Development of an Automatic Pet Feeding and Watering Station

(Technical Paper)

The Effects of User Perceptions on the Development of Smart Home Technologies

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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S. Travis Elliott, Department of Engineering and Society

With an increasing number of smart home devices being introduced each year, the potential benefits that these technologies promise to deliver seem to be endless. A smart home is defined as a residence that contains multiple smart devices that are connected through the Internet of Things (IoT), which allows the technology to "monitor, control, and support residents" (Marikyan et al., 2019, p. 139). Current applications of smart home technologies include supporting the disabled and aging population through health-care related services, monitoring and controlling home energy consumption, providing home security, and improving comfort through the automation of daily routines (Marikyan et al., 2019, p. 146). Despite these potential benefits, the adoption of smart home technologies has been slower than expected due to discrepancies between the potential benefits of the technology and users' perceptions of these benefits, which constitute barriers in the diffusion of the technology (Li et al., 2021, p. 6; Marikyan et al., 2019, p. 145). This lower rate of diffusion may hinder the development of smart home technologies (Marikyan et al., 2019, p. 148), including domains within the home environment that are currently underdeveloped with respect to other smart home technologies. One such domain that has had less development is smart pet care, which seeks to automate many of the tasks that pet owners perform on a day-to-day basis (Yao, 2021).

The technical project and the loosely coupled STS research project proposed in this prospectus address these issues. The objective of the technical project is to create an automatic pet food and water dispenser that can be used in a smart home environment to automate the pet feeding process. By creating this device, the technical project serves as a continuation in the implementation of smart home technologies within a domain that has not seen the same level of development as other areas of the smart home. The STS research project will look at the perceptions that users have towards smart home technologies, the factors that affect these

perceptions, and the effects these perceptions have on the development of smart home technologies. By identifying these effects and the factors that go into the perceptions users have regarding the technology, solutions for increasing the adoption rate of smart home technologies can be identified in future research. The technical project will be completed during the Fall 2021 semester, and the STS project will be completed during the Fall 2021 and the Spring 2022 semesters.

Development of an Automatic Pet Feeding and Watering Station

It is no secret that society exhibits a pet-loving culture where pets and their respective owners share a mutual bond dominated by companionship. These relationships are capable of delivering a host of benefits to pet owners. For instance, human-dog interaction has been shown to enhance quality of life by providing companionship and comfort to owners, as well as many other psychological and physical benefits (Knight & Edwards, 2008, p. 438). In this way, pets provide a great amount for their owners. However, this relationship works in two ways and can only be made sustainable if owners are willing and able to take adequate care of their pets. One important responsibility that pet owners must perform is providing food and water to their pets throughout the day. Although several feeding regimens exist, one that gives owners the most control over their pet's weight and health is portion controlled feeding, where a fixed amount of food is provided to the pet during specific times of the day (Wortinger, 2013, p. 136). According to Wortinger (2013), this regimen also has the benefit of allowing owners to observe behavioral differences based on their pet's feeding habits to determine possible health issues (p. 136).

Although the controlled feeding regimen gives owners the most control over their pet's health, it also requires that owners spend a greater amount of time planning and preparing these meals. For many owners, this time requirement is not an issue. However, not all pet owners have

the necessary time to consistently feed their pets. This is confirmed by a survey carried out by the American Humane Association (2012), which identified time constraints as a major barrier to pet ownership among previous dog and cat owners (p. 19). Thus, busy pet owners, including students and employees, may have time constraints that inhibit their ability to properly plan and prepare meals for their pets throughout the day. Another group of owners that may struggle to consistently provide food and water for their pets consists of elderly and disabled pet owners who may have mobility or psychological issues that pose a challenge in the feeding and watering process. Each of these groups must be provided a means of consistent feeding and watering if their pets are to be kept happy and healthy.

The technical project aims to remedy these issues by creating a smart home device that automatically dispenses controlled amounts of dry pet food and water into separate bowls when user specified conditions have been met. The user will be able to select feeding and watering times, the amount of food and water to be dispensed during each mealtime, and optionally, a constant water level to be maintained within the water bowl, which provides pets with an available water source throughout the day. This device, called the Smart Pet Feeding Station, will be developed over the course of a semester long project with assistance from fellow Electrical and Computer Engineers Landon Rhodes, Matthew Garrison, and William Mulquin, and guidance from Electrical and Computer Engineering Professor Harry Powell.

