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

A Technical Report Submitted to the
Department of Electrical and Computer Engineering

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

James O'Connell
December 5, 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
Adam Barnes, Department of Electrical and Computer Engineering

Statement of work

Ethan was tasked with much of the circuit communications and testing with the microcontroller. This included things such as soldering current drivers and sensors along with configuration requirements of both the user driven potentiometer, brush motor and stepper motor drivers. Additionally, Ethan worked with CAD to develop preliminary designs of both the Smart Fan base and the fan top. He assisted with circuit testing and systems integration of the Smart Fan.

Ryan contributed to the initial design of the Smart Fan, including sensor selection and the rotation mechanism consisting of gears and a slip ring. Ryan then led development and testing of the embedded software, including the motor control code and person detection algorithm on the microcontroller. He also developed a Windows application to view real-time data from the sensors alongside results from the algorithm.

Ezemet designed and 3-D printed the planetary gear rotation system, component housings, and the rest of the physical structure of the Smart Fan. Populated the PCB with the circuit components and aided in PCB testing and troubleshooting. Assisted in full system integration. In addition, Ezemet aided in troubleshooting of the stepper and brushed DC motor drivers.

James designed and ordered each iteration of the printed circuit board and designed the power supply system. To accomplish this, James used NI Multisim to choose circuit components and run numerical testing. To design the PCB, James used NI Ultiboard to create a good component layout and initialize custom non-library components. He also helped set up, integrate, and test the motor driver environments. Finally, James assisted in creating the sensor software algorithm by writing a weighted-centroid calculation algorithm in C.

Table of Contents

Table of Figures

Abstract

The Smart Fan is a smart motion detection desk fan designed to provide optimal cooling to those without air conditioning. Designed with an infrared thermal camera and two wide angle infrared sensors, The Smart Fan will adjust to changes in movement in real time efficiently with a complete 360-degree field of view. This product will contain an STM32 microcontroller controlling the fan's movements to ensure the target remains cool. The design will follow that of a centrifugal fan using a motor control from a PCB to dictate rotational speed based on user input. When a user enters the room, The Smart Fan will turn on and point to the target without the user having to turn the fan back on if it is plugged into a wall outlet. Considering the warmer summers, the product is an alternative to ensuring cool comfort through automation.

Background

As global temperatures climb due to climate change, more households are turning to air conditioning systems for relief. However, this growing reliance on air conditioning comes at a cost. On average, households see their electricity bills increase by 35% to 42% when they use air conditioning. Surprisingly, approximately 20% of the world's total electricity consumption is now devoted to air conditioning, exacerbating our overall energy consumption, and placing significant stress on the power grid. [1]

Electric fans offer a cost-effective and energy-efficient alternative to air conditioning. They are affordable, portable, and consume little energy. Their efficiency is further enhanced by the fact that they only circulate air in a specific area where it is needed. However, this efficiency comes with a drawback in convenience. A user must point the fan towards the part of the room they are occupying, and re-orient it if they move around. Moreover, when leaving the room, they must either remember to switch off the fan manually or let it continue running, which increases its energy consumption. This project addresses these common issues associated with conventional fans available in the market today. It is equipped with IR sensors that enable it to detect and track people in a room, it can rotate a full 360 degrees providing the user with a constant cool breeze wherever they may be in the room.

There have been many similar projects that have explored the concept of smart fans capable of tracking and following individuals. For instance, ECE students at Cornell university designed a human tracking rotating platform that supports a fan. They used a PIR sensor for sensing the person and a rotating platform that directs air flow to whatever position a person moves to [2]. Our project has two main advantages over this one. First, our design integrates the rotating platform directly into the fan, resulting in a single, unified product that is more portable. Second, our fan will be able to rotate a full 360 degrees whereas the one they built is limited to 180 degrees.

Another project in this vein was developed by Tajrin Ishrat and their team [3]. Their smart fan for human tracking utilized an ultrasonic distance sensor for tracking and a temperature sensor to regulate the fan's speed. The primary distinction between their project and ours lies in the choice of sensors. While they opted for an ultrasonic distance sensor, we opted for an IR sensor. It is worth noting that the ultrasonic sensor comes with certain drawbacks compared to the IR sensor. For instance, it can only track a single person at a time, its tracking range is influenced by temperature, and it cannot differentiate between objects and humans.

The ECE classes we all took at UVA have equipped us with the knowledge and skills needed to excel in this project. Alongside the electrical theory covered in the ECE Fundamentals series, we have taken on practical projects such as the boost converter in ECE Fundamentals 1, the audio analyzer in ECE Fundamentals 2, and the electrocardiogram in ECE Fundamentals 3.

Additionally, Introduction to Embedded Computer Systems exposed us to the MSP430 microcontroller, where we have successfully completed various embedded projects and learned skills that we will be implementing in this project. These courses have provided us with essential electrical and embedded expertise making us well-prepared to take on this challenging Capstone project.

Societal impact constraints

One of the most important stakeholders to consider will be the end user. Because our product may serve as an alternative to more expensive and complicated air conditioning systems, a commercially viable version of this product should be optimized to reduce costs for both the product itself and the energy needed to run it.

Other stakeholders include anyone who will be around the device while it is operating; we need to account for their health and safety as well. This means avoiding dangerous materials in our choice of components and ensuring that wiring is properly insulated to mitigate the risk of electrical shock. The spinning fan blade will be entirely inside the enclosure to prevent any injuries.

A particular subset of individuals that this product will serve is the elderly and those with mobility issues. Considering this, our product will be designed such that turning it on and varying the speed of the fan is very straightforward and requires minimal effort by the user. Once the desired speed is set, there is nothing more that needs to be done.

