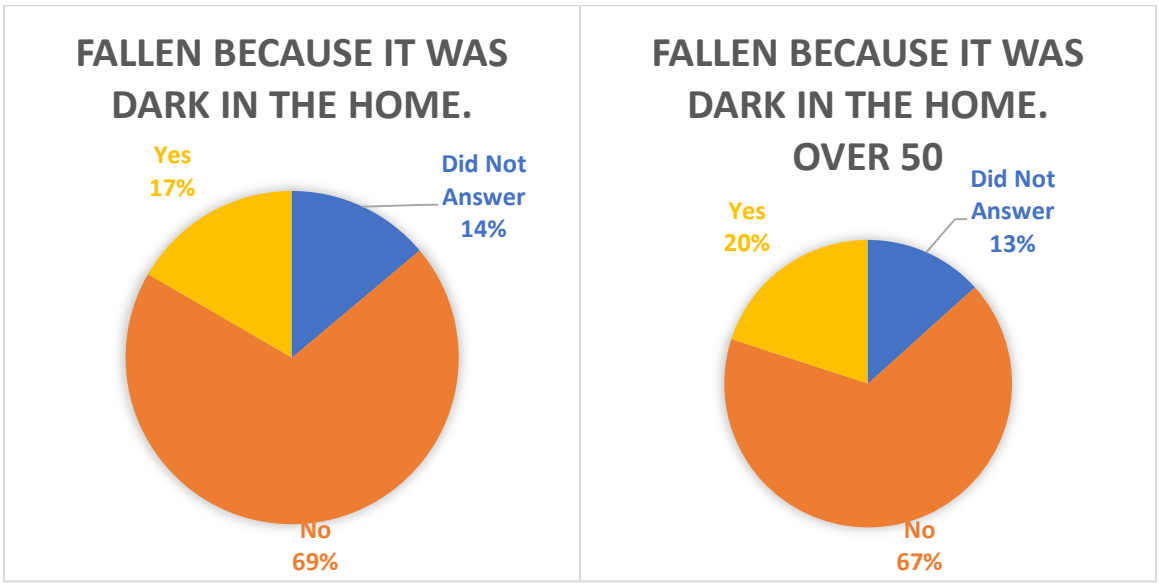

Figure 2.7: Fallen because of Darkness in Home

Within the surveyed group, we can see an interesting distribution of technology usage as seen in Figure 2.8. We can see that all surveyed (from Facebook) are answering correctly and do use the internet. We also see an interesting distribution of virtual assistants.