The technical project will be completed using a structured design process to ensure that the project is completed in the allotted time. The first step in this design process is researching current artifacts to identify what improvements can be made to current designs. Next, user requirements are specified so that subsystems can be defined. The system components are then researched and selected so that the project schematics can be designed. After the schematics and

board layouts are completed, the software for each of the subsystems is implemented and individually tested. Finally, the subsystems are integrated into the overall system, and the resulting system is tested. To design the system schematics and PCB layout, the circuit design software tools Multisim and Ultiboard will be used. The 3D design of the automatic pet food and water dispenser will be created using the CAD software Solid Works. Once designed, the structure will be printed from the Mechanical Engineering Department's 3D printer. The device will be assembled and tested in the Electrical Engineering Department's National Instruments Laboratory. To complete this project, the team has been allotted $500 for spending on components, 3D printing materials, PCB manufacturing, PCB component population, and other project related expenses.

The Smart Pet Feeding system is composed of three main subsystems, which include the user interface and the individual food and water dispenser subsystems. A block diagram of the general system architecture is shown in Figure 1.

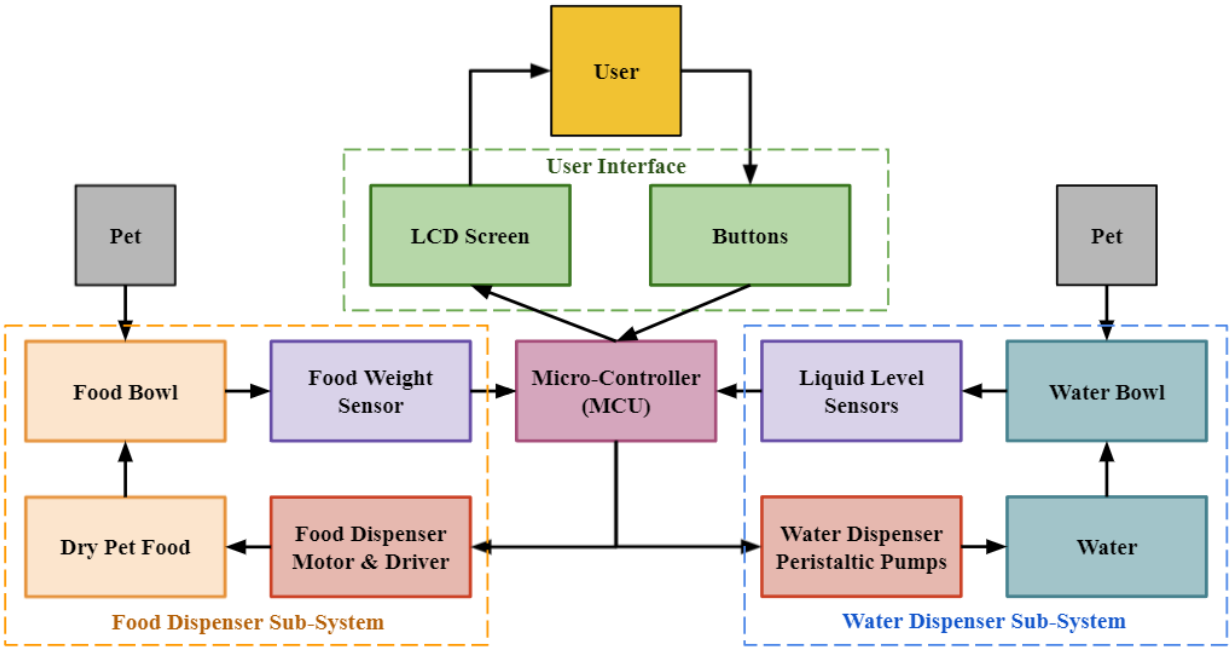

Figure 1: Smart pet feeding station block diagram. Mapping of the relationships between users, components, and sub-systems of the overall system. (Orioli, 2021)

The user will interact with the device using an LCD screen and a set of buttons attached to the front of the device, from which the user can select feeding and watering constraints. The instructions are sent to the system micro-controller (MCU), which controls the different functions and subsystems of the device. When a user specified feeding time occurs or when the water level in the water bowl has changed, the MCU instructs the food and water dispenser motors to dispense the contents from the respective storage containers into the bowls. Sensors embedded in the bowls track the amount of each substance that has been dispensed and send this information back to the MCU. A compression load cell weight sensor will be placed under the base of the food bowl to measure the dispensed food weight. This sensor contains strain gauges that exhibit different electrical resistances when stress or force is applied to the sensor, which changes the sensor's output voltage, and by extension, the weight read by the MCU (Muller et al., 2010, p. 15). The water bowl will contain two optical liquid level sensors, a sensor that can detect the presence of water using infrared light (Hunt, 2007, p. 203), which will be embedded into the side wall of the bowl at two discrete levels. The use of sensors and motors in the two dispenser subsystems creates two feedback loops which allow controlled amounts of food and water to be dispensed.