We also consider the project's potential impacts on the environment and society at large. We want our device's energy consumption to be as low as possible, to minimize its contribution to air pollution and climate change.

Physical constraints

Development of the prototype faces two major constraints. First, our budget is limited to $500. Second, the prototype must be completed within one semester and ready to demonstrate by December 8, 2023. Because of the time constraint, we can only order parts from distributors that currently have them in stock.

If this product were to be developed beyond the prototype stage, a key priority would be further reducing costs to make this affordable for consumers. Specifically, we would aim to reduce the cost to $100 or lower.

Moreover, the budget constraint will likely make choosing custom parts for the fan structure more difficult. Some of the peripherals (IR sensor and camera) need to rotate with the fan which will make wiring more complex and will demand more sophisticated parts.

In the development process, Multisim was utilized for power supply and driver circuitry design, while Ultiboard was used to layout the PCB. Components like resistors, driver ICs, and capacitors were soldered onto the PCB using a soldering iron and heat gun. VirtualBench and a multimeter aided in analyzing and troubleshooting the PCB.

Moving to the mechanical design, Solidworks was employed to design the physical structure, motor and PCB housings, and fan gears. Ultimaker Cura was then utilized to prepare the Solidworks design for 3-D printing. Anycubic Kobra Plus 3-D printer was used to print all mechanical components of the fan. None of our team members had prior experience in 3-D CAD design or printing, so we had to learn these tools from scratch.

Regarding the software system, STM32CubeIDE facilitated communication with sensors, motors, and controlled the brushless motor's speed using a potentiometer. The algorithm used for human detection was written using this IDE. While no one in our team had previous experience with STM32CubeIDE, we all had some familiarity with Code Composer Studio, a similar integrated development environment.

External Standards

The printed circuit board for this project will be manufactured in accordance with IPC-A-600 [13]. This is a general standard that applies to all PCBs and will ensure that the final product matches with our intended design.

The power adapter we will use conforms to UL 60950 [14], a standard for electrical devices that plug into a wall outlet. This standard is important to ensure that our device can be used effectively and safely with power outlets across the country. Because our device is an electric fan, it is also subject to UL 507 [15], a standard pertaining specifically to electric fans and related safety issues.

This project will use passive sensors and not communicate wirelessly; therefore, compliance with regulations concerning electromagnetic radiation is unlikely to be an issue.

All motor drivers used in this project are RoHS 3 (Restriction of Hazardous Substances) compliant [16], guaranteeing that they are virtually free from several hazardous substances, including lead and mercury. This is an important safety standard to follow as we handle, implement, and test motor drivers. Moreover, this EU standard would make it easier to sell our product outside the United States.

The project’s physical design will be 3D-printed using polyethylene terephthalate glycol (PETG) filament. According to the FDA Code of Federal Regulations (CFR) Title 21 [20], this filament is safe to use when handling foods. This is a safety concern for our project, as its practical implementation would most likely take place in a home where food and drink are present.

Intellectual Property Issues

There are several designs of patented “smart” fans that encompass a design that is like our capstone project. The smart fan designed by Baek et al. is an oscillating axial fan that has 3 embedded sensors: distance, humidity, and temperature [17]. The user can monitor the humidity and temperature through an app on their smart phone. The speed of the fan is controlled by an analogue operation. The ultrasonic sensor is capable of presence detection and can detect certain hand gestures. The hand gestures can then be used interpreted to control the speed of the fan.

L Liang’s [18] self-adjusting fan design is comprised of a probe, a temperature sensor, wireless signal emitter, wireless signal receiver, and a microcontroller. The main feature of this fan is its person detection system, when the probe detects a person it sends a wireless signal to the microcontroller which then turns on the fan. The temperature sensor continuously monitors the ambient temperature of the environment and adjusts the speed of the fan based on the temperature.

Edward’s [19] interactive occupant-tracking fan is a fixed forced air nozzle design with multi-axis positioning. It uses an array of ultrasonic sensors to detect a target as well as movement and occupant shape. Fan speed is controlled by a remote controller.

While the Smart Fan shares certain features with previously patented technologies such person detection, fan speed control, and person tracking. It distinguishes itself by a unique capability: the ability to detect and track individuals in a continuous 360-degree rotation. This innovative feature represents a significant advancement in the field, providing a level of user interaction and adaptability unparalleled by existing fan technologies. By enabling seamless tracking of individuals within a full rotational range, our Smart Fan not only enhances user experience but also revolutionizes the way cooling and airflow systems are utilized. This distinctive functionality sets our project apart, presenting a compelling case for patentability due to its unprecedented and valuable contribution to the domain of fan technology. The continuous 360-degree tracking capability positions our invention at the forefront of innovation in the industry, offering a promising and patent-worthy solution to improve user comfort and convenience.

Project Description

Performance Objectives and Specifications

The objective of the Smart Fan is to direct a cool breeze to a singular user based on automated motion detection. This automated motion will be primarily dictated by the thermal camera along with supplementary PIR sensors. It will also have a knob so that a user can dictate the desired speed of the fan. Unlike an axial fan, this design will follow that of a Dyson bladeless fan containing a brushless motor. A bladeless fan design is desirable for a variety of reasons. Besides the more aesthetic appeal, bladeless fans offer improved air flow and efficiency. All mechanical movement and functionality will be pre-programmed through the micro-controller, with power distribution set through the PCB. The Smart Fan is a portable desk device, with all the hardware and electronics embedded within the base of the fan with only the sensors and camera exposed to the user.