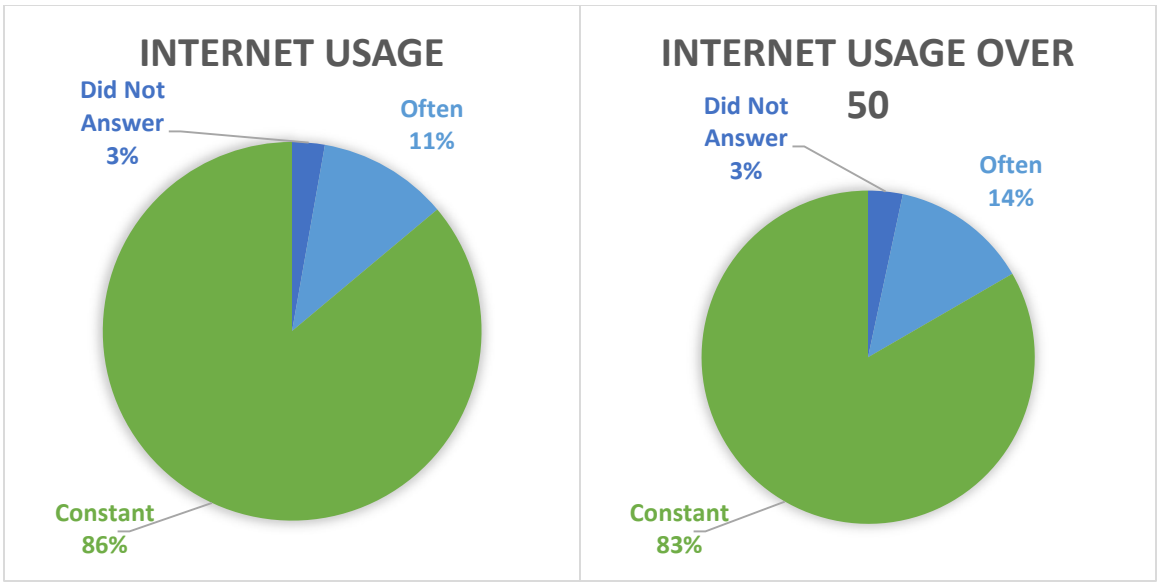

Figure 2.8: Internet Usage

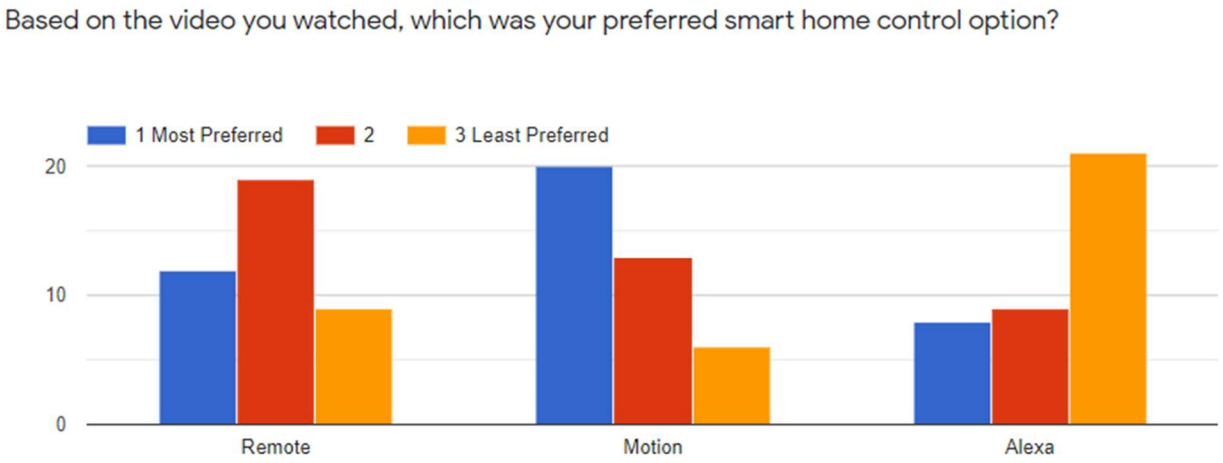

Figure 2.9: Preferred control Method

From the preferred control methods in Figure 2.9, we can see that people overwhelmingly preferred motion sensors. This can be justified as it is the least effort that one would have to impart on a system to activate it. It is interesting to see that Alexa (voice control) was the least preferred among this population. This could fall on perceived reliability or connections from the

rest of the system knowledge, although this question was designed to only rate the control methods rather than the adjacent systems.

3. RESULTS

Among the survey respondents, I selected 18 possible participants for semi-structured further phone interviews with 7 continuing through the process. Here, I detail the findings of these interviews, resulting in both confirmation of the hypothesis as well and some unexpected results.

3.1 Phone Interview Overview

3.1.1 Inclusion Criteria: Qualifiers for Call Back

Here, I set two criteria to choose in-depth phone interview participants.

- Must be over 50
- Must have included phone number

3.1.2 Interview Script

The interview script was used as a basis for questions and functioned as the guide for the conversations and is included in Appendix B.1.

3.2 Results

In this section, I will summarize the responses from the phone interviews. Overall, the interviewed population supported the idea of an offline smart home and felt that it would increase their perceived and actual privacy.

3.2.1 Offline Versus Online

As with the survey, most people still prefer the offline options, but some interesting points were made about how both systems can be improved. In the instance of online options, some of the people surveyed said that “I think at this point the security is the bigger issue in relation to [online systems]”. This distrust leaves a market gap until smart home systems become proven in the eyes of the public. At that point, even some of the older people interviewed would

like it “if [security] is addressed it opens up a lot of options like video tracking within the home and having access to that.”

