

ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Design Document for ECE 445 Vehicular Edge Computing System

Team #38

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April 26, 2024

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1 Introduction

1.1 Background

The intelligent transportation system has received great interests from the academia and industry. The growing volume of data to be processed and the goal of short response time requires the development of edge computing system[1].

1.2 Problems

1.2.1 Energy Consumption

Energy-saving is always the issue being emphasized in computing server, as for the most of the computing devices, it consumes a significant amount of energy for computing and cooling. For example, as for the traditional cooling systems, such as fans or air-conditioners, the devices at a data center can consume over 40% of the total energy needed[2]. In presence, with the rapid development of Artificial Intelligence, the electrical energy required has the tendency to rise explosively in the following years. Elon Musk predicted that even maybe in the next year, AI will run out of electricity[3]. In order to ensure the electricity provision, it's in an urgency to find solutions to reduce energy consumption for electronic devices. In this project, we want to take the step to find proper way to save more energy for edge computing systems.

1.2.2 Immobility of edge servers

The general idea of deploying edge computing systems is to locate the them at fixed points near the user end, which covers a fixed service region[1]. But it encounters the problem of low utilization rate for some reasons. For one thing, the time duration of a car being served by a certain edge server is limited, which fundamentally stop the server from accomplishing time-consuming work, like deep learning problems. So the server either not provide the service at all, which makes the server idle, or transfer the data to the next server where the car is going to approach, which is also sophisticating.

1.3 Solutions

1.3.1 Propose

Considering the problem above, we aim to deploy the edge server on-board the vehicle, e.g. a car. We propose that making use of the movement of the vehicle, the server can be cooled down greatly by the wind. Also, the service coverage is dynamic so that statistically, the average utilization rate of a server rises. That's because there should be a server station having no way but to stay at a particular location to serve the area with a lower vehicle flow rate.

1.3.2 Scheme

Now that the server is put on-board, we need to design a shelter with a ventilating structure to make it stable enough, immune to rain, and realize effective wind cooling. In order to improve the performance of the server and save more energy, we want to design a control module of adjusting the CPU utility according to the cooling effect. Also, as the server cannot be accessed in wires, we need to add a wireless communication module to make it accessible to the nearby base station.

1.4 Visual Aid

1.5 High-level requirements list

1. Energy saving:

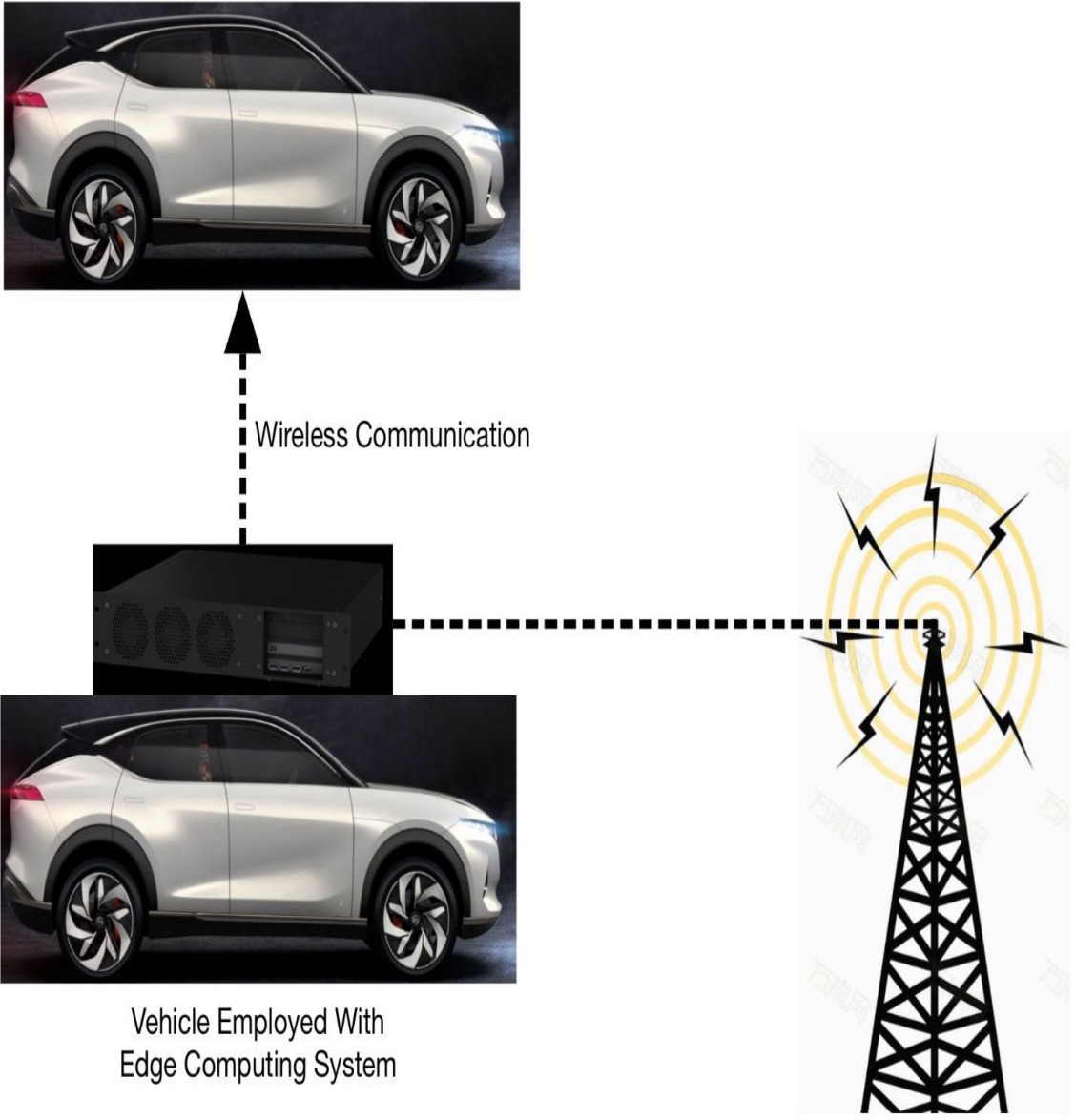
The cooling system can save 40% of the electricity, compared with the traditional temperature-only based cooling system, i.e. using fan or air-conditioner only.

2. Cooling effectiveness:

The peak server temperature can be consistently controlled under 70°C regardless of the speed of the car.

3. Computational performance improvement:

The computing intensity can be dynamically adjusted with the help of the wind cooling to improve the overall utilization and performance of the server. The server on-board vehicle can accomplish more than 10% work load compared with the server deployed indoors.