How it Works

A final block diagram of the Smart Fan is shown in Figure 1.

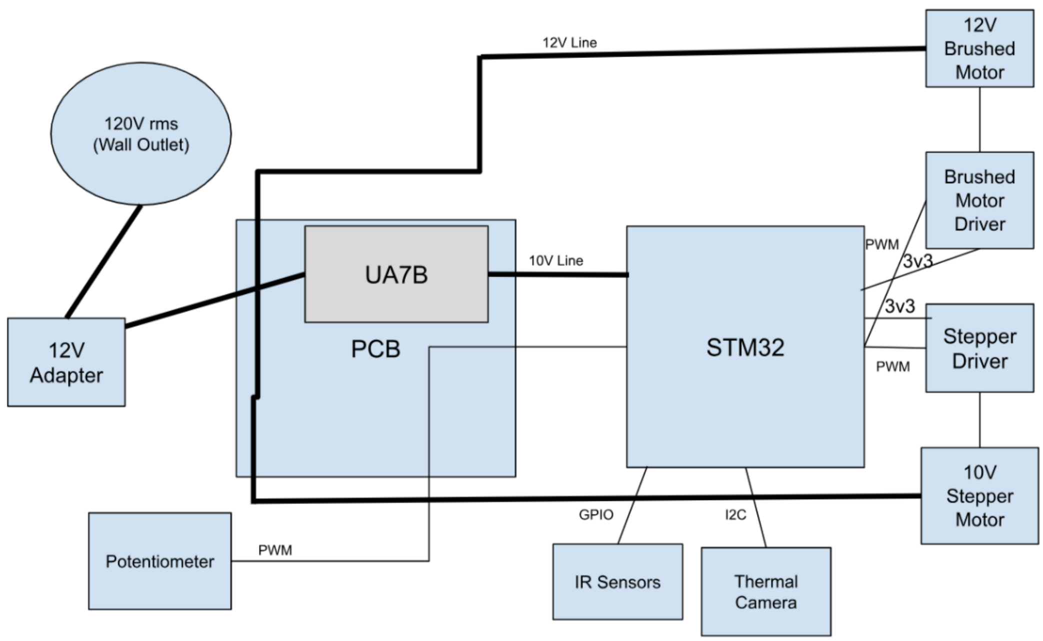

Figure 1. Block diagram of the Smart Fan

The entire device will be powered by a wall outlet. An STM32 microcontroller will process sensor data to determine which way to orient the fan. The orientation will be adjusted using a stepper motor. The fan blade itself will be spun by a brushed DC motor.

Person detection and localization will be performed using infrared sensors. We chose this technology because it is affordable and low-power, computationally simple, allows for precise localization, and works even in low-light conditions.

We chose a set of sensors to satisfy two constraints: (1) they must provide a combined 360° field of view so the device can detect a person anywhere nearby, and (2) they must be able to localize a person precisely enough to point the fan in the correct direction. Within these constraints, we wish to use the simplest and lowest-cost configuration.

Technical Details

Our chosen sensor configuration includes one forward-pointing infrared camera [4]. This camera produces images with a low resolution (32 x 24 pixels), which will reduce cost and processor load while still being precise enough for our purposes. However, the camera only has a 110º field of view. To supplement it, we will add two infrared sensors [5] mounted towards the back of the device, one on the left and one on the right. Each offers a 150º field of view, so that when combined with the forward camera they will cover the entire 360º range.

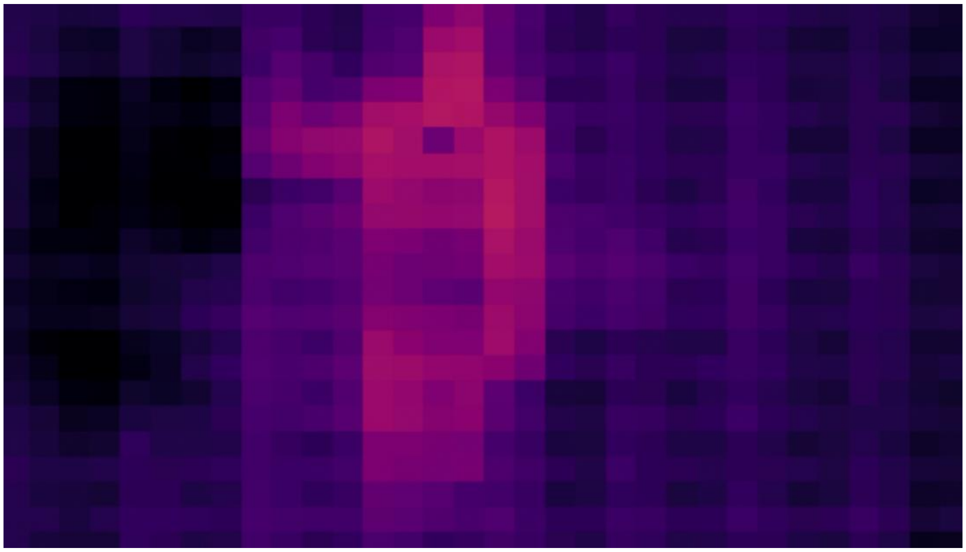

Figure 2. A processed frame of image data from the IR camera, showing a team member standing up and raising their hand

Our choice to include an infrared camera comes with benefits as well as drawbacks. Similar applications may use different sensors, such as PIR and ultrasonic sensors [6]. Our infrared camera is more precise, but also more expensive. We partly mitigate this problem by using less precise rear sensors. The rear sensors can only determine if the device needs to rotate left or right, after which the forward camera can be used for finer adjustments. This reduces the cost with minimal effect on the performance of the system.

