The Smart Fan: A Dyson-Style Desk Fan That Uses Infrared Motion Detection to Follow Users

(Technical Paper)

Autonomy in Assistive Technology for The Elderly: Not as Simple as "Plug N Play"

(STS Paper)

A Thesis Prospectus Submitted to the
Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia
In Partial Fulfillment of the Requirements of the Degree Bachelor of Science, School of Engineering

James O'Connell
October 27, 2023

Technical Project Team Members
Ethan Bacica
Ryan Bloom
Ezemet Burkut

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

ADVISORS
Kent Wayland, Department of Engineering and Society
Adam Barnes, Department of Electrical and Computer Engineering

General Research Problem: Shaping Motion Detection Systems to Provide Care

How should home motion detection systems be designed to best serve the elderly and disabled?

Advances in medicine and healthcare in recent years have caused a sharp rise in older adults who live alone. A significant subset of this group, whose physical ailments increase their risk of accidents and sudden emergencies, require constant home monitoring to preserve their health and safety. Without extensive technology to help facilitate care for this population, there will eventually be a huge strain on human resources: "The WHO reported that […] a shortage of the global health workforce was 17.4 million in 2013, and it would be 14.5 million in 2030. Moreover, the WHO stated that the population of over 60 would be more than 22% of the total of world population" (Tateno). Many solutions to this issue propose the use of smart home motion detection systems to automate this care, and most of them have many valuable capabilities. However, this technology will be partially responsible for facilitating direct home services and healthcare. The consequences of even one poor implementation of such a system could cost lives. Therefore, it is important to shape the design of motion detection systems with the user and their values in mind. A few core principles of the *user* that will be studied in this inquiry include autonomy, accessibility, and ease of use. Conversely, principles of the *system* that will influence and shape these user values include the type of data collected (infrared vs visual), the intended processing of the data (algorithms), and the interface between the data and human care workers. The technical project will explore how to make home appliances more accessible using infrared sensing technology. On the other hand, the STS research project will aim to design a home monitoring system that not only preserves user autonomy through non-invasive data collection and distribution, but also accurately processes the data to provide correct and effective care.

The Smart Fan: Transforming a Desk Fan with Infrared Sensing Technology

How can infrared sensing be used to create a Dyson fan that pivots to follow the user?

The technical portion of this inquiry will explore how motion detection can be used to build home appliances that are accessible to both those with mobility issues and others who are mentally disabled. The design transforms a typical desk fan into a smart device that can identify, rotate to face, and follow human targets within six feet of it. The Smart Fan accomplishes this by employing both infrared localization sensors and a low-resolution infrared camera. The sensors simply emit a digital indicator (0 or 1) to detect the thermal presence of a human, while the camera provides a detailed 24 by 32-pixel image of human thermal activity. The infrared sensors cover a 150-degree field of view each, while the camera covers 110 degrees, ensuring that the fan can always identify a target. The camera and sensors send data to an STM32 microcontroller using both I2C and GPIO communication protocols, respectively. The microcontroller represents the “brain” of the system and uses a control algorithm to process the data into instructions for physical motors. This algorithm will be discussed in more detail later. Fan blade rotation is controlled by a 12V DC brushed motor and a potentiometer, while the fan structure rotation is guided by a 10V DC stepper motor, a driver circuit, and a gear assembly. The physical structure of The Smart Fan will resemble a Dyson fan that uses a blade to concentrate air into a steady stream, shown in Figure 1. Finally, the electrical components of the system are organized on a printed circuit board (PCB), including the power supply unit and the bushed motor driver. The device will receive wall outlet power and will step the voltage down to 12V DC for the main power supply line on the PCB. Voltage regulators and safety capacitors will be used to control voltage to the microcontroller, the sensors, and the motors. Additional circuits will be designed to interface microcontroller potentiometer input with the brushed motor and to control current draw.

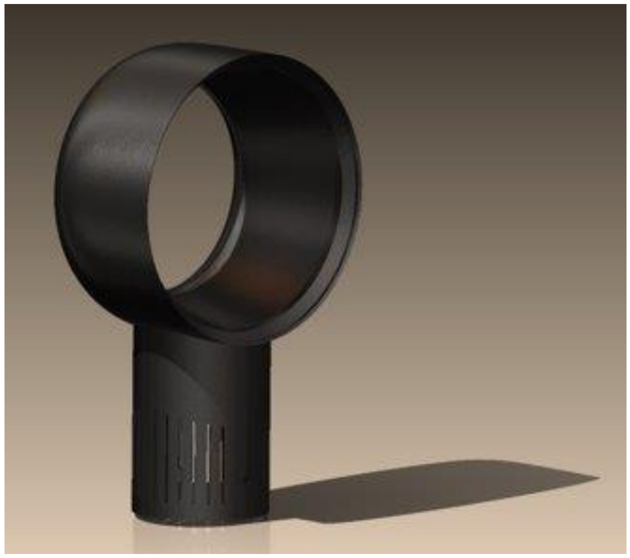

Figure 1. The Smart Fan CAD Design

With the device specifications in mind, the focus can now be shifted to details about device functionality. The desired behavior of the device is summarized in two cases. In the base case, there is one target that enters the field of view of the camera. To respond, the camera will supply data about the centroid of the target and will rotate accordingly. In the case where the target instead enters the field of view of either infrared sensor, the sensor will supply data about the location of the target, so that the fan will rotate and face the target. Once focused on the target, the camera will take over following the target. In the advanced case, there are multiple targets, and the device must decide whether to oscillate between them, and how long to focus on each target. The algorithm that will decide will be designed with known data about how wide the fan's air stream can reasonably cover, so that it knows whether to treat multiple targets close together as just one.