Automatic pet feeders and water dispensers are not novel ideas as quite a few of these devices already exist and can be readily purchased. One example of an automatic dog feeder (US6401657B1, 2002) contains a food storage bin located above a motorized dispenser and a food bowl. This device also contains sensors that allow the device to adequately control the quantity of food dispensed during each meal. Although the technical project is similar with respect to both the structure and functionality of these current artifacts, the project builds off of these devices by creating a two-in-one system that dispenses both food and water in a

synchronous manner. This means that the user will be able to use a single device to take care of all their pet's feeding and watering needs. In addition, the system's 3D design will be designed to facilitate the "aging in place" paradigm by considering elderly and disabled pet owners as future users of the device.

By completing this project, the technical group will experience the process of a real-world engineering design project, where previous coursework will be used to create a physical artifact from scratch. The project will allow the group to apply previously learned engineering concepts since the design process requires the use of circuit design principles and software design methodologies learned in previous classes. For example, the use of sensors and motors to create the dispenser subsystems will require the use of linear control system principles. The circuit design principles and methodologies learned in the Electrical Engineering Fundamentals series will be used to design and test the PCB layout for the project. Embedded software design principles and methodologies from the Introductory Embedded Computing course will be used to design the system software from scratch. Finally, STS frameworks obtained from the Science, Technology, and Society courses will be used to identify social and ethical implications related to the project and how possible users may perceive and use the device. At the conclusion of the project, the technical team will submit a conference style technical paper outlining the design process and the intricacies of the design. The Smart Pet Feeding Station will also be demonstrated to the UVA community. The technical team hopes that the completion of this project introduces new engineering techniques and knowledge related to the construction of smart home technologies, and that future smart pet care technologies can build off of the technical project's design.

The Effects of User Perceptions on the Development of Smart Home Technologies

With recent break throughs in smart technologies and the accelerated growth of the Internet of Things (IoT), smart home technologies (SHT) are becoming more widespread throughout society. This rapid diffusion of the technology is highlighted by the expected increase in the value of the smart home market from about $85.6 billion in 2021 to approximately $137.9 billion by 2026 (Zion Market Research, 2021). It is no surprise that the adoption of SHTs is increasing as the technology promises to deliver a host of health-related, environmental, financial, and psychological benefits to its users (Chang & Nam, 2021, p. 2; Li et al., 2021, p. 6; Marikyan et al., 2019, p. 147). Even so, the diffusion of smart home technology has not been without its challenges. According to Shin et al. (2018), although a large rate of growth has been observed, this growth has largely been due to the early adopters of the technology rather than the common person that the technology was designed to help. Shin et al. describe this situation as a "chasm between early adopters and the mass market" (p. 246). A question that may follow is, why are normal individuals not adopting this technology in their homes? To understand the answer, it needs to be recognized that the adoption process of technology is "based on the concept of perceived value that comprehensively considers both the sacrifices and the benefits that accompany the use of the technology" (Chang & Nam, 2021, p. 2). In other words, a user's perception of the technology will ultimately determine if they choose to adopt it or not. If a user perceives a large utility of the technology, they will be more likely to adopt it, whereas if that individual perceives the risks of the technology to outweigh the benefits, the technology will remain unadopted. Unfortunately, in the case of SHTs, user perceptions regarding the benefits do not necessarily match the potential benefits (Marikyan et al., 2019, p. 145). Therefore, to further

the adoption of SHTs, user perceptions of the benefits and risks of the technology, as well as the barriers to adoption, must be considered.

Barriers to Smart Home Adoption

In an attempt to determine the factors leading to the lower than expected diffusion rate of SHTs, Li et al. (2021) have identified several barriers to the adoption of the technology, which include (1) distrust and resistance, (2) limited understanding of SHTs, (3) financial considerations, (4) privacy and security concerns, (5) technology anxiety, and (6) negative social influences (p. 6). The problems that users have with SHTs that are associated with these barriers are depicted in Figure 2, along with several potential solutions provided by Marikyan et al. (2019). All of these barriers are related to the perceptions that potential users of SHTs hold, which greatly affects their willingness to pay for and use the technology.