These peripheral sensors are controlled by an STM32G071RBT6 microcontroller [7]. We initially chose this model due to its 32-bit architecture and 64 MHz clock speed, reasoning that it would give us greater flexibility to experiment with different algorithms for person localization, compared to more power-constrained alternatives.

A key part of our project's functionality is detecting and localizing a person near the device. The basic algorithm for this is as follows. When the front camera detects IR light, it orients towards the source of that light; otherwise, it uses the rear IR sensors to decide which direction to pivot in. If IR light is not detected from any direction, the fan stays put and turns off. The algorithm is depicted as a flowchart in Figure 3. The microcontroller executes this algorithm approximately 4 times every second.

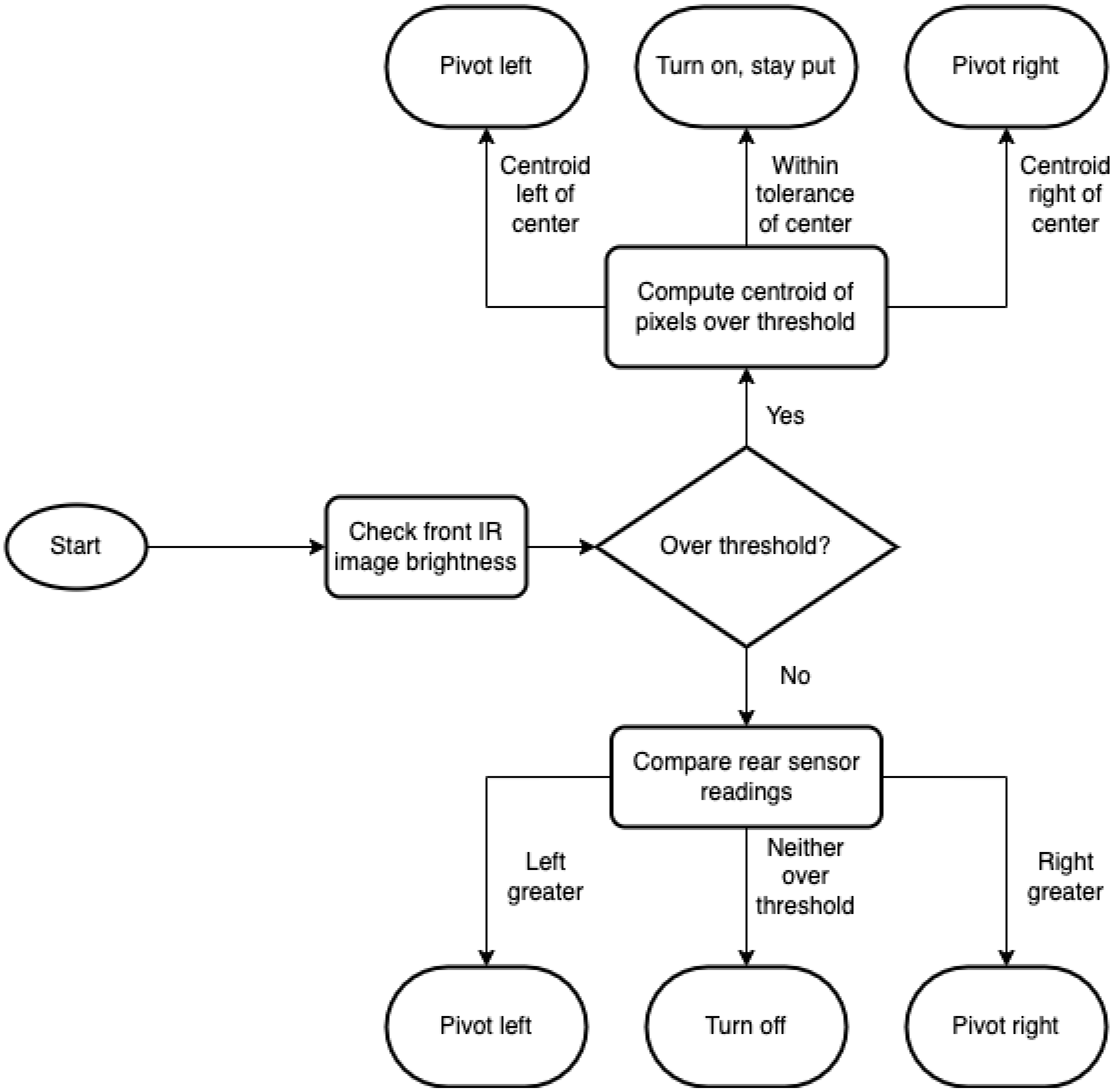

Figure 3. Flowchart for determining how to pivot the fan

The microcontroller also provides different PWM functionality to the motor drivers and optimal speed controls. In our design, the STM32 initializes two timer channels to provide a PWM signal into both the stepper and the brushed motor drivers. One of the inputs to this microcontroller is from a potentiometer [22] that the user controls to regulate the PWM entering the brush motor system. The MCU also consists of different logic pins designed to configure setting on the motor systems. This includes a direction pin for the stepper motor which the driver reads high or low to change the direction of the stepper motor. A myriad of other logic pins are also implemented to configure these drivers which will be discussed later in this section.