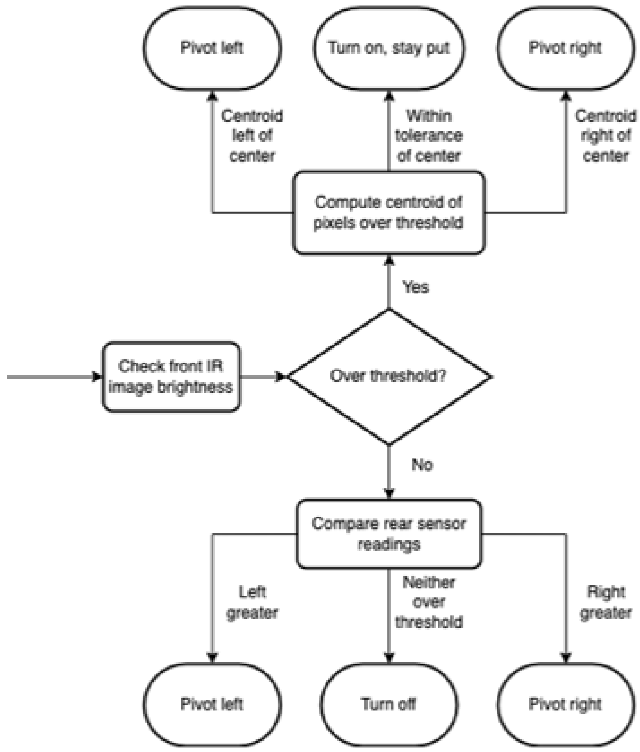

Figure 2. The Smart Fan Algorithm Flow Chart

The software algorithm used to perform the functions of The Smart Fan is outlined in Figure 2. The microcontroller will acquire a target either through the camera by identifying and calculating the centroid of active IR data from the camera or will rotate toward a target identified by the left or right infrared sensors. Moreover, the algorithm will use a threshold value for thermal activity to avoid detecting non-human targets that emit less thermal energy. This data processing will synchronize with the clock speed of the microcontroller updating the state of the target input data many times every second, resulting in accurate behavior and reduced latency.

A final consideration in this technical project is what specific role each person will fill. It has been decided that Ezemet will complete design and 3D printing of physical parts, Ryan will complete software architecture design and implementation, James will complete the printed circuit board design and motor driver parts specifications, and Ethan will be team leader and facilitate system wide testing.

Integrating Monitoring Systems into Elderly Care with Emphasis on Autonomy

How should home-monitoring systems be designed and implemented to best serve care workers and preserve patient autonomy?

Though it has a very specific function, "The Smart Fan" fits into a much larger sociotechnical system that will be examined here in the STS part of this inquiry. The first aspect of the system that must be addressed is the problem that mandates its existence. As mentioned before, there is an explosive population of elderly adults who are physically compromised and require nonstop monitoring. Because a strictly human care implementation would require massive amounts of service work, smart home technologies such as infrared sensors and visual cameras are used together in a network to provide synchronous monitoring of human movements and behavior patterns. Additionally, there is often an interface that allows health care workers to interact with sensor data and make important care decisions and address problematic trends. Finally, there is a processing algorithm that takes raw data input and transforms it into meaningful results that are used by humans. Hence, the principal actors that this system comprises are patients, care workers, and the monitoring systems that the workers use to care for the patients.

An initial assessment of this paradigm suggests that these components will fit together very well, so long as the technological design is "functionally correct". However, when introducing a new technology, it is important to bear in mind the social factors that will shape its implementation. To this end, the importance of considering the desire for autonomy by the stakeholders cannot be overstated. When caring for individuals, the values of security and personalized care often clash with autonomy, making it difficult for care workers to decide how to use the technology. For example, when installing home telehealth systems in Spain and the

United Kingdom, researchers found that one user initially preferred the device to be installed in a place where it would not be visible to others (Grosen). This stakeholder seemed to value the position of the device over its efficacy, as the device must be in an area where the user can be heard clearly. This dilemma represents a clash between home autonomy and the efficacy of technology. Upon hearing that the device would work better in an open area, the user immediately agreed. The elderly have a propensity to initially reject technology out of fear or surprise, sometimes caused by *culture lag*. This concept results from the culture of elderly communities moving forward much slower than the technology that serves them. There is a disconnect between social norms of the elderly and regular use of such technology.