Vehicle Employed With
Edge Computing System

Figure 1: Visual Aid

2 Design

2.1 Block Diagram

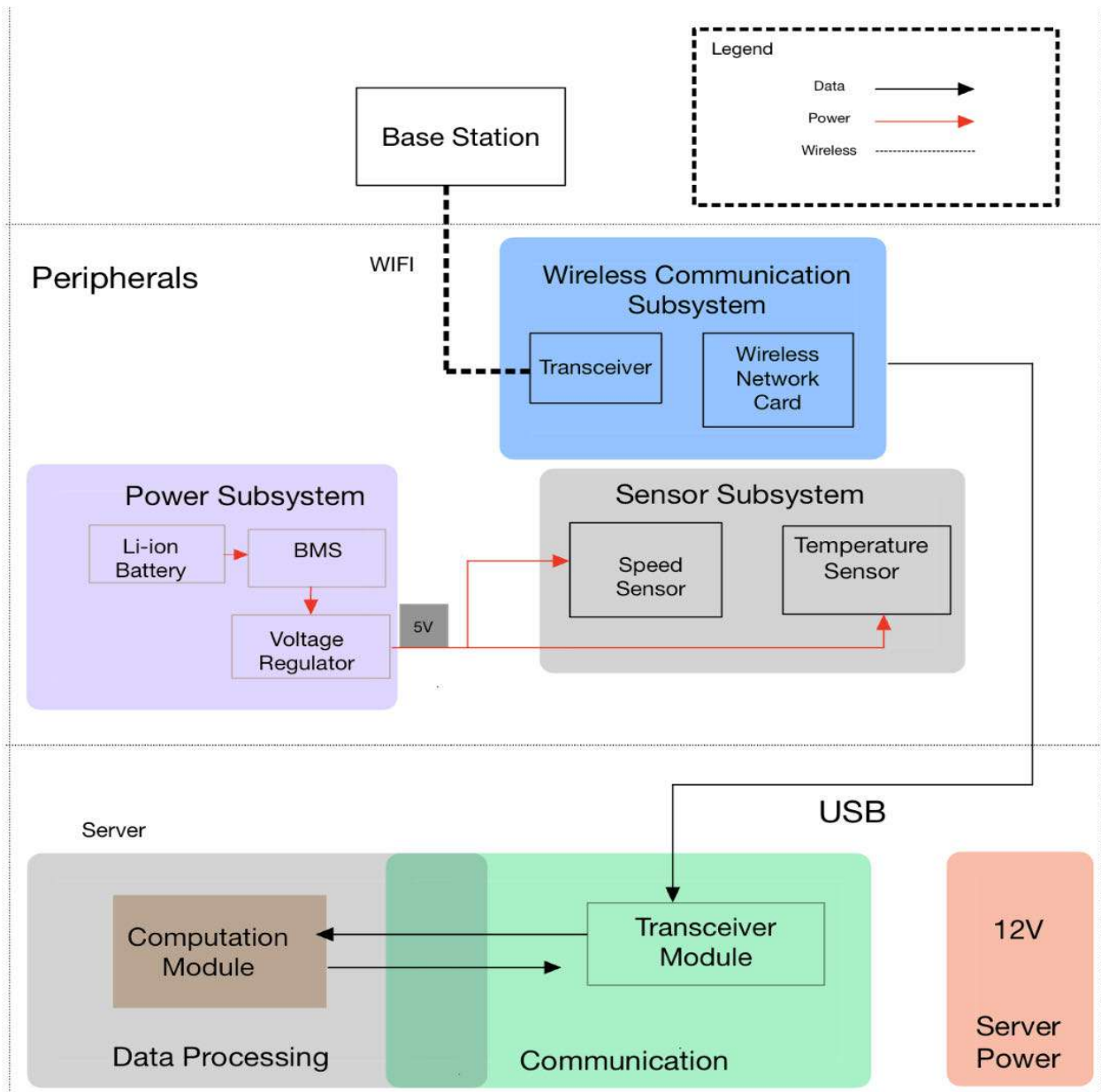


Figure 2: Block Diagram

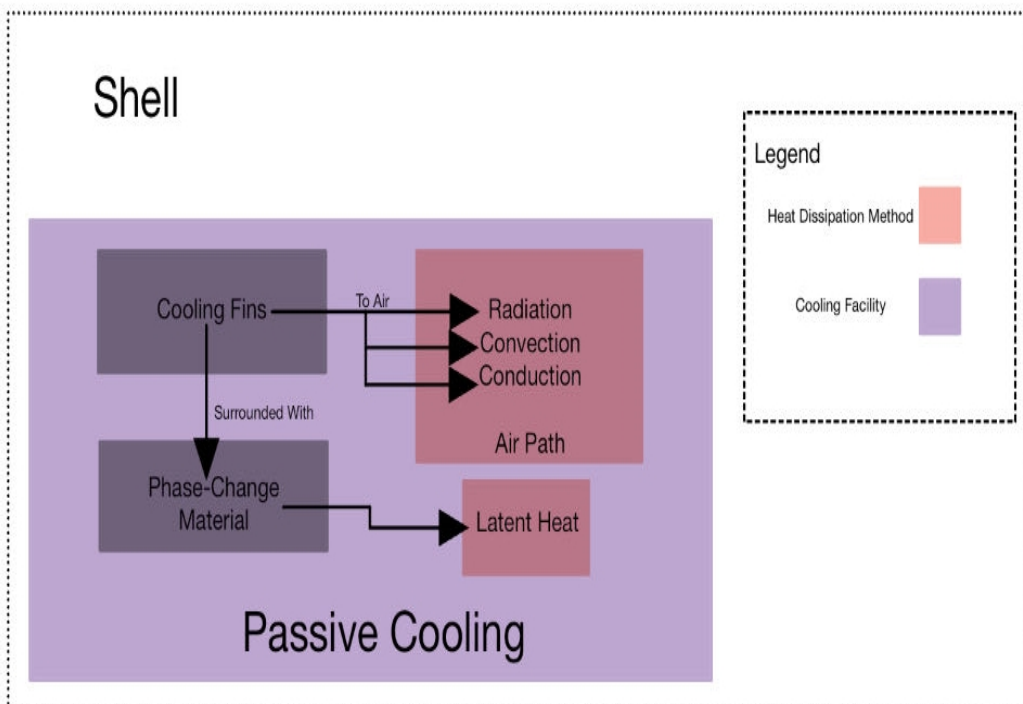


Figure 3: Block Diagram

2.2 Physical Diagram

The physical diagram of the protective and functional shell to accommodate our server is shown in Fig(4) and Fig(5). From these two figures, the design block diagram in Fig(3) is clearly justified. In Fig(4), Aluminum 6061 is adopted as the shell material, while in Fig(5), the wiring diagram clearly demonstrates the dimensions and inner structures of the shell. We can see that three wind tunnels are used as air cooling subsystem. The server is placed at the center, where the container has adjustable size and surrounded by fins. So servers with different sizes could be contained in this shelter. The fins are down slope to avoid surface ponding. The front of the shelter is outward-shaped so more air can be accumulated into the wind tunnel, leading to a considerable funnelling effect and increasing convection heat transfer rate between fins and air.