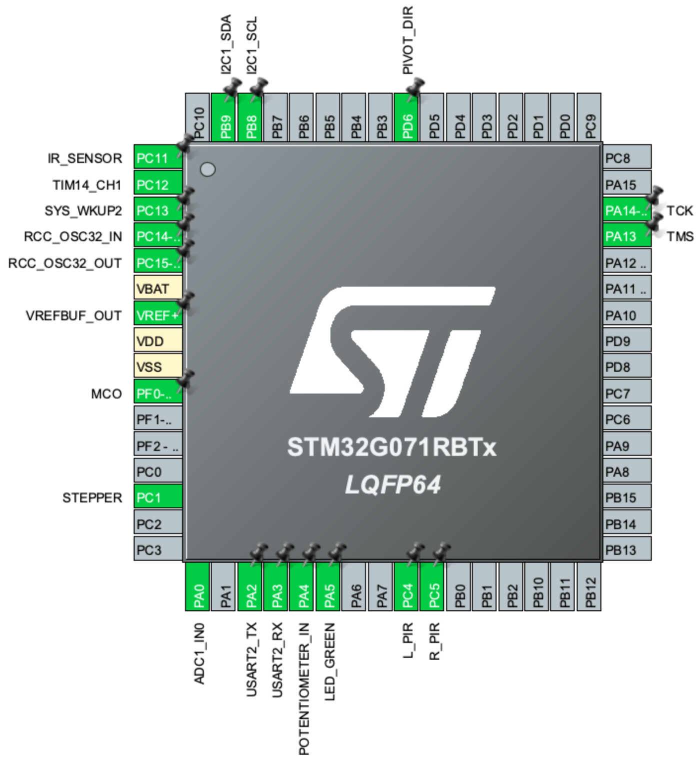

Figure 4. Pinout of Smart Fan STM32 MCU

Another part of this system that must be considered is the power supplies and junctions that will electrically connect every component together. This system will use an adapter [8] to step down and convert the 120V rms AC wall outlet voltage to 12V DC, with 30W power. This component was chosen because the minimum DC voltage required to power the system is 12V, as required by the DC brushed motor [12] that operates the fan blade. Moreover, the current draw maximum of the brushed motor, stepper motor, and controller are 1.8A, 0.5A, and 0.1A respectively, yielding a system maximum current consumption of 2.4A, or 29W power. The 12V line enters the base of the fan system through a PJ-102A connector jack [21] onto the printed circuit board (PCB). The final circuit board iteration is shown below.

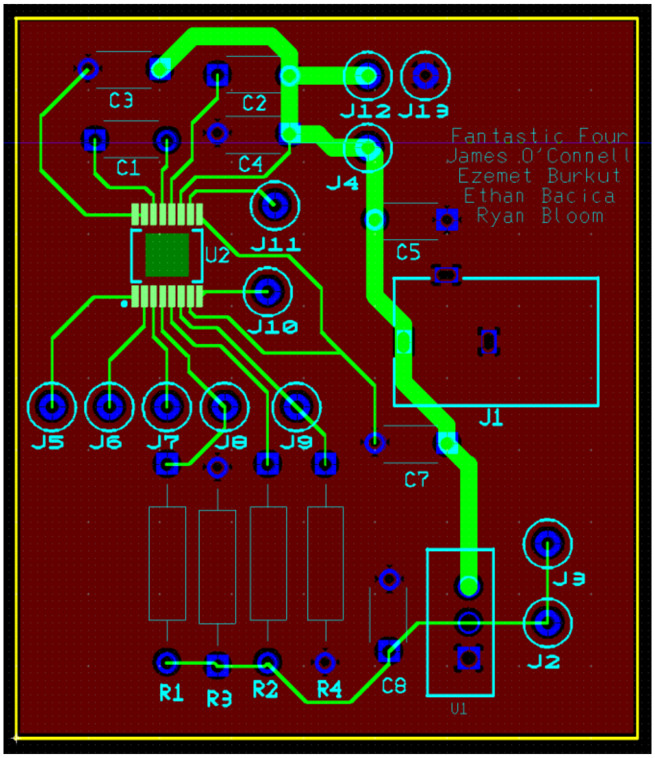

Figure 5. Final PCB Iteration Schematic

Initially, the project design planned to drive the STM32 microcontroller with 3.3V DC and drive the stepper motor with 10V DC. However, later it was discovered that the stepper motor driver board already had an internal regulator, and that it was far more effective to drive the controller with 10V DC through the "Vin" pin, because the controller also had an internal regulator. These modifications produced a printed circuit board with two 12V DC lines and one 10V DC line. To step down the voltage, one BD433M5FP-CE2 regulator [10] was used, in place of the original planned UA7810CKCSE3 [9] voltage regulator. Another component that was initially planned for use on the PCB was a DRV8874 IC [23] to drive the brushed motor. This was thoroughly tested and was ultimately removed due to major concerns about the safety of the microcontroller from noisy signals. Finally, many bypass and filter capacitors were used throughout the PCB for protection of connected ICs.

To control the orientation of the fan, we chose a stepper motor so we would be able to turn it in precise increments. Specifically, we chose a 2183-1208-ND stepper motor [11]. This motor can turn at eighth steps, so that the fan turns smoothly and makes minimal noise. The stepper motor is also located at the base of the fan design and is controlled using an MP6500 Stepper Motor Driver [24]. This motor driver has two principal pins, STEP and DIR, that are driven by the microcontroller. The STEP pin is driven using PWM, so that on each rising edge, the motor executes one full step. The direction of this step is determined by an indicator on the DIR pin. Unlike the fan rotation, the fan blade itself does not need this level of precise control; we only need to be able to turn it on, off, and adjust the power. We therefore selected a standard brushed DC motor for this purpose, the DIA42B 20W [12]. The DC motor is located at the top of the fan assembly, where is drives the blade to push air into the Dyson-style top. The DRV8871 Brushed DC Motor Driver [25] was chosen to control the fan blade. There are two main pins on the driver, IN1 and IN2, that are used to control the motor. In this project, only one direction of rotation is needed for the fan blade, so IN1 is tied to ground, and IN2 is driven with PWM to control motor speed. The PWM originates from an analog value from a potentiometer dial at the base of the fan that is converted to a PWM timer period on the microcontroller with its internal ADC.

