ECE 445

Senior Design Laboratory

Design Document

Thermo-Camera based energy consumption monitoring system

Team #16

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1 Introduction

1.1 Problem

In the field of chip and circuit research, power consumption is an important indicator. Thermal imaging is a method to analyze power consumption. For example, thermal analysis can assist designers to determine the electrical performance and reliability of components on PCB and help determine whether components or PCB will fail or burn out due to overheating.

A circuit board contains many components. We want to simulate the power consumption related to temperature. At present, due to the different thermal properties of each circuit element, the current thermal imaging equipment is not necessarily flexible and accurate for analyzing circuit power consumption. For example, the existing thermal camera cannot move freely. [1]

Our goal is to design a convenient, dedicated, and accurate thermal imager to assist in the research of chips and circuits.

1.2 Solution

To solve the problems mentioned above, we plan to design a thermo-camera and corresponding software to analyze the temperature distribution over a circuit board such as the motherboard of a computer.

The product has 4 parts: a thermo-camera, a cuboid frame, a control system, and an image analyze system. More specifically, the thermo-camera should be able to record the thermal distribution of the circuit in real-time. The mechanical structure of the whole system is very straightfor- ward. Therefore, it’ s just a cuboid frame with a board and a mechanical lever to control the thermo- camera. In addition, a control system for the camera is required. The hardware of the control system is a self-designed circuit together with an electro machine. The software of the control system is a self-designed image processing software, which can calculate the power consumption after we take screenshots of the required components. Then we can use data lines such as Type-C line to connect the hardware and the software. According to the circuit components we want to analyze, the camera can move to the corresponding location. Knowing the temperatures over the board, we will estimate how much energy is consumed at different parts of the board. Furthermore, we can try to view the temper- ature distribution from outside of the laptop, and use the image of motherboard when the laptop has been opened. To achieve the estimation, we will refer to the data sheet of electronic components and base the formula between temperature and power.

In conclusion, through such a system, we can obtain real-time thermal images to analyze the power consumption of the circuit.