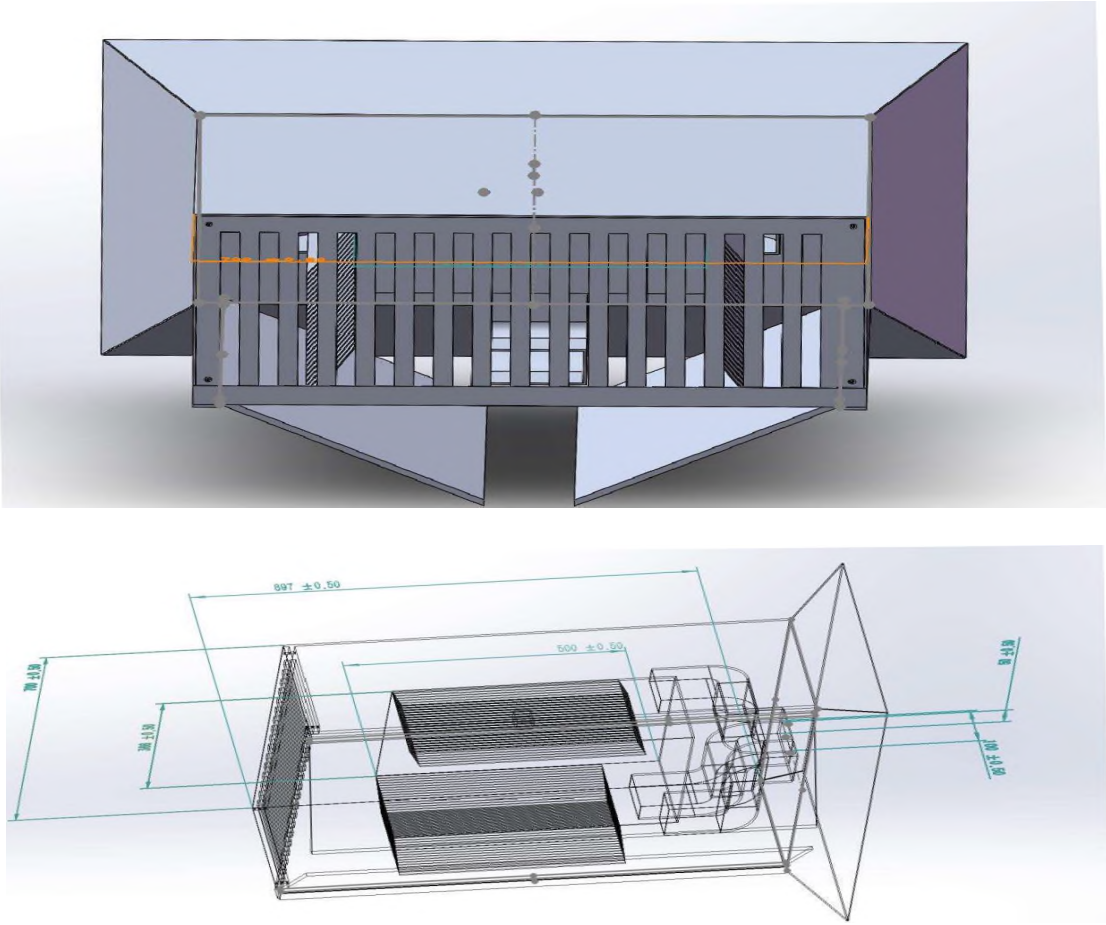


Figure 4: Physical Diagram

2.3 Subsystems

Our design is divided into three main systems, which are the server, the shelter of the server, and the peripherals.

2.3.1 Server

This block includes the software part of the server, including Data processing and communication , and also the server power provider. The server will be configured as if it's practically used in edge computing.

Configuration:

- We will configure Ubuntu in the server, deploy Docker based on Ubuntu, which is popularly proposed in edge computing, and run deep learning algorithm to make the server work under certain intensity.

Experiment participation:

- Under this condition, we will settle the server in front of a wind tunnel outlet in the lab, and test whether the cooling by wind is functioning well or not, i.e. effectively cool the server under the safe temperature.

Communication:

- We will enhance its ability of wireless communication, so that it can get access to the user ends through the Internet. In this part, we install a driver for USB wireless network card (which will be introduced later). And Ubuntu has several integrated software tool supported for Internet access such as "nmcli", "iw" and "wpa-suppllicant". We install and configure it into general use. These tools construct the inner connection of the hardware to form the transceiver module in the server.

Data Processing:

- As we want to model the real situation of a mobile server. In this part, we make the server run some traditional Deep Learning problems to model the real data processing the server may take, like decision-making for self-driving. For working performance, the CPU computational intensity and the operation condition of the fans(embedded in the server) is adjusted according to the temperature of CPU. We design a block of code to control and adjust the hardware resources occupation of the server. Also, we set the highest temperature at which the CPU should halt and alarm. The document in "/etc" directory in Linux is modified. Thus, during the experiments, we will mainly record the data of CPU temperature, the CPU occupation statistics, and the speed of the embedded fans.

Power:

- In practice, the battery will be along with the server on the vehicle to provide power to the server.

2.3.2 Shelter

This block is the shelter of the server. It has three main functionalities.

- The basic functionality is to carry and fix the server on the vehicle.
- Second, it functions as a cooling system. The cooling functionality is achieved by two methods, which are demonstrated as mechanical structures in the physical diagrams, Fig(4) and Fig(5). The first method is the double-deck shelter. Inspecting the physical diagrams, you can see that the shelter is composed of two layers, an outer shelter and an inner shelter. The inner shelter upholds the server and has cooling fins and phase-change material surrounding it. The fins will help dissipate heat through three processes: radiation, convection, and conduction; the phase-change material helps through latent heat. The outer shelter blocks away direct sunlight on the server creating a stable temperature environment in the shelter. The second cooling method is the adoption of three air tunnels. The air tunnels collect wind at the front of the shelter, where funnelling effect utilizes most air to increase the convection heat exchange rate among cooling fins.
- Third, the shelter is water-proof and protects the server entirely in rainy days, as you may inspect from the physical diagram. The shelter can also prevent water from accumulating, by utilizing some tilted devices, like fins and two disconnected boards that tilts down.
- Moreover, the size of the inner shelter is adjustable so servers of different sizes can fit in it.