The achieve a continuous 360º range of rotation we used a planetary gear system with a slip ring to prevent wire tangling. The inner gear is mounted on the stepper motor and the outer gear is loosely fitted inside a housing on top of the PCB housing to allow for smooth rotation. The slip wire is secured on a raised platform in the middle of power PCB housing.

Resources and Equipment Required

The geometry of the fan requires precise machining so this project used a 3D printer to print the structure of the fan housing and blade. One of our team members already owned a 3D printer, which we used to print all of our parts at cost.

For our microcontroller, we used an STM32 unit borrowed from the UVA ECE department. We ordered other electronic parts through the University using our $500 project budget. Standard tools such as soldering irons and multimeters were borrowed from the NI Lab.

Software Tools

We developed and validated circuit schematics using NI Multisim and designed the PCB using NI Ultiboard. This project also involved developing substantial embedded software for the STM32 microcontroller. For this we used STM32Cube IDE, which is the officially supported development environment for our microcontroller. We used Git and GitHub to track changes to our code and facilitate collaboration between team members. For previewing data from the IR camera, we developed a special-purpose Windows application using Python, PySerial, and OpenCV.

Timeline

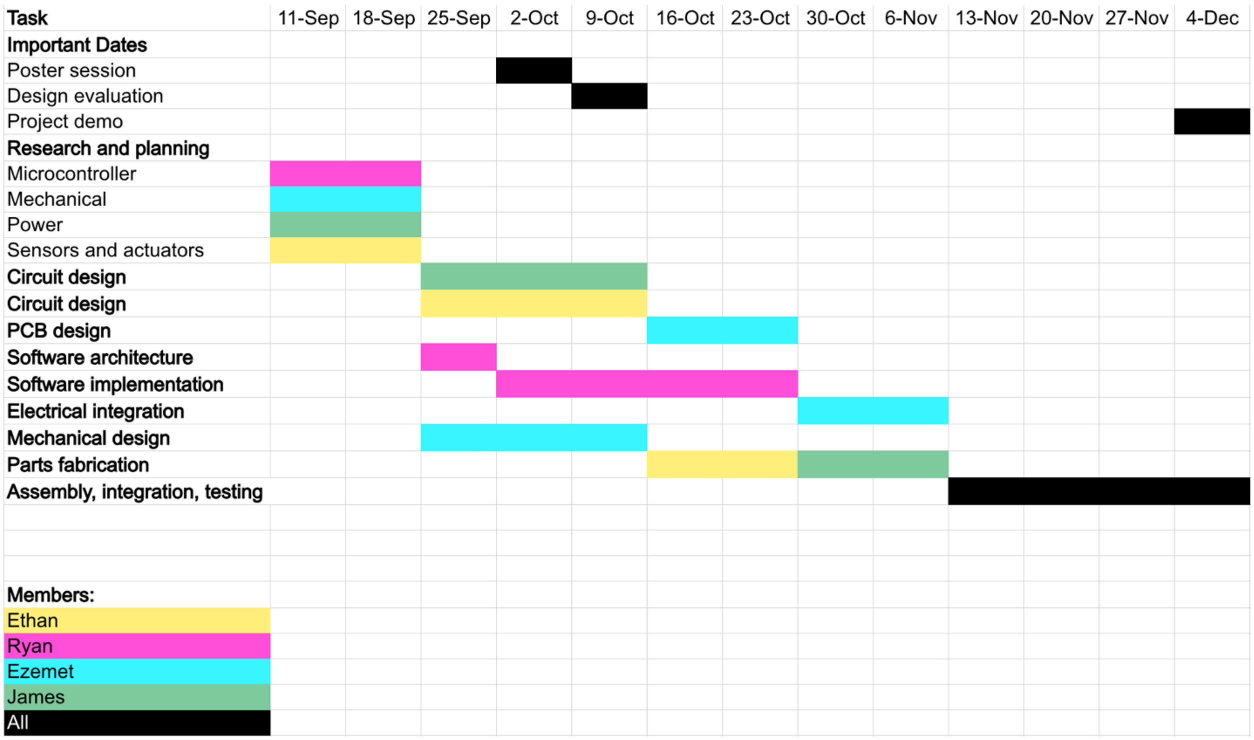

Figure 6. Gantt chart for the project

Costs

For this project, our budget was $500 for this semester. The specific list of costs is appended to the bottom of the report. Our total costs exceeded our initial estimates due to mishaps with both the PCB and microcontroller. We had 3 iterations of our PCB to adapt to challenges that occurred in our project which increased the cost. Additionally, we had an emergency purchase of an STM32 costing roughly ten percent of our budget. With regards to large scale manufacturing of this product, the costs would most certainly decrease. For items such as voltage regulators and motor drivers, ordering at the scale of thousands reduces the unit price by roughly 50%. It is with reasonable estimation that the price of each smart fan unit would decrease by 50%. This is due to this per unit discount along with the lack of needing to buy additional materials due to malfunction. Due to the lack of limited space to develop circuitry, automation would be difficult to incorporate for this design. One aspect of the project that could include automation would be with parts manufacturing. Our prototype was 3D printed in house; however, if this product was being manufactured at large scale an automation of the manufactured parts would be advantageous for time of production.