1.3 Visual Aid

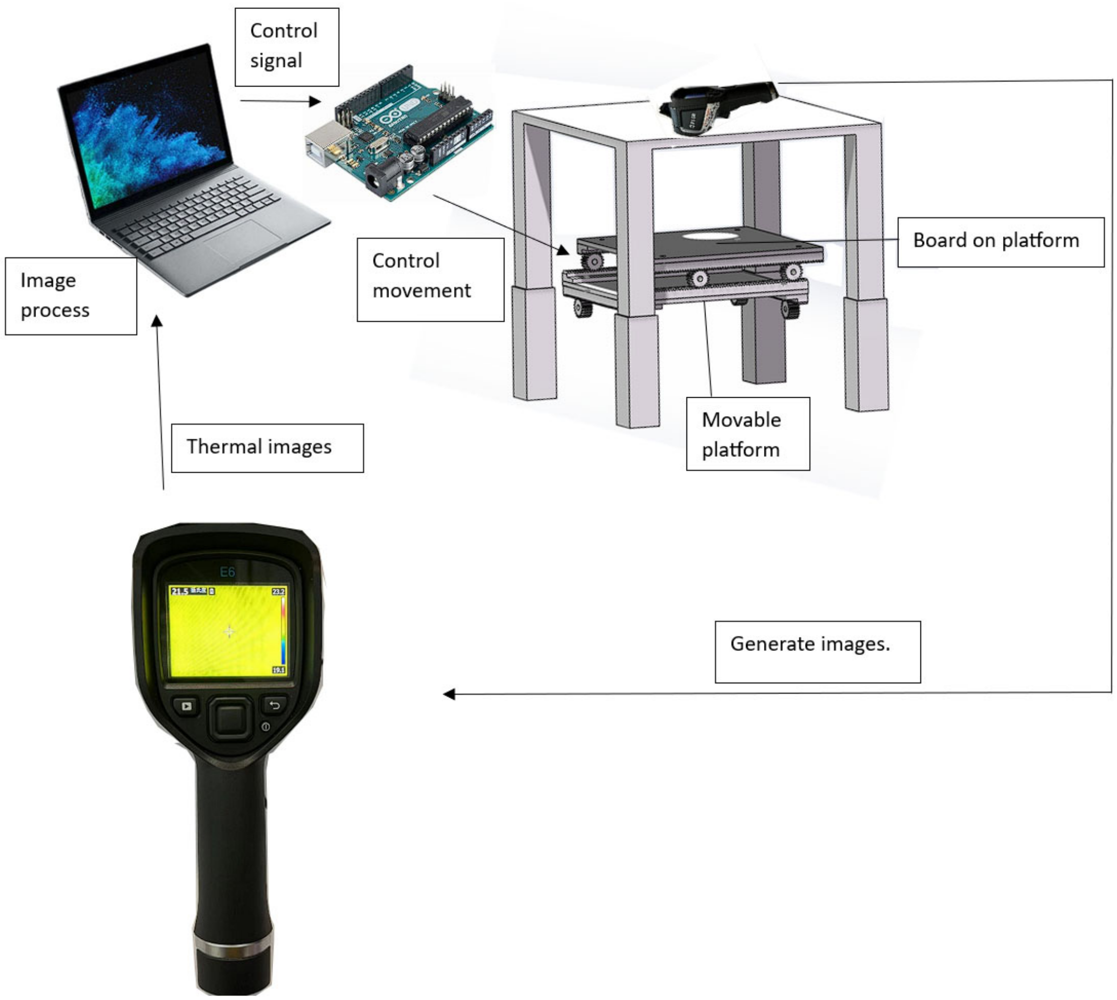


Figure 1: visual aid

1.4 High-level Requirements List

1. Thermo-camera: Thermo-cameras should be accurate and reliable, with a minimum margin of error, to ensure that the results are useful and actionable. Thermo-cameras should be sensitive enough to detect small temperature differences. Thermo-cameras should have a high resolution to capture detailed images of individuals and objects, enabling better analysis and decision-making. Thermo-cameras should be easy to use and operate, with simple controls and clear instructions, to enable efficient and effective monitoring. Thermo-cameras should be easily moved vertically and horizontally to locate specific electronic components.

2. Image processing software: The computer should calculate the energy consumption based on the temperature image. The computer should obtain the point temperature for a thermal image. The computer should Develop a GUI to view images and analyze images efficiently.

3. Bracket: The movable hardware is capable of supporting the thermal camera and achieving free height adjustment in the vertical direction. The telescopic rod can support a weight of 1 kg.

4. Control system: The ability to change the camera position. The keyboard signal strength is approximately 200 milliseconds. The position of the camera can be adjusted by controlling the rotation of different motors through the keyboard, as well as the rotation direction of the motors and whether they are turned on or off. The power supply of the motor should be able to offer a stable voltage between 7 and 12V.