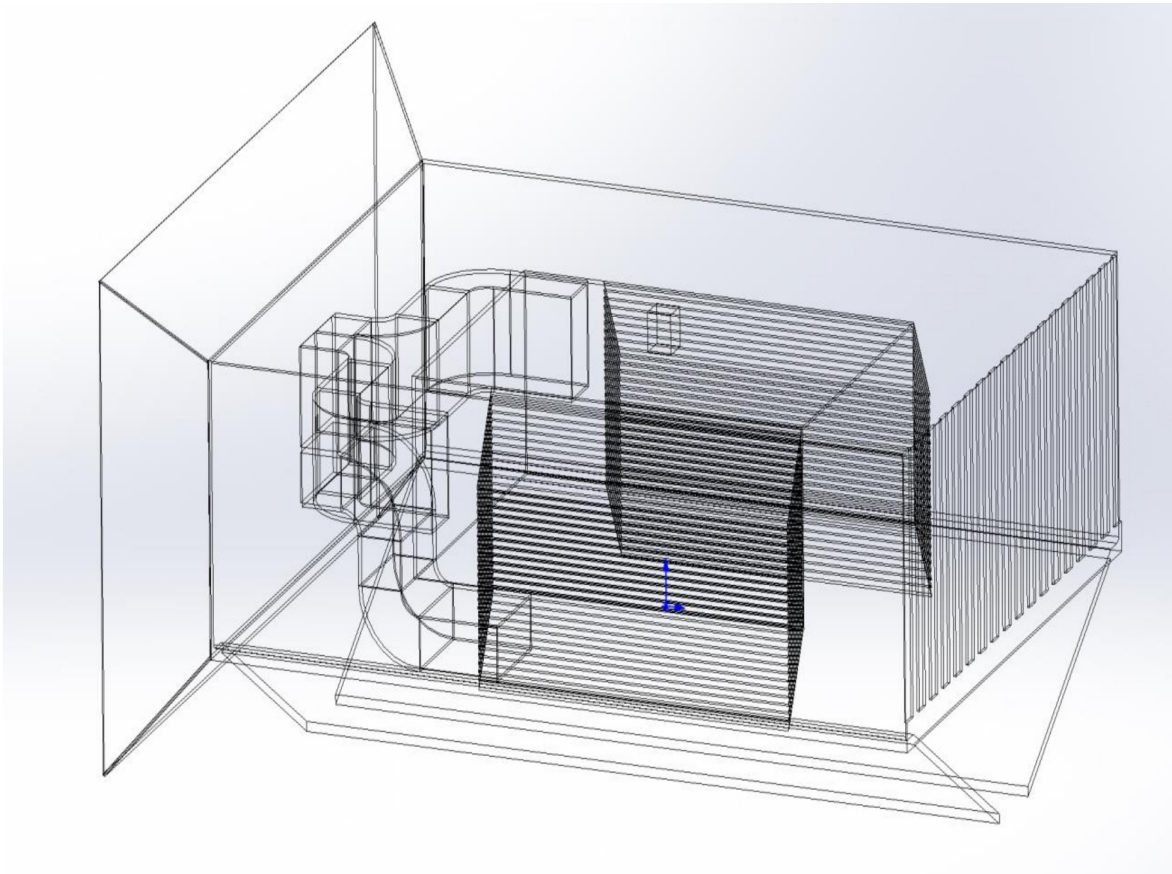


Figure 5: CAD Model for Double-Deck Shelter

In manufacturing, the server shell should be made by different materials and assembled separately.

This is because the main goal of the design is to achieve a perfect balance between cooling and energy-consumption. Since the design is mostly sealed, the water-proof should not be a significant element in choosing materials. From the famous kinematic energy equation:

$$K = \frac{1}{2}mv^2 \quad (1)$$

We know that a lighter material will consume less energy. Therefore, a first principle is that the overall material should be light enough.

To maximize cooling effect, considering the famous heat transfer function:

$$q = -kA\frac{dT}{dx} \quad (2)$$

Therefore, the heat conduction rate of the material is vital in heat dissipation. I choose Al6061 for material of inner shell, because it is light and has a very high heat conduction rate. For the outer shell, the selection should be more careful. Considering the ease of manufacturing, the front, as well as the air tunnel should be manufactured by alloys. Therefore, Al6061 is applied. However, the majority of the outer shell should not be alloy. Considering in hot weather, the outer shell ought to be less heat conductive to create a lower inner temperature environment, while in cold days, the heat conductivity of the outer shell does not matter that much since server would be less likely to overheat in cold environment temperature. Therefore, the material of the majority of outer shell ought to be plastic. By careful selection, POM is used as the material of the rest of outer shell, which is also hard enough to withstand the weight of server.

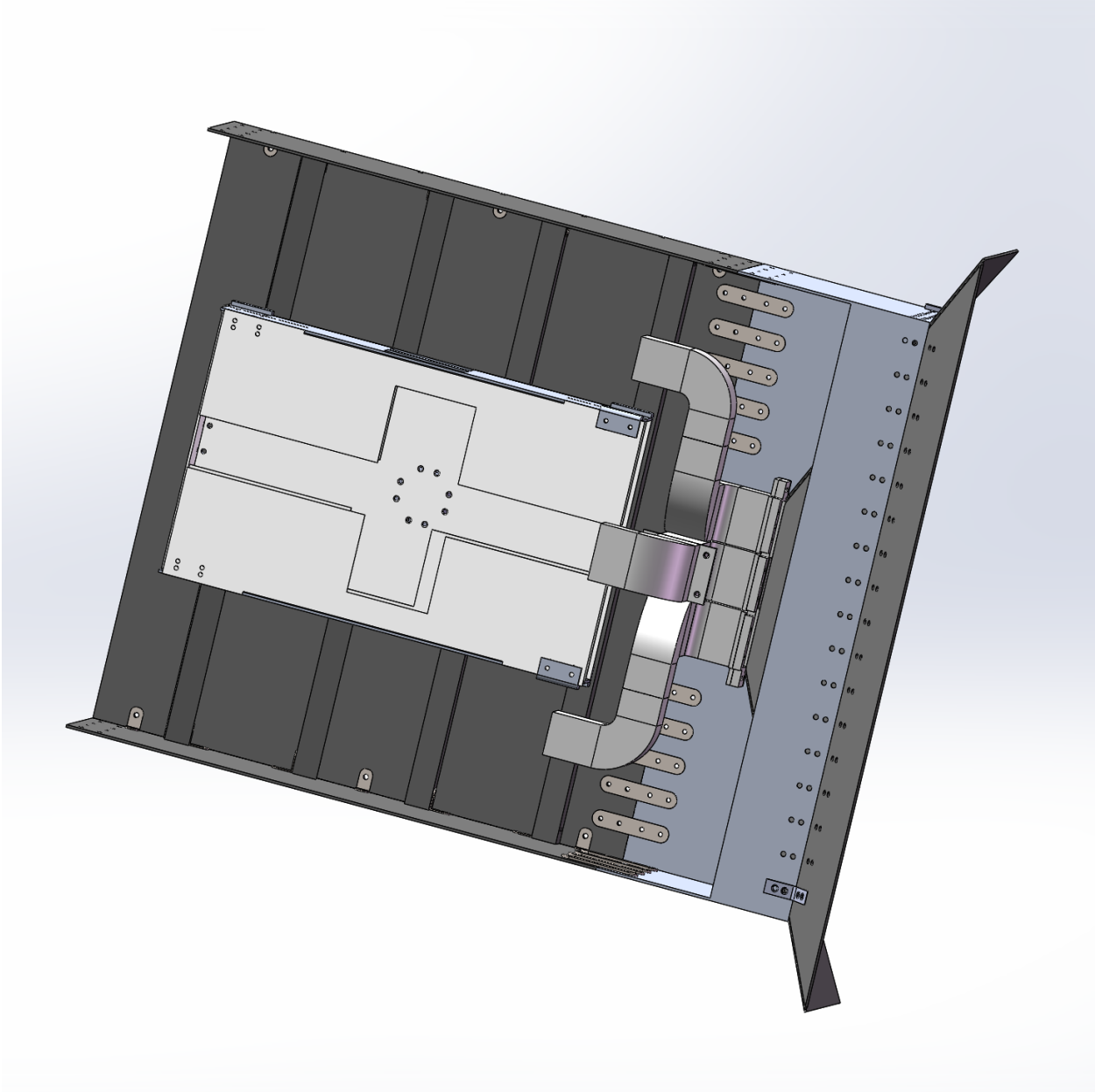


Figure 6: Server Shell in Reality

2.3.3 USB Wireless Network Card

We use AX300 high-gain USB wireless network card by company "MERCURY". It establishes wireless connection with the base station by nearby WiFi or hotpot with reliable accessibility through certain protocols. It uses a high-gain transceiver antenna to realize stable data sending and receiving. And it is easily connected to the server via USB protocol. Only the software for a driver provided by the company is needed to be downloaded to the Linux system so that it's enough for the wireless network card to work well. The followings are the schematic diagram for the entire device and the RTL8818-series chip it uses.