Final Results

Outlined below in each row of Table 2 is a performance requirement of the final product, and descriptions for varying levels of the requirement's successful implementation.

Requirement	A	B	C	F
Airflow	Airflow is useful for cooling off on a hot day	Airflow is perceptible but less than comparably sized desk fans	Airflow is barely perceptible	Fan does not blow air
Orientation range	The fan has full rotation range (360 degrees)	The fan has slightly less than full rotation range	The fan has very limited rotation range (< 180º)	Fan does not rotate
Presence detection	Fan detects human >95% of the time within 3 meters	Fan detects human 50-80% of the time within 3 meters	Fan detects human less than 50% of the time within 3 meters	Fan does not detect human

Dial operation	Dial switches between fan speeds smoothly	Dial works but the switching is choppy or non-uniform	Dial barely works, fan speed change is not very noticeable	Dial does not work
Human localization	Fan will follow a human walking slowly (1 m/s)	Fan will usually point towards a human after a delay	Fan localizes human inconsistently or identifies spurious targets	Fan does not pivot towards a human

Table 1. Rubric for evaluating the final product

Airflow

After running air flow tests with the propeller brushed motor, the air flow is perceptible but not comparable to other desk fans on the market. The air flow test was conducted with multiple fan speeds and a perceptible airflow was felt on the highest speed of the fan. This is mostly likely caused by the mechanical of the Dyson design and the roughness of the 3-D printed texture of the top of the fan.

Orientation Range

The orientation range test was tested by having a user walk in a circular path around the fan. The fan was successfully able to continuously rotate 360º and no wires were tangled upon inspection. Thus, this meets the targeted requirement of a full 360º rotation range.

Presence Detection

In regards to our presence detection, using a preview mode on our software we were able to distinguish a user from the thermal camera approximately two meters away with a high success rate. It could also distinguish multiple users within the frame. However when other heat sources such as laptops were included in the frame, the preview would have a hard time distinguishing between a human also within the frame.

Dial Operation

The dial operation was extruded from the base of the fan and was configured with a potentiometer. Based on the response of our system the potentiometer could successfully turn on and off the brush motor fan while also transitioning between speeds fairly smoothly. One of the main challenges of this system was that the motor driver would occasionally not drive enough current to the brush motor, delaying the rotation of the fan.

Human Localization

The human localization test was performed by having a user walk at different speeds: 0.5 m/s, 1 m/s, and 2 m/s. In all cases, the fan was able to successfully rotate and keep up with the user. In this case, this feature fully meets the requirements set in the beginning of the semester.

Future work

Although we have finished demonstrating our idea with a prototype, there remain many areas where The Smart Fan could be improved.

Firstly, because the primary focus of this project was electrical and computer engineering, we spent relatively little time iterating on the mechanical design of the fan. As a result, we found that airflow was significantly less than a conventional fan. More experimentation could uncover ways to improve airflow by changing the intake position, blade shape, and exhaust direction. Better airflow would significantly enhance the utility of the fan.

In addition, the efficiency of the DC motor subsystem could be improved. In our prototype, the motor driver produces significant heat, which constrains the speed at which we can run the fan blade. This problem could most likely be addressed by selecting an alternative driver that is better suited to our system's operating profile. Also, because energy efficiency was one of the original motivations for our project, reducing power consumption would improve a key selling point for customers.

With regards to the software, we met our basic goal of detecting and tracking a human near the fan. However, we did not finish implementing functionality related to multiple users. With further development of the software, it may be possible to have the fan track two people and oscillate between them.

Lastly, although we selected relatively inexpensive components where feasible, the combined costs were over $150. Making this product commercially viable would require designing for low-cost, high-volume manufacturing. For example, injection-molded parts would cost less and look better than our 3D printed parts. There may also be lower-performance microcontrollers and sensors available that meet our requirements for a lower cost. Integrating more components onto the PCB would eliminate the need for separate breadboards and breakout boards. These, and other similar modifications, would be important steps towards a marketable product.

References

[1] T. Randazzo, E. De Cian, and M. N. Mistry, "Air conditioning and electricity expenditure: The role of climate in temperate countries," *Economic Modelling*, vol. 90, pp. 273–287, 2020. doi:10.1016/j.econmod.2020.05.001

[2] E. Park and J. Fridlander, "Smart Fan," Smart Fan - A Human Tracking Fan, https://people.ece.cornell.edu/land/courses/ece4760/FinalProjects/s2011/esp57_jmf293/esp57_jmf293/index.html.html (accessed Sep. 19, 2023).

[3] T. Ishrat, M. A. Rahaman, and A. Ahammad, "Smart fan for human tracking," *2014 9th International Forum on Strategic Technology (IFOST)*, Dec. 2014. doi:10.1109/ifost.2014.6991086

[4] Melexis NV, "MLX90640 32x24 IR array." Dec. 03, 2019. Accessed: Sep. 19, 2023. [Online]. Available: https://www.melexis.com/-/media/files/documents/datasheets/mlx90640-datasheet-melexis.pdf

[5] Panasonic Corporation, "Panasonic PIR Motion Sensor," 2016. https://www.mouser.com/datasheet/2/315/bltn_eng_papirs-1365490.pdf (accessed Sep. 19, 2023).

[6] O. A. Hasan, A. T. Rashid, R. S. Ali, and J. Kosha, "A practical performance analysis of low-cost sensors for indoor localization of multi-node systems," in *2017 internet technologies and applications (ITA)*, 2017, pp. 284–289. doi: 10.1109/ITECHA.2017.8101955.