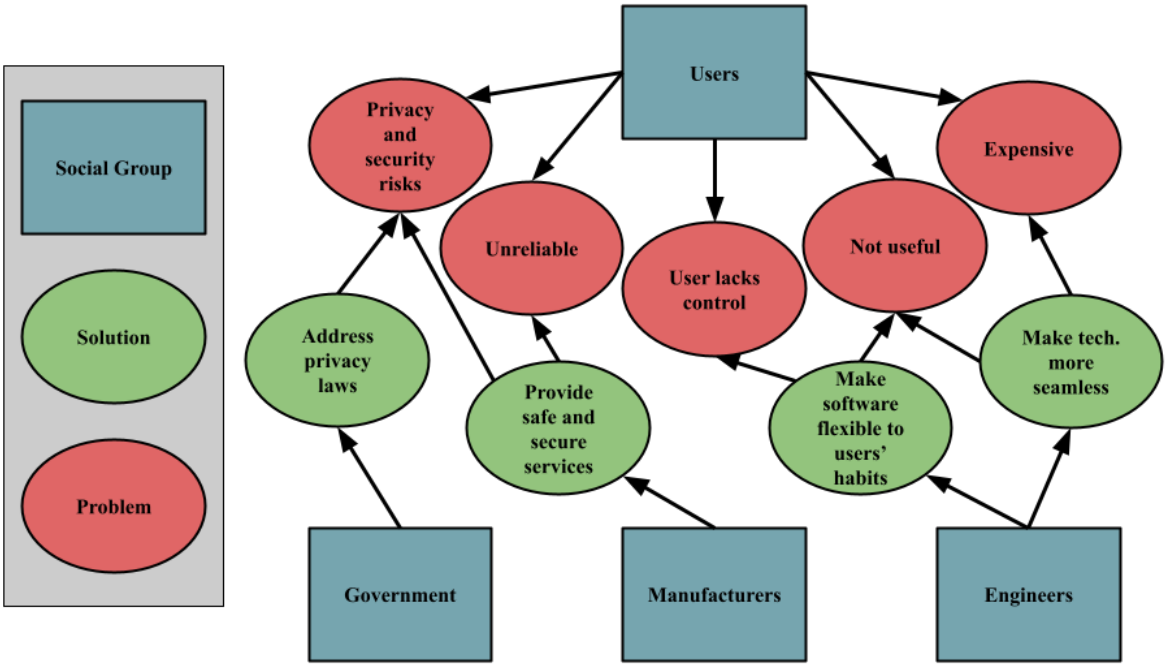

Figure 2: Smart home technology user problems and solutions. User problems associated with SHT result from adoption barriers and user perceptions of the technology. (Orioli, 2021)

One observation that Li et al. (2021) make in their research is that the portrayal of smart home technologies in media and the reporting of privacy breaches has had a large impact on people's trust in SHTs (p. 7). An example that highlights this idea is in the form of an opinion piece, published by The New York Times, which claims that advanced voice biometric technologies will soon be embedded into smart home devices, like Amazon's Alexa, and will be capable of characterizing a person's age, gender, weight, height, emotional state, and other traits based solely on the user's voice (Turow, 2021). After reading this article, users may feel concerned about the possible collection of voice data from technology companies and may not be so inclined to trust the smart devices or companies, even if the scenario is unlikely to occur. Thus, the adoption barriers (1) distrust and resistance of smart home devices and manufacturers, (4) privacy and security concerns related to SHTs, and (6) negative social influences, in the form of the mainstream media, are all working together to heighten the user's perception of security and privacy risk while lowering their perception of the utility of SHTs.

Development of Technology Under the Guide of User Perceptions

Although a large amount of research has been carried out to identify user perceptions of SHTs and the social barriers to the adoption of the technology, solutions that lower these barriers and speed up the adoption process still largely remain to be determined. In their research, Marikyan et al. (2019) propose several high-level solutions to problems that users have with SHTs (pp. 148–150), which are shown in Figure 2. Even so, these solutions only tackle the issues related to the broader field of SHTs and the general user base of the technology, rather than looking at each user group as a separate entity. As Chang & Nam (2021) suggest, "the adoption of smart home services should be analyzed based on a detailed understanding of the target users

for each service type" (p. 14). Therefore, solutions to low SHT adoption should be made by individually considering each user group and their unique perspectives.