Now we briefly explain the core part, wireless network card. It works in Link Layer in OSI network model, connecting host and the physical hardware via NIC(network interface controller). Basically, it works as "gateway" to help label the server by IP and MAC address and processes data in the format of "Frame" coming in and out of the transceiver antenna. It uses some protocols like CDMA for data privacy and performance.

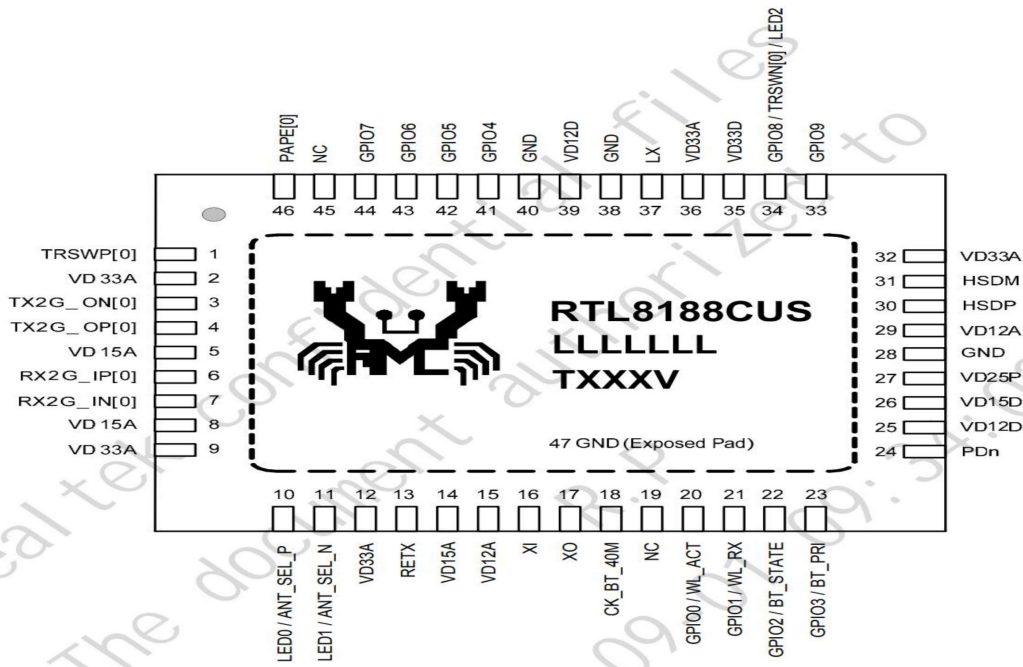
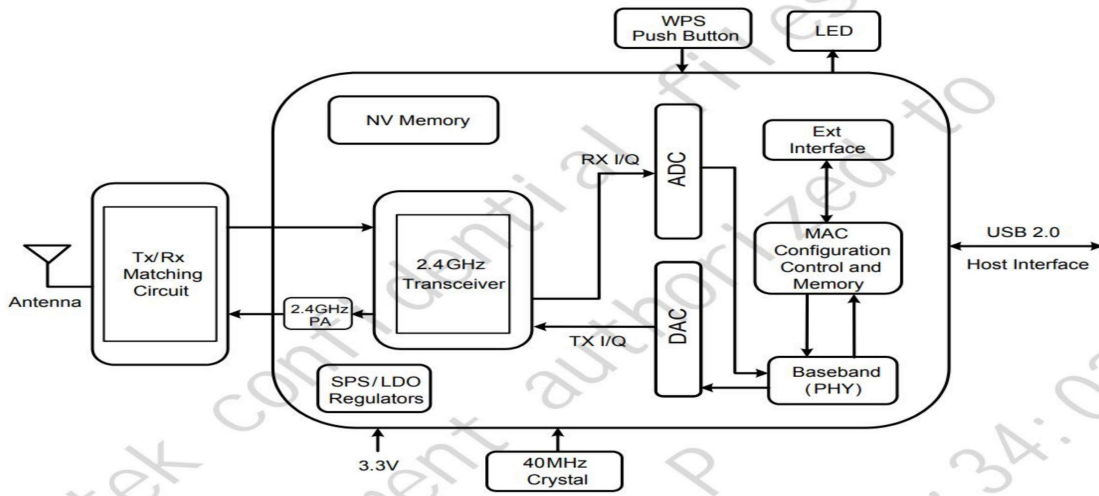


Figure 7: The block diagram of USB Wireless Network Card

2.3.4 The sensor subsystem

- A temperature sensor.

Input: Li-ion battery.

Output: The environment temperature [°C].

We use DS18B20 temperature sensor. Sensing the temperature of some specific spot on the body of the server, collaborating with the sensor clinging to the CPU, the server can get more well-rounded temperature information of itself, as the wind cooling system cannot ensure an even effect all over the server. Here is the circuit schematics for DS18B20[4].