2 Design

2.1 Block Diagram

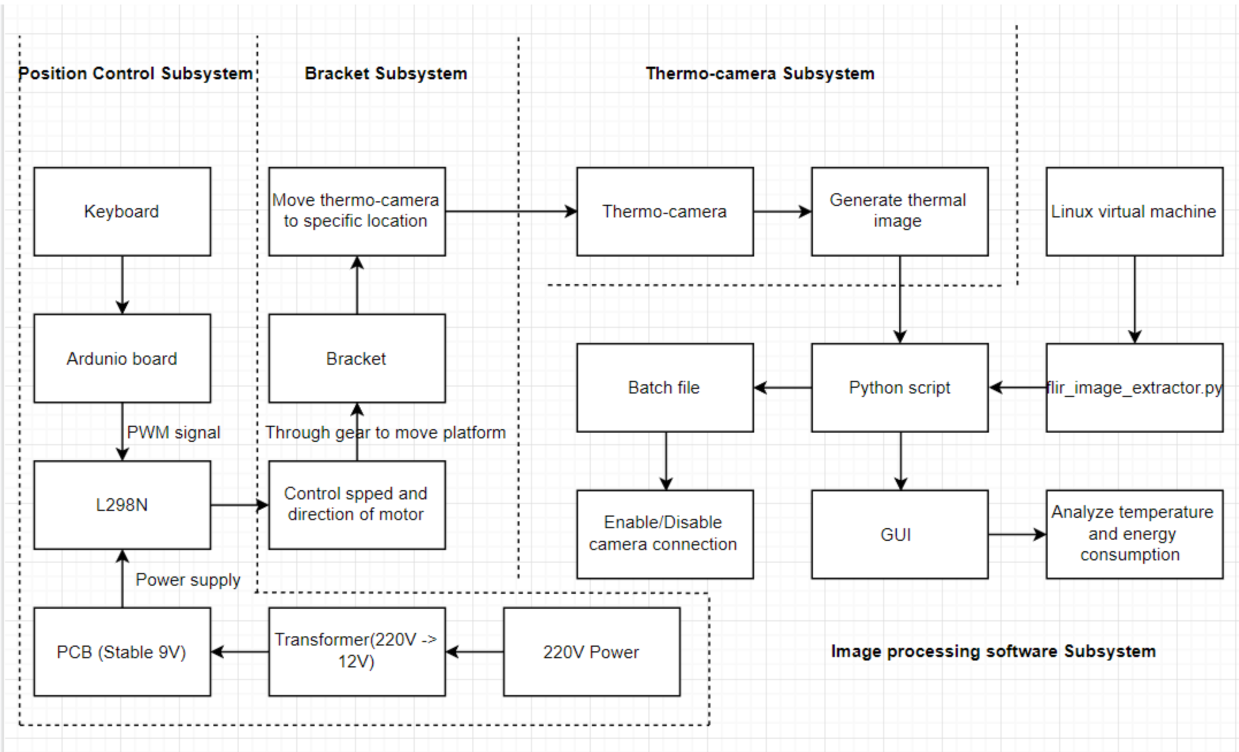


Figure 2: Block Diagram

2.2 Schematic diagram

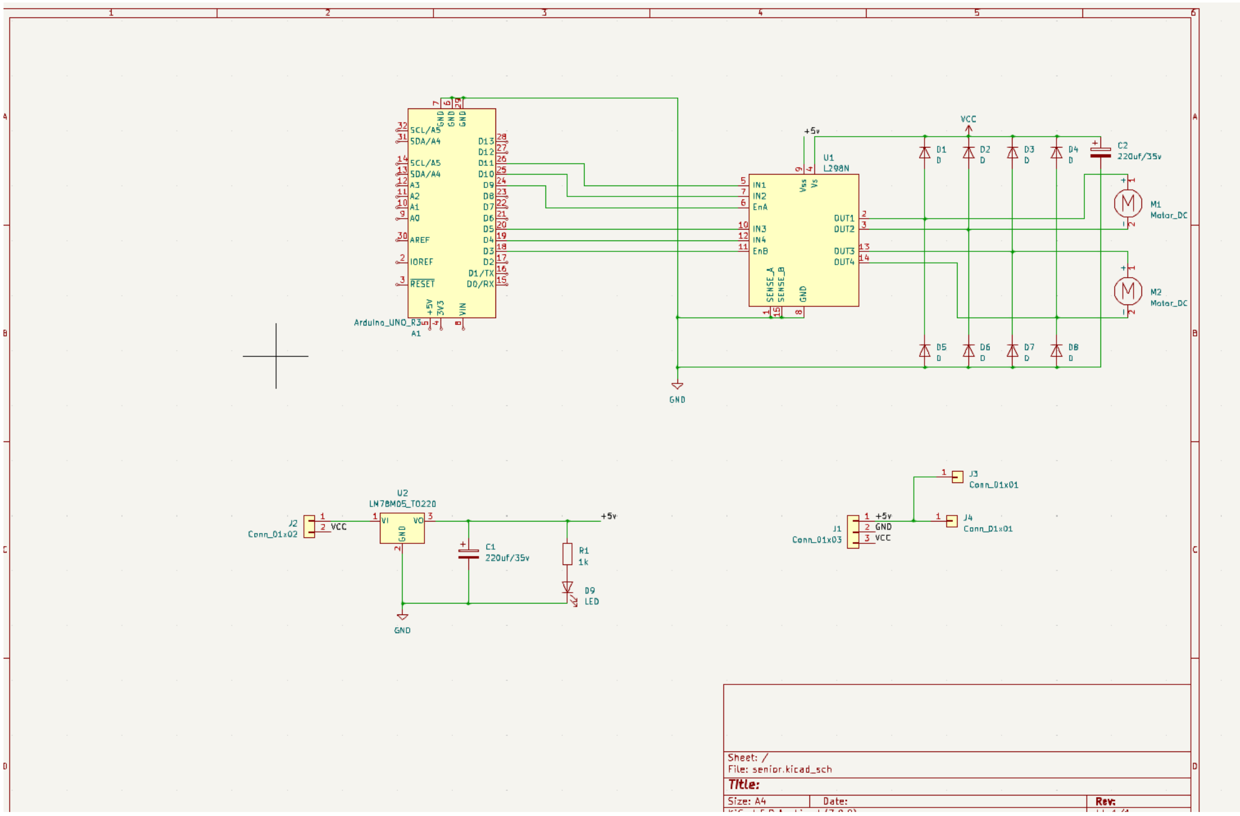


Figure 3: Arduino , L298N connection