3.2.2 Control Methods

As said in the survey, people still tend to prefer the motion sensors, but the reasons have become clearer. During my interviews, one participant mentioned that “Walking in and voice activating is annoying” and “[voice control] is just unreal for the older people to understand”. These were somewhat unexpected, as the idea of voice commands is to be very natural and easy to use. Some of the interviewees preferred the remote for specific tasks but did not place it above the motion sensors because it was not general purpose enough since “There are specific areas where the remote works well” but it does not consistently place above the motion sensor.

3.2.3 Other Notes

The interviews also revealed some other interesting information such as many of the interviewees talking about how “the retrofit in an older home is somewhat challenging” as one of the major issues. This has some solutions since the wiring already exists, but in a new construction, it can be due to the fact that larger sections can be controlled and in existing construction “you have to put in a control device at every [outlet] location.” This can simplify construction like how “the modern PEX plumbing systems where all the pipes return to a central control hub instead of using the older more mainstream trunk and branch system.”

Returning to internet reliability, I got a specifically interesting response to this question from one subject where he/she discussed varying internet outages where short internet outages (seconds) occur often (weekly), and major outages (hours) occur roughly twice per year. This is an on-going concern in rural communities, as it is a common occurrence with radio frequency and satellite-based internet distribution systems. This is a section that is undergoing major

innovations currently in rural internet providers with a new major company joining in the competition, and it would be of merit to revisit during Spring of 2022 once the system is reaching maturity.

4. CONCLUSION

In this thesis, I researched the attitudinal and informational barriers to technology that exist within the senior citizen community to validate if there is a need for an offline smart home system and if individuals feel that the created system provides a benefit over current online systems. In an attempt to increase independence for this specific and valued population, I created an offline device that has the potential to add convenience and safety to their homes. After disaggregating all their surveys and discussing their comments and concerns over the phone, I feel confident that our senior population would embrace an offline smart home and increase their independence and overall well-being.

Typically, seniors lag behind the general population when it comes to technology. In many scenarios, a lag may not impede the quality of life of the individual; however, stagnation in the technology realm can significantly decrease both the physical safety and the security of senior citizens. We have a moral obligation to our aging population to provide simplified and manageable devices that assist with day-to-day protocol. In this study, the primary reason seniors stated for not using smart home technology is their lack of confidence about selecting and operating the devices.

In addition to confusion about smart home systems, seniors also expressed fears about losing their privacy to big corporations, hackers, and/or the government. A majority of participants declared they would have less fear of using a smart home system that functioned without accessing the internet.

By creating a streamlined and simplified smart home device that does not access the internet, our aging population would be more receptive to utilizing devices that assisted with safety and security.

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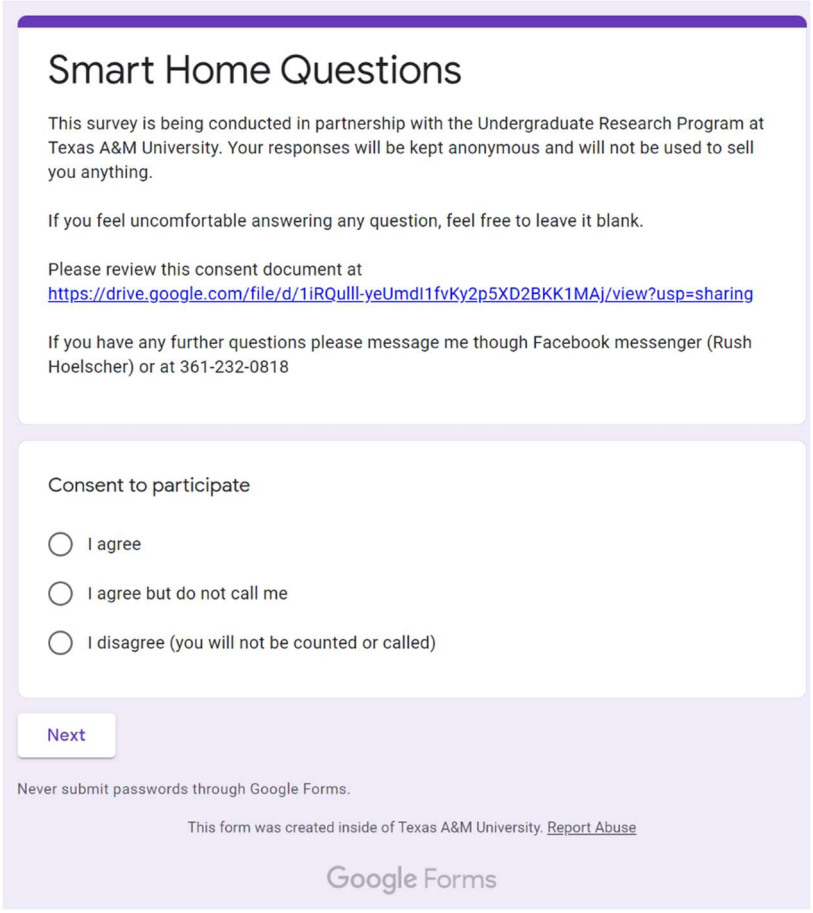
"U.S. Internet Reach By Age Group 2019." *Statista.* Web. Jan 24, 2021 <https://www.statista.com/statistics/266587/percentage-of-internet-users-by-age-groups-in-the-us/>.