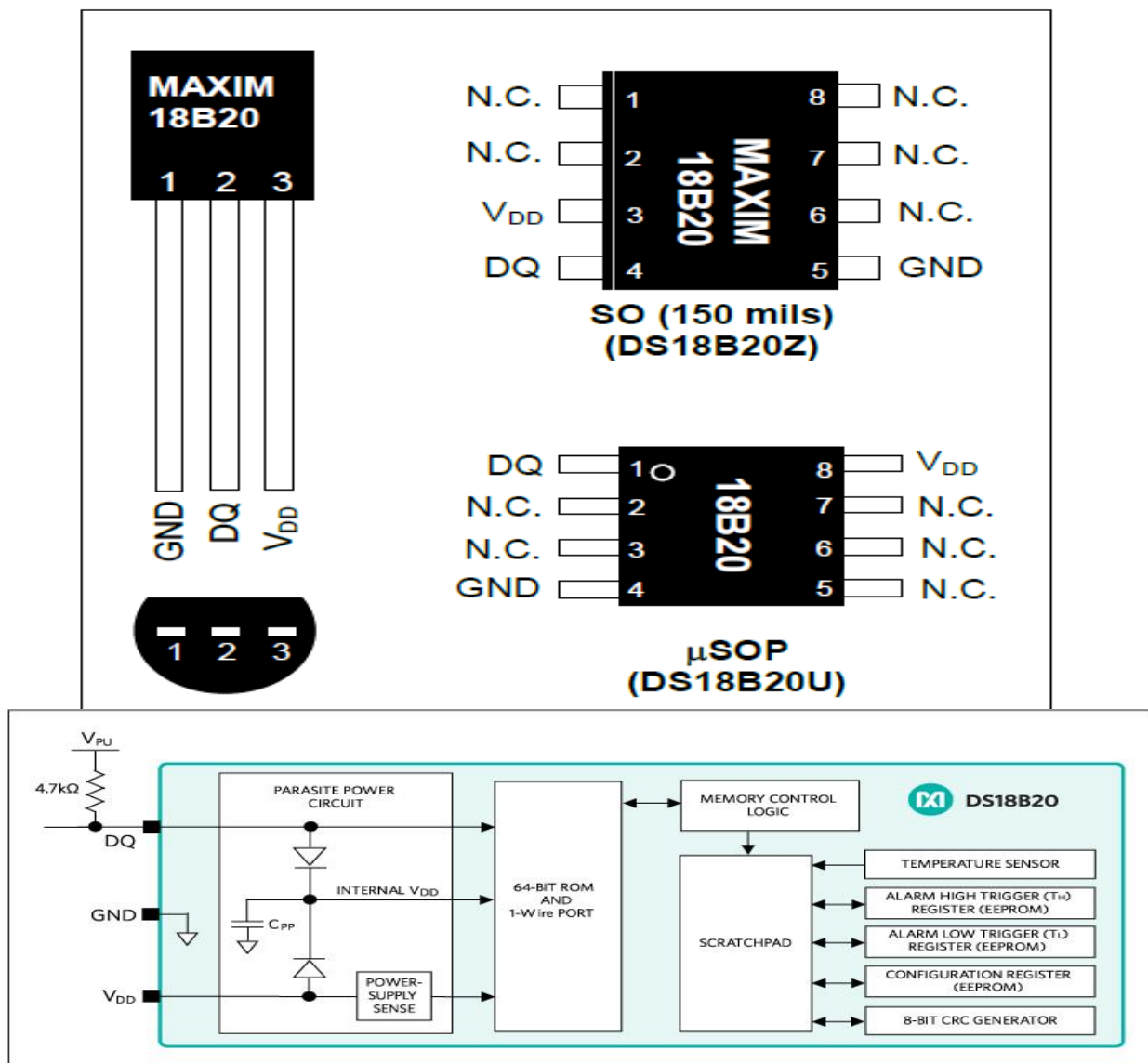


Figure 8: Temperature Sensor

- A wind speed sensor.

Input: Li-ion battery.

Output: wind velocity [m/s].

We use SM5388M wind speed sensor. The reason why we need a wind speed sensor is that as the wind tunnel outlet in the lab is smaller than the cross-sectional area, so the air flux is smaller than the practice. So we will first expand the outlet to fit the shelter and test the wind speed that coming to the shelter by the wind speed sensor. We will record the data for quantitative analysis later. The following shows a photo of our wind speed sensor and its simple schematic diagram (in Chinese).

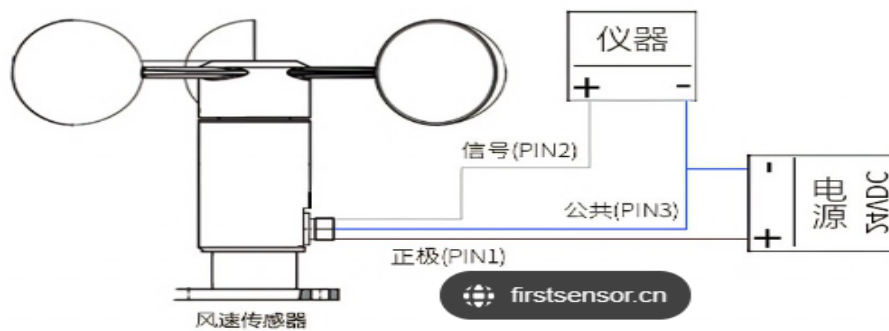


Figure 9: Wind Speed Sensor

2.3.5 The power subsystem

The power subsystem must be able to supply to the sensors continuously at a certain level like 3.3V or 5V (depending on the specific sensor).

The following are the block diagram for the power subsystem and the diagram of inner structure of the voltage regulator (in Chinese). The functionality of the voltage regulator is to provide stable voltage output considering the load is dynamic. It uses several NPN transistors to realize it.

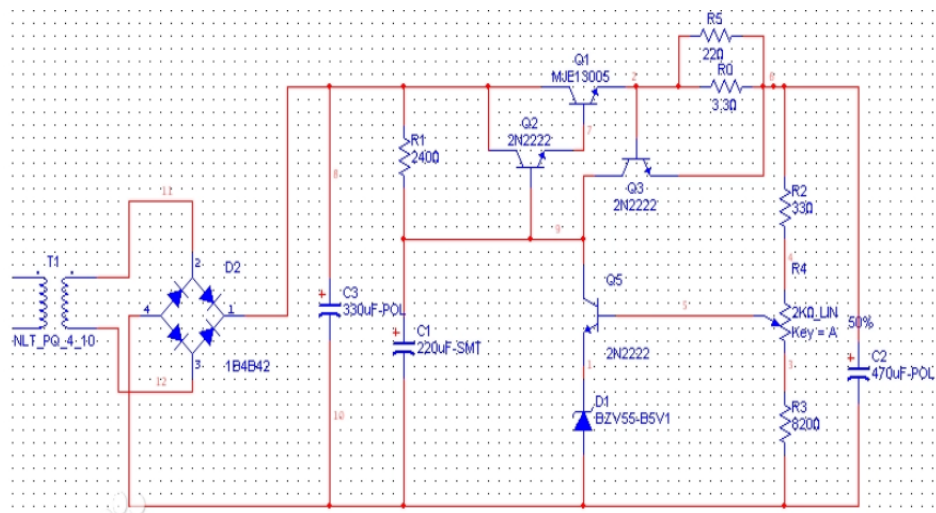
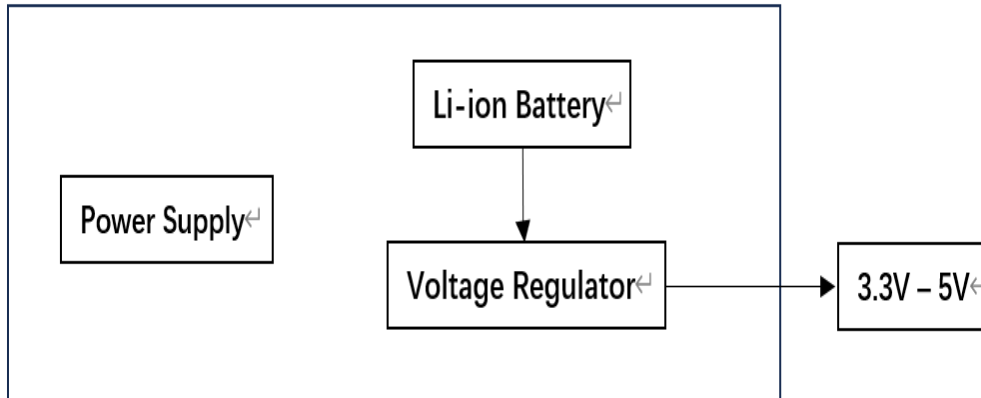