Conversely, specific technological requirements of the system have great impact on what data care workers can access, and how they can use the data to make care decisions for their patients. The most notable of these design choices is between infrared and visual sensor data input. Infrared sensors generally provide an additional layer of security and privacy, as the data quality tends to hide sensitive human movements and features. On the other hand, visual data is highly accurate when processed and can be used to provide more accurate and advanced data about patient movements (Tateno). For example, researchers studying the effect of motion sensor technologies in homes observed a care worker that was asked by a patient to provide sleeping pills. However, the care worker had access to the patient's nightly behavior patterns and noticed that the patient was in fact sleeping for the entire night (Sanchez-Criado). This situation also presents a dilemma, a clash between the privacy of the user and the desire of the care worker to provide the right help. Without the sensitive data, the care worker would likely have given the sleeping pills. This raises a very important question concerning autonomy. Should care workers be able to act on data that might compromise the autonomy of a patient? Moreover, should the data interface be abstracted to hide this sensitive information, and only provide crucial details?

These complicated interactions and trade-offs between actors reveal that in the case of a home monitoring system, the *user* must not be defined strictly in a technological sense. Indeed, this system should be analyzed as an *instauration*; the factors that shape a user are not only defined by understanding the existing bias of this population toward new technology, but also the social network of care workers that interact with both the user and the technology. This research will treat the system as an instauration by analyzing both the technical and relational requirements of the system separately before fitting them together (Sanchez-Criado).

The most effective method for collecting data to answer these questions is use cases. The experiences of both the patients and care workers should be documented for the principal types of data collection techniques, both infrared and visual. For example, infrared cameras and sensors collect much less detailed data than video cameras or Kinect sensors, making them much less invasive (Eldib). It would be worthwhile to gather statements from and observations of care workers who use these different types of data, and their opinions on the degree of privacy and autonomy of the user that is preserved. Experiences with different processing algorithms would also shed light on how useful the data is to workers based on its quality. Similarly, the experiences of patients with these systems should be heavily researched, especially with respect to the usability and interface of the technology. Additionally, the invasiveness of the technology from the perspective of the patient should be considered, with cases and testimony. To complete a comprehensive survey of the use case of the entire system, the proximity, organization, and placement of sensors could also be considered. Data from these use cases will be used to form definitive pillars of design for home monitoring systems that preserve user autonomy.

Conclusion

As technology is increasingly intertwined with otherwise human-oriented interactions and services, the need for a socially minded design is critical. Hopefully, the STS research inquiry outlined here will yield clearer boundaries between the roles of care workers and monitoring systems that provide care for the elderly and the disabled, affording them maximum autonomy while keeping consistent care. These boundaries can be used to form design requirements for these systems, ensuring the true concept of the *user* is involved in the design process. Similarly, the technical research inquiry will hopefully reveal home appliance solutions for those with mobility issues. In the future, technology will most likely completely replace some human service jobs. This transition will never be successful without extensive and continual assessment of social situations, and how technology can approach them.

References

Chen, M.-Y. (2022). Establishing a Cybersecurity Home Monitoring System for the Elderly. *IEEE Transactions on Industrial Informatics*, *18*(7), 4838–4845. https://doi.org/10.1109/TII.2021.3114296

Eldib, M., Tongda Zhang, Deboeverie, F., Philips, W., & Aghajan, H. (2016). A data fusion approach for identifying lifestyle patterns in elderly care. In *Active and Assisted Living: Technologies and Applications* (pp. 81–102). IET. https://doi.org/10.1049/PBHE006E_ch5

Grosen, S. L., & Hansen, A. M. (2021). Sensor-floors: Changing Work and Values in Care for Frail Older Persons. Science, Technology, & Human Values, 46(2), 254-274. https://doi-org.proxy1.library.virginia.edu/10.1177/0162243920911959

Le Fang, Yu Wu, Chuan Wu, & Yizhou Yu. (2021). A Nonintrusive Elderly Home Monitoring System. *IEEE Internet of Things Journal*, *8*(4), 2603–2614. https://doi.org/10.1109/JIOT.2020.3019270

Qamar, A. M., Khan, A. R., Husain, S. O., Rahman, Md. A., & Basalamah, S. (2015). A multi-sensory gesture-based occupational therapy environment for controlling home appliances. *ICMR 2015 - Proceedings of the 2015 ACM International Conference on Multimedia Retrieval*, 671–674. https://doi.org/10.1145/2671188.2749412

Sánchez-Criado, T., López, D., Roberts, C., & Domènech, M. (2014). Installing Telecare, Installing Users: Felicity Conditions for the Instauration of Usership. Science, Technology, & Human Values, 39(5), 694-719. https://doi.org/10.1177/0162243913517011

Tateno, S., Fanxing Meng, Renzhong Qian, & Hachiya, Y. (2020). Privacy-Preserved Fall Detection Method with Three-Dimensional Convolutional Neural Network Using Low-Resolution Infrared Array Sensor. *Sensors*, *20*(20), 5957 (23 pp.). https://doi.org/10.3390/s20205957