APPENDIX: A – PARTICIPANT RESOURCES



Smart Home Questions

This survey is being conducted in partnership with the Undergraduate Research Program at Texas A&M University. Your responses will be kept anonymous and will not be used to sell you anything.

If you feel uncomfortable answering any question, feel free to leave it blank.

Please review this consent document at
https://drive.google.com/file/d/1iRQulll-yeUmdI1fvKy2p5XD2BKK1MAj/view?usp=sharing

If you have any further questions please message me though Facebook messenger (Rush Hoelscher) or at 361-232-0818

Consent to participate

- ◯ I agree
- ◯ I agree but do not call me
- ◯ I disagree (you will not be counted or called)

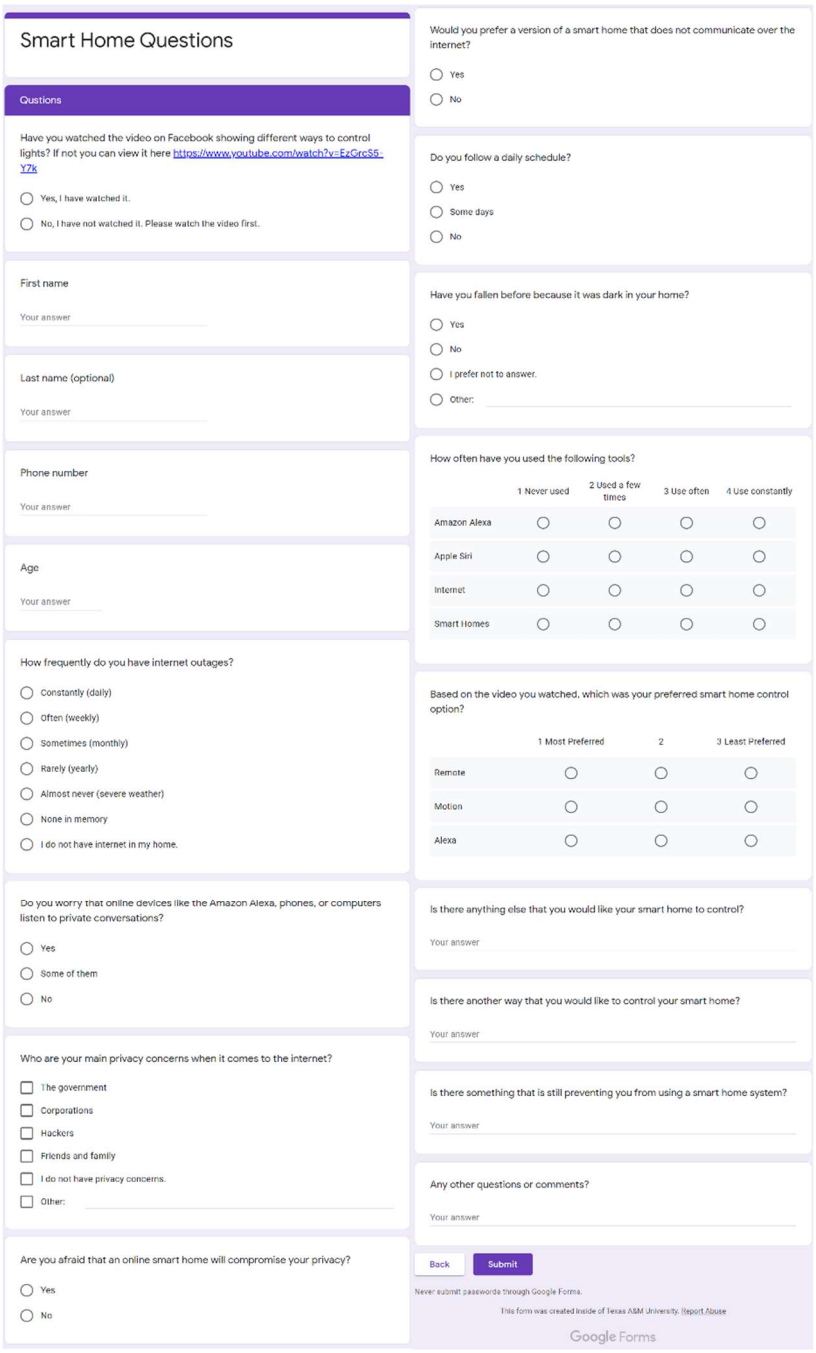
Next

Never submit passwords through Google Forms.

This form was created inside of Texas A&M University. Report Abuse

Google Forms

Figure A.1: Consent to Participate



Viewable at
https://docs.google.com/forms/d/e/1FAIpQLSfKdoIEEuUKUEFPfoQo89o-OuFgjrU6JZDjK4IDt7Ias4dgZw/viewform