Figure 10: Li-ion Battery and the structure of regulator

2.4 Requirements and Verifications

2.4.1 Shelter

Table 1: Shelter

Requirement	Verification
1) The shelter is required to adapt itself in rainfall environments, it has to protect the server from being moistened by rainfalls while the vehicle is driving on the highway.	1) Use wind tunnel experiments to test the waterproof capability. Use a spray to simulate rainfall at different vapor concentrations. If the server can sustain from being moistened by extremely large water sprays and wind, the shelter meets its water-proof requirement.
2) Traditionally, we need air-conditioner to cool the server running at full load as the embedded fans in the server is not enough for cooling. In our project, the shelter without air-conditioner is required to cool the server effectively by wind into the air-path of the shelter outdoors. The shelter has to avoid the server from being overheated while the vehicle is driving slow (wind speed is also low).	2) In a wind tunnel laboratory, let the server run at full load so that it will heat up. Run the wind generator and blow the shelter. Record the CPU temperature data versus time. For comparison, repeat the process with wind generator off. If the CPU temperature in the first case can be stable at a certain value, it's verified an effective cooling system.

Notes: Further description of the experiments and success measurement is shown in the following pages.

2.4.2 Server

Table 2: Server

Requirement	Verification
1) The server is configured well.	1) Running a block of deep learning code to test whether it can finish as expected.
2) The server can send and receive data through the Internet.	2) Sending the server with dataset needed by the DL problem. Then check if the data is received correctly by the server.
3) The server can control its CPU temperature under 70°C all time.	3) In the wind tunnel Lab, give the server the wind with speed varying from 0 to 30 m/s to test if the server can adapt different movement condition of the car. At low wind speed, the server will automatically stop running if its temperature reaches 70°C; at higher wind speed, the server can be cooled down below 70°C all the time.

Notes: Further description of the experiments and success measurement is shown in the next page.

For specific experiments, we are planning to conduct waterproof experiments and wind tunnel experiments.

1) Waterproof experiments will be conducted in a wind tunnel.

- First, place four humidometer inside the container at four corners, turn on the wind tunnel to a set wind speed.
- Second, use a water spray to simulate rainfall and spray water into the air tunnel.
- After a while, record the values and differences between initial and final humidity shown on the humidometers.

The effectiveness of water-proof will be determined by two elements. One is the maximum final humidity (among four humidometers, MFH for short), the other is the maximum difference of humidity (among four humidometers, MDH for short). By plotting diagrams between wind speed/ spray rate and MFH/MDH, we can determine the effectiveness of water-proof from the slope of the diagrams.

2) Cooling experiments will be conducted in a wind tunnel

- Run deep learning programs on the server, record the temperature curve of CPU w.r.t time. If overheated at 70°C, make sure the server will automatically halt the computing.
- Use the same computing load and activate wind tunnel, let the wind pass to test if the CPU temperature can be stabilized on a specific value below 70°C. Then adjusting the wind speed to test at which range of the average wind speeds can make the server stay at a stable temperature below 70°C. Record these data.

If under the largest possible computing load, the server temperature can be stabilized under alarming temperature with a natural wind speed (maybe 25km/s in practical traffic condition), then the cooling effectiveness of the structure is justified. (If the wind speed is low, the speed sensor should have a feedback to the CPU to lower the computing load).

Notes: Due to the vulnerability of the server, we have another plan, which is to use a heat generation bar with constant heating power to substitute the running server. In this experiment, we will conduct two tests of heating simulation, one with no wind, one with wind by wind tunnel. We will record the time duration of the bar being heated from room temperature to a certain higher temperature for the two tests and compare them.

2.4.3 Sensors

Table 3: Sensors

Requirement	Verification
1) The speed sensor is required to measure wind speed in the wind tunnels of the shelter within 5% error.	1) Use wind tunnel to test the speed sensor effectiveness and correctness. Place the speed sensor at the outlet of the tunnel and compare measured speed to the wind tunnel panel speed. If within 5%error, the speed sensor is verified.
2) The temperature sensor should respond immediately to the temperature changes because we need to record the transient temperature values as the electronic components in the server is very sensitive to the temperature. We're required to act instantly to the temperature change.	2) Before the lab, we will first compare with the mercurial thermometer if they have the same room temperature and record it. Then put the temperature sensor in iced water, if panel temperature is within ± 1 from 0 Celsius's, the temperature sensor is verified. Meanwhile we record the time of response for the sensor to show from the room temperature and the freezing point. This data may be used to rectify some result in physical experiment.

2.5 Tolerance Analysis

For the heat transfer, due to the container's complex shape and 3-tunnel combining effect, the final temperature distribution is done by Fluent. Here we roughly calculate the rate of convective heat loss.

With:

- T_{air} is the ambient air temperature,
- T_c is the surface temperature of the server,
- L_c is the horizontal length of the server which is seen as a flat plate,
- L is the vertical length of the plate,
- u_{air} is the wind speed,
- ν is the kinematic viscosity of the air,
- k is the heat conductivity of the air,
- Pr is the property of the air,
- Re is Reynolds number.

Known: $T_{\text{air}} = 298\text{K}$, $T_c = 348\text{K}$, $L_c = 1\text{m}$, $L = 0.6\text{m}$, $u_{\text{air}} = 10\text{m/s}$

Analysis: $\bar{T} = \frac{T_c + T_{\text{air}}}{2} = 323\text{K}$, at 323K , $\nu = 18.9 \times 10^{-6}\text{m}^2/\text{s}$,

$k = 28.9 \times 10^{-3}\text{W/mK}$, $Pr = 0.707$,

$Re = \frac{u_{\text{air}}L}{\nu} = \frac{10 \times 1}{18.9 \times 10^{-6}} = 1.058 \times 10^6 > 5 \times 10^5$, turbulent flow

Use correlation $Nu_L = 0.037Re^{4/5} - 871Pr^{1/3}$

$$\frac{hL_c}{k} = Nu_L$$

$$\Rightarrow h = \frac{Nu_L \cdot k}{L_c}$$

$$\Rightarrow h = \frac{(0.037 \times (1.058 \times 10^6)^{4/5} - 871) \times 0.707^{1/3} \times k}{L_c}$$

$$\Rightarrow h = \frac{(0.037 \times (1.058 \times 10^6)^{4/5} - 871) \times 0.707^{1/3} \times 28.9 \times 10^{-3}}{1}$$

$\Rightarrow h = 13.87\text{W/m}^2\text{K}$ is the avg HT coefficient

$$q_{\text{known}} = hA(T_{\text{air}} - T_c)$$

$$= 13.87 \times 2 \times 1 \times (348 - 298)$$

$$= 416.1\text{W} > 300\text{W}$$

The critical surface area is 0.433m^2 , with this area, the heat transfer rate is 300W . Therefore, as long as the effective contact area between the air and aluminum is bigger than 0.433m^2 , the temperature rise is desirable.