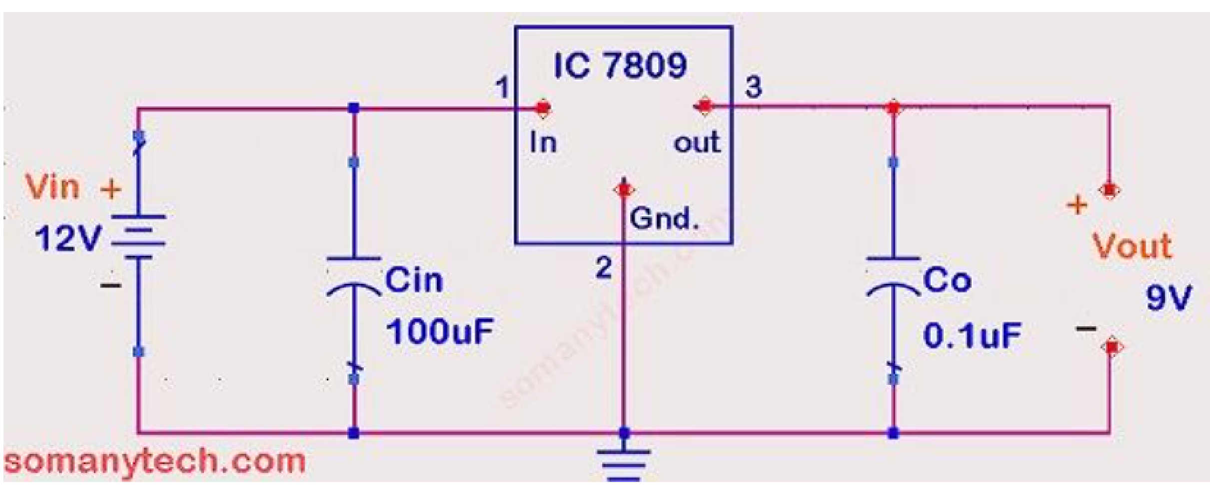


Figure 4: Electric Circuit [2]

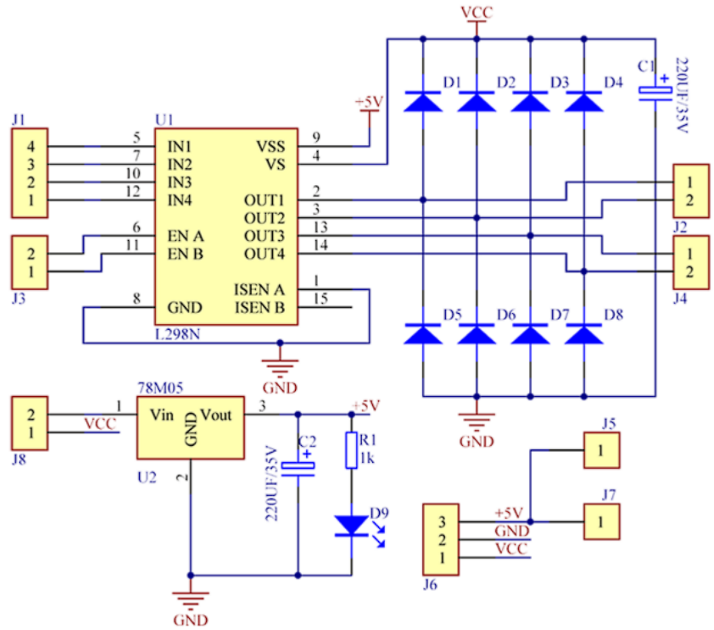


Figure 5: L298N schematic diagram

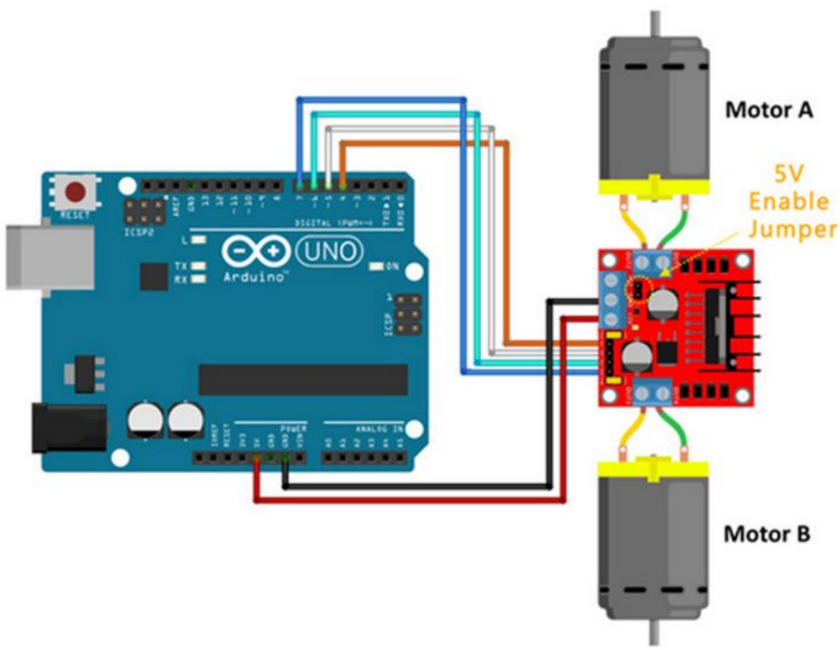
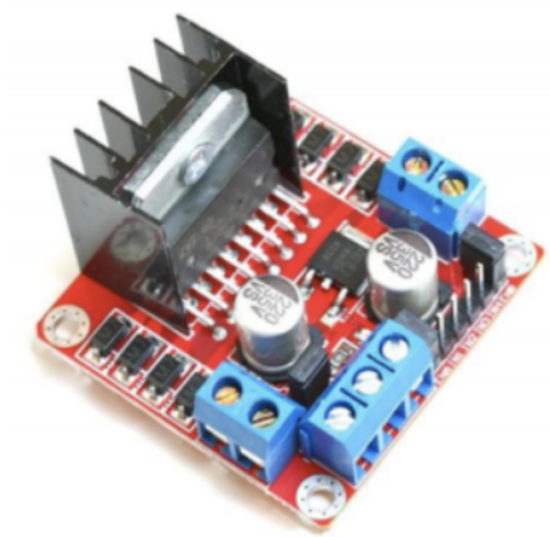