[7] ST Microelectronics, "Arm® Cortex®-M0+ 32-bit MCU, up to 64 KB Flash, 18 KB RAM, 2x USART, timers, ADC, DAC, comm. I/Fs, 1.7-3.6V", [Online]. Available: https://www.st.com/resource/en/datasheet/stm32g071rb.pdf

[8] XP Power, "VER18 Series AC-DC Power Supplies." Jul. 25, 2023. Accessed: Sep. 19, 2023. [Online]. Available: https://www.xppower.com/portals/0/pdfs/SF_VER18.pdf

[9] Texas Instruments, "µA78xx Fixed Positive Voltage Regulators." [Online]. Available: https://www.ti.com/general/docs/suppproductinfo.tsp?distId=26&gotoUrl=https://www.ti.com/lit/gpn/ua78

[10] ROHM Co., Ltd., "500-mA 3.3-V or 5.0-V Output LDO Regulators." Feb. 22, 2017. [Online]. Available: https://fscdn.rohm.com/en/products/databook/datasheet/ic/power/linear_regulator/bd4xxm5xxx-c-e.pdf

[11] Pololu Robotics & Electronics, "Stepper Motor: Bipolar, 200 Steps/Rev, 35×28mm, 10V, 0.5 A/Phase." https://www.pololu.com/product-info-merged/1208 (accessed Sep. 19, 2023).

[12] Minebea Co., Ltd., "Minebea DIx42B20 20W." 2015. Accessed: Sep. 19, 2023. [Online]. Available: https://mm.digikey.com/Volume0/opasdata/d220001/medias/docus/871/DIx42B20.pdf

[13] IPC International, Inc., "IPC-A-600: Acceptability of Printed Boards." Jul. 1, 2020

[14] UL Standards, "UL 60950-1: Information Technology Equipment - Safety - Part 1: General Requirements." Mar. 27, 2007.

[15] UL Standards, "UL 507: Electric Fans." Nov. 9, 2017.

[16] The Publications office of the European Union, "Commission Delegated Directive (EU) 2015/863," *Official Journal of the European Union*, March 31, 2015.

[17] B. Jeong-hyeon and K. A-ra. "smart electric fan using distance/temperature/humidity sensor working with portable mobile phone and Driving method of the same ," Dec. 15, 2016

[18] L. Li, Z. Li, Z. Li, L. Guo, W. Zhang, and L. Zhang. “Self-adjusting smart fan,” Dec, 19, 2016

[19] E. A. Arens, “Interactive occupant-tracking fan for indoor comfort and energy conservation ,” Jun. 23, 2020

[20] National Archives and Records Administration, “177.1630 Polyethylene phthalate polymers,” *Code of Federal Regulations,* Title 21, Chapter 1, Subchapter B, Part 177, Subpart B, March 15 1977.

[21] CUI Devices, “PJ-102A DC Power Jack,” October 30, 2019. [Online]. Available: https://www.cuidevices.com/product/resource/pj-102a.pdf

[22] Bourns Pro Audio. “PDB18 Series – 17mm Rotary Potentiometer” [Online]. Available: https://www.bourns.com/docs/Product-Datasheets/PDB18.pdf

[23] Texas Instruments, “DRV8874 H-Bridge Motor Driver With Integrated Current Sense and Regulation,” December 2019. [Online]. Available: https://www.ti.com/lit/ds/symlink/drv8874.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1701818890017&ref_url=https%253A%252F%252Fwww.ti.com%252Fgeneral%252Fdocs%252Fsuppproductinfo.tsp%253FdistId%253D10%2526gotoUrl%253Dhttps%253A%252F%252Fwww.ti.com%252Flit%252Fgpn%252Fdrv8874

[24] Monolithic Power Systems, “MP6500, 35V, 2.5A Stepper Motor Driver”, June 22, 2017. [Online]. Available: https://www.pololu.com/file/0J1447/MP6500_r1.0.pdf

[25] Texas Instruments, “DRV8871 3.6-A Brushed DC Motor Driver with Internal Current Sense (PWM Control)”, July 2016. [Online]. Available: https://www.ti.com/lit/ds/symlink/drv8871.pdf?ts=1701709511177&ref_url=https%3A%2F%2Fwww.ti.com%2Fproduct%2Fes-mx%2FDRV8871

Appendix: Budget Outline

Part	Unit price	Quantity	Cost
IR camera	$48.29	1	$48.29
IR sensor	$11.08	2	$22.16
12 V DC Brushless motor	$3.24	1	$3.24
DC motor driver (TI)	$3.39	3	$10.17
DC motor driver (HiLetgo)	$8.15	2	$16.31
Stepper motor	$19.49	1	$19.49
Stepper motor driver (Polulu)	$6.95	3	$20.85
Stepper motor driver (Adafruit)	$4.20	5	$21.00
12 V Adapter	$9.93	1	$9.93
PCB Jack	$0.77	2	$1.54
Potentiometer	$1.52	3	$4.56
Regulator (3.3v)	$1.99	2	$3.98
Regulator (10v)	$2.08	1	$2.08
3D PETG Filament	$23.99	1	$23.99
3d PLA Filament	$53.00	1	$53.00
Slip Ring (6 wire)	$14.95	1	14.95

Slip Ring (12 wire)	$18.62	1	$18.62
STM32 G071RB	$42.85	1	$42.85
Resistors (10k, 16k, 47k, 3k)	$0 .05	40	$2.06
Filter Caps	$0.19	20	$3.86
Bypass Caps	$0.16	10	$1.57
Header Pins	$0.02	24	$0.46
Jumper Wires	$2.10	2	$4.20
Total			~$349.16
Additional Funds			~$122