Figure A.2: Main Questionnaire

Howdy, this is Rush Hoelscher. I am following up about my Smart Homes for Senior Citizens project. I would like to record this call so that I can transcribe your information accurately, then I will permanently delete the recording. I would like to confirm once again that you are over 18? May I record this call?

- Why does having an offline smart home make you feel more at ease with the technology and your privacy?
- Why did you choose _____ as your favorite control method?
    - Do you not like the other options or was this one just better? Why?
- Discuss current possibilities of both my offline system and consumer systems and ask if my system would dispel their concerns with smart homes.
- Is there anything else you would like to discuss?

Figure A.3: Interview Script

APPENDIX: B – PROCESS INFORMATION

https://github.tamu.edu/rushhoelscher1/SmartHomesForSeniors

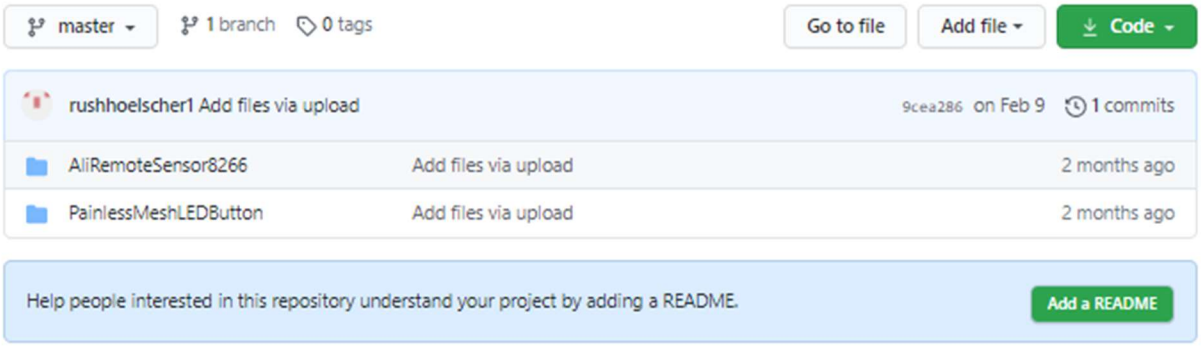


Figure B.1: GitHub Repository