Figure 6: Control system, Arduino L298N and motor

2.3 Physical Design

Figure 7: Thermo-Camera

Figure 8: Thermal Image of components



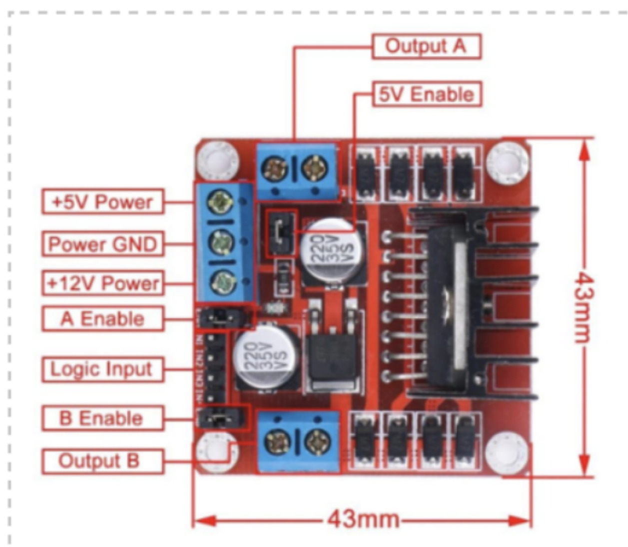


Figure 9: L298N board dimension and pins function[3]

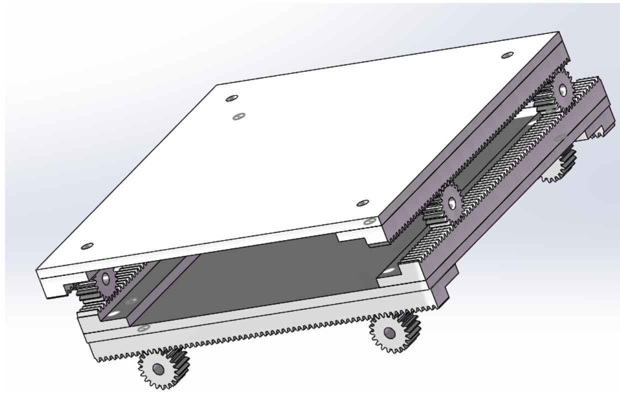


Figure 10: Gear transmission system

Figure 11: telescopic rod

We use rack and gear to connect with the base to realize the horizontal movement of the base. Also, we buy metal telescopic rod to support heavy cameras and realize vertical movement.

2.4 Subsystem Overview

The whole product has four main subsystems as shown on the block diagram above.

1. A thermo-camera that sends images to a computerin real-time.
(1)thermo-camera
(2)Data line(type-B)

2. A bracket capable of three-dimensional movement for placing the thermo-camera.
(1)Platform
(2)Telescoping frame

3. Image processing software to inform physics-based models of energy consumption in electrical circuits.
(1)Batch file to enable/disable camera connection
(2)Linux virtual machine
(3)Canulating formula: Energy vs. temperature

4. A control system for the mobile camera, which is very useful for adjusting its position and zooming to obtain the correct real-time image. (1)Arduino
(2)PCB
(3)Motor
(4)Power supply

2.5 Subsystem Requirement

2.5.1 thermo-camera subsystem

(1) The thermo-camera needs to be able to transmit images in real time and have a macro lens to ensure that the components of the circuit board can be seen clearly. In addition, the temperature range of temperature measurement should at least include the working temperature of the circuit board, such as 0 °C to 100 °C. Some common thermo-camera is at - 10 °C to 400 °C, which is sufficient for use. What's more, the camera should be able to focus automatically to a certain extent, avoiding our inability to obtain sufficiently clear images due to insufficient horizontal control accuracy.