We can perform a basic thermal analysis to estimate the airflow required to prevent overheating.

Assumptions:

- The server generates a uniform heat load, which we will assume is 300 W (a typical value for a small server).
- The shell is made of a thermally conductive material (like aluminum).
- The ambient temperature is 25°C.
- The target maximum internal temperature is 75°C to ensure electronic components operate within safe temperatures.

Heat Transfer Calculation:

Using the formula $Q = \dot{m} \cdot c_p \cdot \Delta T$, where:

- Q is the heat power (Watts),
- \dot{m} is the mass flow rate of air (kg/s),
- c_p is the specific heat capacity of air (approximately 1005 J/(kg·K) at room temperature),
- ΔT is the temperature difference (K).

We need to solve for \dot{m} , given that $Q = 300$ W and $\Delta T = 50$ K (from 25°C to 75°C):

$$\dot{m} = \frac{Q}{c_p \cdot \Delta T}$$
$$\dot{m} = \frac{300 \text{ W}}{1005 \text{ J/kg} \cdot \text{K} \times 50 \text{ K}}$$
$$\dot{m} = \frac{300 \text{ W}}{50250 \text{ J/kg}}$$

The volumetric flow rate of air required is:

$$\dot{m} = .00597 \text{ kg/s}$$

We can also convert this mass flow rate to a volumetric flow rate using the density of air (which is approximately 1.225 kg/m³ at sea level and at 25°C):

$$\dot{V} = \dot{m} \cdot \frac{1}{\rho}$$
$$\dot{V} = .00487 \text{ m}^3/\text{secs}$$

The calculation is done only in an ideal way. However, under certain condition of the server operating, the flow rate of air required will change. We'll use the experimental data to do the mathematical analysis later.

The main functions of the shelter include waterproofing and cooling. For waterproofing, it is ensured with proper shape regardless of the manufacturing precision since the rain-drops are blocked by gravity and are navigated to the drainage.

2.6 Cost and Schedule

2.6.1 Cost Analysis

Labor:

From the internet, we know that average salary for an ECE student from Illinois would be \$87,769 per year. The average salary per hour is \$36. We assume 160 hours are needed for each student in this project. Therefore, the labor can be estimated by the equation:

$$\$36 \times 4 \times 160 = \$23040$$

Parts:

Table 4: Cost of Parts

Parts	Cost(CNY)
1) Aluminum Shelter and manufacturing (Manufacturer: "A 90" Hardware Manufacturer)	¥3500
2) Air Speed Sensor (Part: SN-3009TH-FS; Manufacturer: Puruisenshe)	¥120
3) Server (Part: 1U Black; Manufacturer: Hankong)	¥10800
4) Arduino Board (Part: UNO R3; Manufacturer: Youchuangxiang)	¥161.7
5) Temperature Sensor (Part: DS18B20; Manufacturer: Risym)	¥120
6) PCB Three-proof Paint (Manufacturer:Qijialin)	¥15

The sum of costs would be ¥14716.7

2.6.2 Schedule

Team Member Date	Shaohua Sun	Ye Yang	Mingjun Wei	Yinjie Ruan
Mar. 25 – Mar. 31	Build CAD model of the two-layer server shelter shell	Finish Pretreatment part in simulation-SCDC	Connect USB wireless card to the WiFi in Ubuntu	Install USB wireless driver in Ubuntu
Apr. 1 – Apr. 7	Build CAD model of three branches of vent pipes	Mesh Generation for the server shelter	Understand the kinds of running modes of CPU and learn to draw the CPU temperature curve when running at high speed	Get familiar with how the Deep Learning codes are running
Apr. 8 – Apr. 14	Contact manufacturer for the server shelter	Use Fluent solver to iterate to generate nephogram	Set the threshold temperature in Ubuntu so that the CPU will stop even if the cooling system is absent	Search relevant papers and make summary for recent research background
Apr. 15 – Apr. 21	Modify the CAD model for better manufacturing	Iterate design to assist shelter design improvement	Try to do further work to build a better data processing and storage platform in server to model in practical use	Understand why the Docker and Container is useful in edge computing and try to deploy it in Ubuntu
Apr. 22 – Apr. 28	Prepare heat generation bar to substitute the server in experiment and assemble parts of the manufactured components	Finish the heat transfer and temperature simulation of the entire server shelter	Buy temperature sensor and wind speed sensor and make it into the server system	Build a website for the project and find ways to transfer data to the website
Apr. 29 – May 5	Assemble heat pipes and conduct wind tunnel experiment	Think about waterproof experiment and conduct Wind Tunnel Experiment	Let the server run in full speed and conduct wind tunnel experiment	Prepare the materials for lab and conduct wind tunnel experiment

Figure 11: Schedule

3 Ethics and Safety

We admit that we must try our best to guarantee the safety of the team during the project, and the safety of the practical application of the design of the project. We consider some potential safety problems that needs serious attention in our project.

- We will pay attention to our safety during the experiment. Before the experiment, we will make sure that wind generator works well and no litter inside the wind tunnel which is harmful if being blown and keep the environment clean. We will also make sure the wind tunnel has sound suppressor. Once we start the experiment, we will keep away from the wind tunnel. After the experiment, we will clean the laboratory to make a good ending of the lab.
- In commercial application, Since our server is fixed on the car, we must make sure that the fixation is reliable. we make sure that the edge computing system does not negatively impact the vehicle's safe running or emergency handling. We know that the edge server can help to process the data from other cars and we will spare no effort to protect the safety of data with the methods including encryption algorithm to protect user privacy.

Throughout the whole project, we will adhere the IEEE code of ethics. We will "uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities". We will "treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others". We will "strive to ensure this code is upheld by colleagues and co-workers"[5].

References

- [1] L. Liu, C. Chen, Q. Pei, S. Maharjan, and Y. Zhang. "Vehicular Edge Computing and Networking: A Survey." (2020), [Online]. Available: <https://doi.org/10.1007/s11036-020-01624-1> (visited on 07/25/2020).
- [2] X. Zhang, T. Lindberg, N. Xiong, V. Vyatkin, and A. Mousavi. "Cooling Energy Consumption Investigation of Data Center IT Room with Vertical Placed Server." (2017), [Online]. Available: <https://doi.org/10.1016/j.egypro.2017.03.581> (visited on 05/01/2024).
- [3] L. Blain. "Elon Musk: AI will run out of electricity and transformers in 2025." (2024), [Online]. Available: <https://newatlas.com/technology/elon-musk-ai/> (visited on 03/01/2024).
- [4] AnalogDevices. "DS18B20." (), [Online]. Available: <https://www.analog.com/cn/products/DS18B20.html> (visited on 04/14/2020).
- [5] IEEE. "IEEE Code of Ethics." (2016), [Online]. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html> (visited on 02/08/2020).