Since engineers are the individuals who instill value into the technologies that they develop, they are ultimately the ones who must consider the perspectives of the different social groups that make up the larger SHT user group. For example, elderly users of SHTs are generally not as concerned about privacy when compared to younger users, but they value ease-of-use more due to their reduced understanding of the technology (Lorenzen-Huber et al., 2011, p. 234). Thus, engineers may have more freedom in collecting data for aging-in-place smart home devices when compared to devices used by younger people, but they should also make the aging-in-place devices easier to use. Other differences among users that influence the adoption rates of SHTs are user characteristics, "such as age, gender, residential types, and experience" (Chang & Nam, 2021, p. 3), which should also be considered by the engineer.

This development scheme follows the social construction of technology (SCOT) framework developed by Trevor Pinch and Wiebe Bijker (Pinch & Bijker, 1984), which depicts the cocreation of technological artifacts and society. In this case, each SHT user group represents a relevant social group that has its own meanings associated with the technology as part of the group's interpretive flexibility of SHTs. The engineer takes these values from the relevant social groups and implements them into smart home devices, shaping society and the relevant social groups, as a result. In this way, SHTs are shaped by society, and society is shaped by SHTs. This process is shown in Figure 3, which depicts the engineer as the central node in this relationship. The engineer considers each group's perspectives and embeds their values into the technology. By acknowledging the concerns and perceptions of the different user groups, the engineer can alter the technology to better represent each group's values, lowering the barriers to adoption.

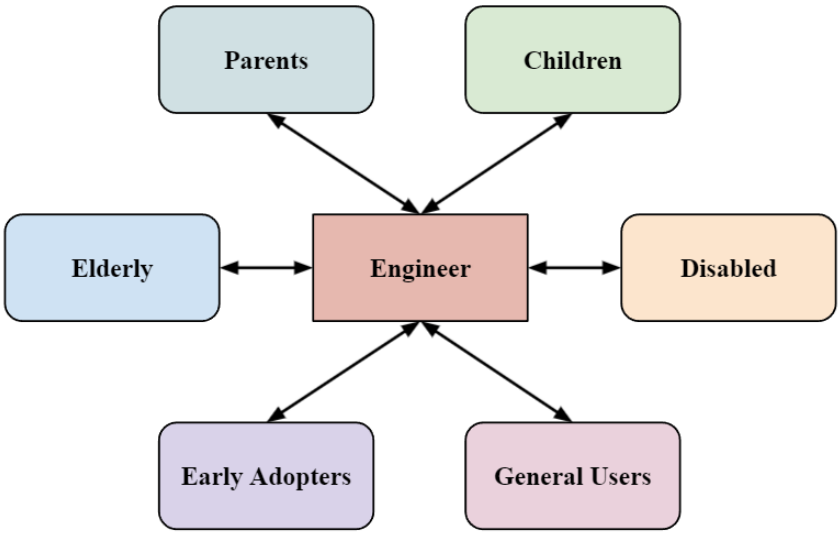

Figure 3: Smart home technology SCOT model. The engineer must consider the perspectives of all relevant social groups in developing smart home technologies. The social groups, in this case, are different types of users. (Orioli, 2021)

The STS research project will be in the form of a scholarly article, mapping the relationships between user perceptions of smart home technologies and the technology's development using the SCOT framework (Pinch & Bijker, 1984). More specifically, the relationships between specific smart home technologies, the relevant social groups, and the problems that these groups have as defined by their perceptions of the technology will be portrayed. By looking at how engineers shape smart home technologies in response to the values and perspectives of these social groups, the social construction and the diffusion of the technology can be better understood. In addition to looking at how user perceptions affect the development of SHTs, the study will focus on identifying the perceptions that different user groups have regarding the technology and the factors that influence these perceptions.

Although smart home technologies have been around for quite a few years, there are still areas within the home environment where the technology can be improved. In addition, the factors that influence the technology's lower than expected diffusion rate should be studied to speed up implementation. To fill these gaps in research, the technical project will support the

development of smart pet care products through the construction of a smart pet feeding and watering device, while the STS project will determine the effects of user perceptions on the development of smart home technologies. Pursuing these related topics will hopefully pave the way for future research in user acceptance of smart home technologies.

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