(2)Data line(type-B). The matching cable for the camera has no compatibility and stability issues, and can quickly and accurately send data

2.5.2 Bracket subsystem

(1)The Bracket subsystem is composed of upper and lower bases. After receiving the movement command from the Position control subsystem, the upper base can complete the movement in X and Z directions, and the lower base can complete the movement in Y direction, thus forming the three-dimensional movement of the camera relative to the chip. (1)The platform is only used for 2D horizontal movement.

(2)For the camera, we use a telescoping frame to ensure that our camera is fixed. This telescoping frame can be adjusted manually Compared to 3D printing, the device we bought is robust enough to prevent accidental detachment of the camera.

2.5.3 Image processing software subsystem

Thermo-image analysis is the process of analyzing the temperature distribution of an object or scene captured by a thermal camera. It mainly consists of 3 steps. Image preprocessing: This step involves filtering, enhancing, and correcting the raw thermal image to improve its quality and accuracy. Feature extraction: This step involves identifying and extracting relevant features from the thermal image, such as temperature gradients, regions of interest, and thermal signatures. Feature extraction can be done using computer algorithms. Data analysis: This step involves analyzing the extracted features to draw conclusions about the object or scene being analyzed. Data analysis may involve statistical analysis, pattern recognition, or machine learning techniques. We then use those data to compute the formula in energy consumption. For example, an energy consumption formula is as follows.

$$T_j = T_a + (\theta_{JA} \times P_D)$$

where T_j is the estimate of chip junction temperature, T_a is the package ambient temperature, θ_{JA} is the thermal resistance of P-N junction to environment (given by component data sheet), and P_D is the total on-chip power consumption.

To briefly explain our thermal image, a flir thermal camera includes both thermal and visual light cameras. The generated image is saved as a jpg image, but the raw visual image and the raw thermal sensor data are embedded in the jpg metadata. So, we can use python tools/libraries to extract and convert the raw light and thermal sensor values of the temperature.

2.5.4 Position control subsystem

The position control system consists of a position control program and a mechanical camera bracket. It can transmit the three-dimensional position movement information to the bracket through a computer, and then complete the corresponding position movement through the mechanical bracket, thereby changing the position of the base. By changing the relative position of the base and the camera, we can obtain the desired image. ”For the camera's view, we use the telescopic frame described in the bracket subsystem because it is a purchased device. To ensure stability, we manually adjust the height.”. Once the height is adjusted, it will not change easily. The base is 3D printed, with built-in gear grooves, and 2D motion on the plane is achieved through motors and gears. In order to achieve the above objectives, the motor should be able to carry equipment above the platform, and its power must be within the appropriate range. Whether it can be used requires practice.

(1)Arduino UNO R3, This microcontroller can control the operation of the motor through PWM.

(2)PCB, Output a constant voltage to convert the battery voltage into the voltage we need. The specific value is regulated in the experiment.

(3)Motor, we plan to use a DC motor with a working voltage of 7-12V.

(4)Power supply, Battery or regulated power supply, matching with the motor. Preferably within 12V. 12V power supply can simultaneously power Arduino.

2.6 Requirements and Verification

2.6.1 Image processing software subsystem

Table 1: Image processing software subsystem

Requirements	Verifications
· Obtain point temperature for a thermal image. · Use temperature data to compute the formula for energy consumption. · Develop a GUI to view images and analyze images efficiently.	· Given a random thermal image, we can pick any point to show its temperature. · When the thermo-camera captures a new image, it will be automatically uploaded to our GUI.

2.6.2 Thermo-camera subsystem

Table 2: Thermo-camera subsystem

Requirements	Verifications
· The camera can be connected to our personal computer. · The camera can save thermal images on a memory card. · The camera can capture thermal images of small circuits without blurring components.	· Our computer can access to the memory card of the camera and the images in the memory card. · The PC can receives images in the correct format. · We can see the edge of components clearly.

2.6.3 Position control subsystem

Table 3: Position control subsystem

Requirements	Verifications
· The ability to change the camera position. The keyboard signal strength is approximately 200 milliseconds. The position of the camera can be adjusted by controlling the rotation of different motors through the keyboard, as well as the rotation direction of the motors and whether they are turned on or off. · The power supply of the motor should be able to offer a stable voltage between 7 and 12V.	· If we want to stop moving, the camera will stop almost immdiately. If we want to move the camera, we can just press keyboard button on PC, and then the motor should work as desired and without significant lantency. · The motor can work as normal for a long time. No other unexpected problems such as burning out the circuit.

2.6.4 Bracket subsystem

Table 4: Bracket subsystem

Requirements	Verifications
· Capable of supporting the thermal camera and achieving free height adjustment in the vertical direction. · After installing the upper bracket and placing the thermal camera, manually adjust the telescopic bracket. Observe whether it can stabilize smoothly at various heights.	· The telescopic rod can support a weight of 1 kg. · After assembling the telescopic rod and support platform, place a weight of 1 kg the table to check whether it can freely and smoothly extend.

2.7 Tolerance Analysis

1. The thermo-camera takes Infrared images of the circuit. It can move as desired through the control system. But the control process may produce delay because of the control signal transmission. And then the thermal images will be transmitted to the computer which may also result in some delay. However, a certain amount of delay is tolerable, since we will take a screenshot of the real time image to analyze the power consumption, which does not require high precision.

2. Because we only take pictures on circuit board, the reachable location of the two-axis base of this product does not require long range. The acceptable result is that the workspace of the camera meets the corner of circuit board.

3. For image processing software, we need to determine the tolerance limits for component segmentation. The software can tolerate the edges of component are not clear while still achieving the desired performance metrics because we only care about the temperature.

4. For the control system, we must ensure that it is stable so that the thermo-camera can remain stationary to capture stable images. This is a crucial aspect. Fortunately, our control system is simple enough to control its displacement, and it is controlled by our own computer input, so there will be no obvious back and forth vibration.

5. For the Bracket subsystem, its platform is strong enough to hold a circuit board weighing 1kg, the frame is strong enough to hold at least 1kg, as the camera weighs 575g (about 1.27 lb). The camera's field of view should only cover part of the platform, but the platform has the ability to move so that the camera can photograph the entire platform.

6. For the thermo-camera itself, the model of camera is FLIR E6-XT. it has a resolution of 240 by 180 (43,200 pixels) and thermal sensitivity <0.06 °C /<60mK. The spatial resolution is 3.4 mrad and the FOV is $45° \times 34°$. The camera is auto-focused, so we don't need to focus manually.

SPECIFICATIONS

Image and optical data	E4	E5-XT	E6-XT	E8-XT
IR resolution	80 × 60 (4,800 pixels)	160 × 120 (19,200 pixels)	240 × 180 (43,200 pixels)	320 × 240 (76,800 pixels)
Thermal sensitivity/NETD	<0.15°C (0.27°F) / <150 mK	<0.10°C (0.27°F) / <100 mK	<0.06°C (0.11°F) / <60 mK	<0.05°C (0.09°F) / <50 mK
Spatial resolution (IFOV)	10.3 mrad	5.2 mrad	3.4 mrad	2.6 mrad
Field of view (FOV)	45° × 34°			
F-number	1.5			
Image frequency	9 Hz			
Focus	Focus-free			
Detector data				
Detector type	Focal Plane Array (FPA), uncooled microbolometer			
Spectral range	7.5–13 µm			
Image presentation and modes				
Display	3" 320 × 240 color LCD			
Image adjustment	Automatic adjust/lock image			
Image modes	Thermal MSX, thermal, picture-in-picture, thermal blending, digital camera			
Color palettes	Iron, Rainbow, Black & White			
Measurement and analysis				
Object temperature range	–20°C to 250°C (–4°F to 482°F)	-20°C to 400°C (-4°F to 752°F) in two ranges	-20°C to 550°C (-4°F to 1022°F) in two ranges	-20°C to 550°C (-4°F to 1022°F) in two ranges
Accuracy	±2°C (±3.6°F) or ±2% of reading for ambient temperature 10°C to 35°C (50°F to 95°F) and object temperature above 0°C (32°F)			
Spotmeter	Center spot			
Area	Box with max/min			
Isotherm	Above alarm, below alarm			
Data communication and interfaces				
Interfaces	USB Micro: data transfer to and from PC and Mac device			
Wi-Fi	Peer-to-peer or infrastructure			
File format	Standard JPEG, 14-bit measurement data included			
General				
Operating temperature range	-15°C to 50°C (5°F to 122°F)			
Battery	Rechargeable 3.6 V Li ion battery			
Battery operating time	Approx. 4 hours at 25°C (77°F) ambient temperature and typical use			
Battery charging time	2.5 hours to 90% capacity in camera. 2 hours in charger			
Drop	2 m (6.6 ft.)			
Camera weight, incl. battery	0.575 kg (1.27 lb.)			
Camera size (L × W × H)	244 × 95 × 140 mm (9.6 × 3.7 × 5.5 in)			
Box contents	Infrared camera, hard transport case, battery, USB cable, power supply/charger with EU, UK, US and Australian plugs, printed documentation			

Specifications are subject to change without notice. For the most up-to-date specs, go to www.flir.com

Figure 12: Flir thermo-camera datasheet[4]

3 Cost and Schedule

3.1 Costs

Most of our components are borrowed from the laboratory. The Thermocamera cost 30000 RMB, The Arduino board costs 100 RMB, L298N module costs 10 RMB, PCB costs 100 RMB, 3D printer consumables costs about 30 RMB and step-down transformer costs about 100 RMB.

Assume the fixed development cost of each of our team member is about 50 RMB/hour and all the team members shall work for 15 hours for each week. This semester takes about 12 weeks long. The salary for each member would be:

$$50\ \ RMB/hr{\times}20\ \ hr/week{\times}12\ \ weeks{\times}4\ \ people = 48000RMB$$

Four Telescopic leg cost 10RMB $\times$ 4 = 40RMB.

Sum of costs about 78380 RMB.

3.2 Schedule

3.12 - 3.19	· Obtain an available Thermo-Camera. · Based data transmission from the camera to our computer. · Simple design of mechanical motion. · Obtain the one-chip computer used to control the mechanical system. · Brief design of PCB
3.20 - 3.26	· Start coding the software for image transmission. · Obtain available motors and fit them to hardware. · Learn and implement basic usage of hardware system. · Continue design on PCB.
3.27 - 4.23	· Test the hardware system to move the circuit board in 2-D space. · Complete the software about getting temperature from the thermal image. · Finish designing PCB about stabilizing power voltage.
4.3 –4.9	· Soldering our PCB and fit it into circuits. · Start working on GUI design to help analyzing thermal image. · Test the hardware system to move the thermos-camera vertically.
4.10 –4.16	· Add some triggers to automatically hit the button to take a thermal image. · Improve the compatibility and accessibility of our GUI. · Combine our base support and vertical support to get a 3D moving system.
4.17-4.23	· Successfully finish the hardware framework of the whole system. · Finish the control system for moving the camera. · Finish the image GUI to analyze thermal image.
4.24-4.30	· Debug our project to get ready for the mock test. · Finish the prototype of our design.
5.1-5.7	· Successfully finish Thermo-Camera based consumption monitoring system. · Prepare for the presentation. · Prepare to write our final report.

4 Ethic and Safety

4.1 Ethics

4.1.1 Ethics of our product

Our group guarantees that the monitoring system will not use dangerous systems that can harm people. Thermo-Camera technology can capture sensitive information of individuals, including their temperature and personal characteristics. Developers and users of this technology must respect personal privacy and ensure that the collected data is properly and safely used.

4.1.2 Ethics of research and development

Security: Thermo-Camera technology must be used safely to prevent unauthorized access to data or technology itself. Developers and users of technology must take appropriate measures to protect security and integrity.

Statement of non-plagiarism: Our team declares that this product will not use any existing codes and products and will not duplicate any existing modeling solutions.

4.2 Safety

(1) Our team guarantees that we will have more than two people in the laboratory.

(2) Our team guarantees that we will complete a mandatory online safety training in order to be allowed to work in the lab.

(3) Our team guarantees that we will complete additional safety training, Safe Current Limits, read, understand, and follow guidelines for safe battery usage before we are working with those things with electricity safety risks.

(4) Our team guarantees that we will use safe mechanical structure and pay more attention to mechanical structure safety. [5]

(5) Consider the safety hazards of the system when moving. Our team guarantees that if there are people nearby, they will not be caught by the equipment due to the wires.

(6) The working temperature of electronic components is generally around 30-50 °C, and there is only local high temperature. We guarantee that the electronic components we are using will be packaged in a frame to prevent people from touching and scalding.

References

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[2] S. Tech. “”12V to 9V converter - best 5 Circuits”.” (2022), [Online]. Available: https://somanytech.com/12v-to-9v-converter/ (visited on 03/22/2023).

[3] H. Technology. “”L298N Dual H-Bridge Motor Driver Guide”.” (2023), [Online]. Available: https://handsontec.com/dataspecs/module/L298N$%5C%$20Motor$%5C%$20Driver.pdf (visited on 03/22/2023).

[4] FLIR. “”EX-SERIES DATASHEET”.” (2019), [Online]. Available: https://flir.netx.net/file/asset/17975/original (visited on 03/22/2023).

[5] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 03/22/2023).