ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Design Document for ECE 445 Vehicular Edge Computing System

Team #38

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Contents

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 75°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.

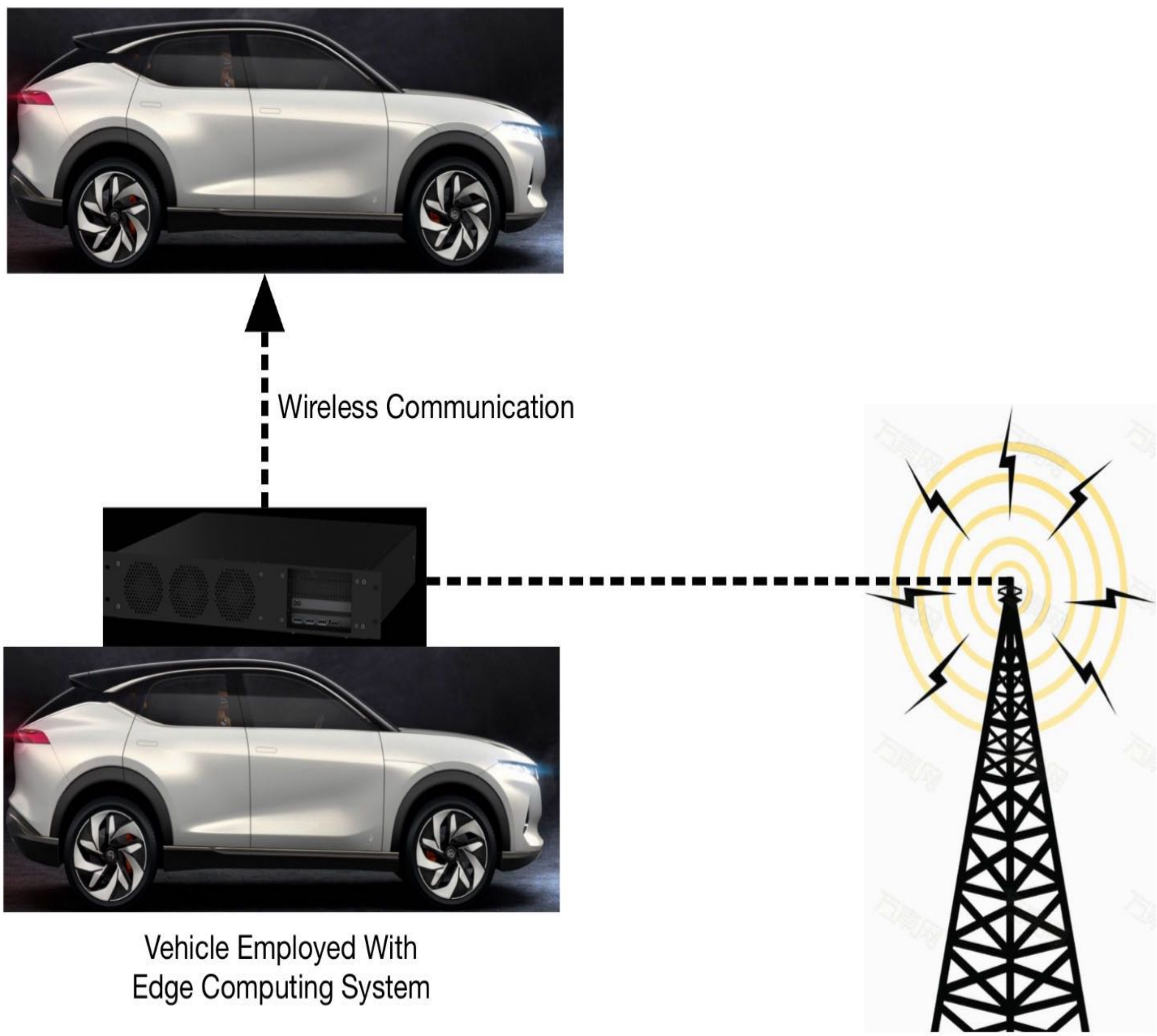

Figure 1: Visual Aid

2 Design

2.1 Block Diagram

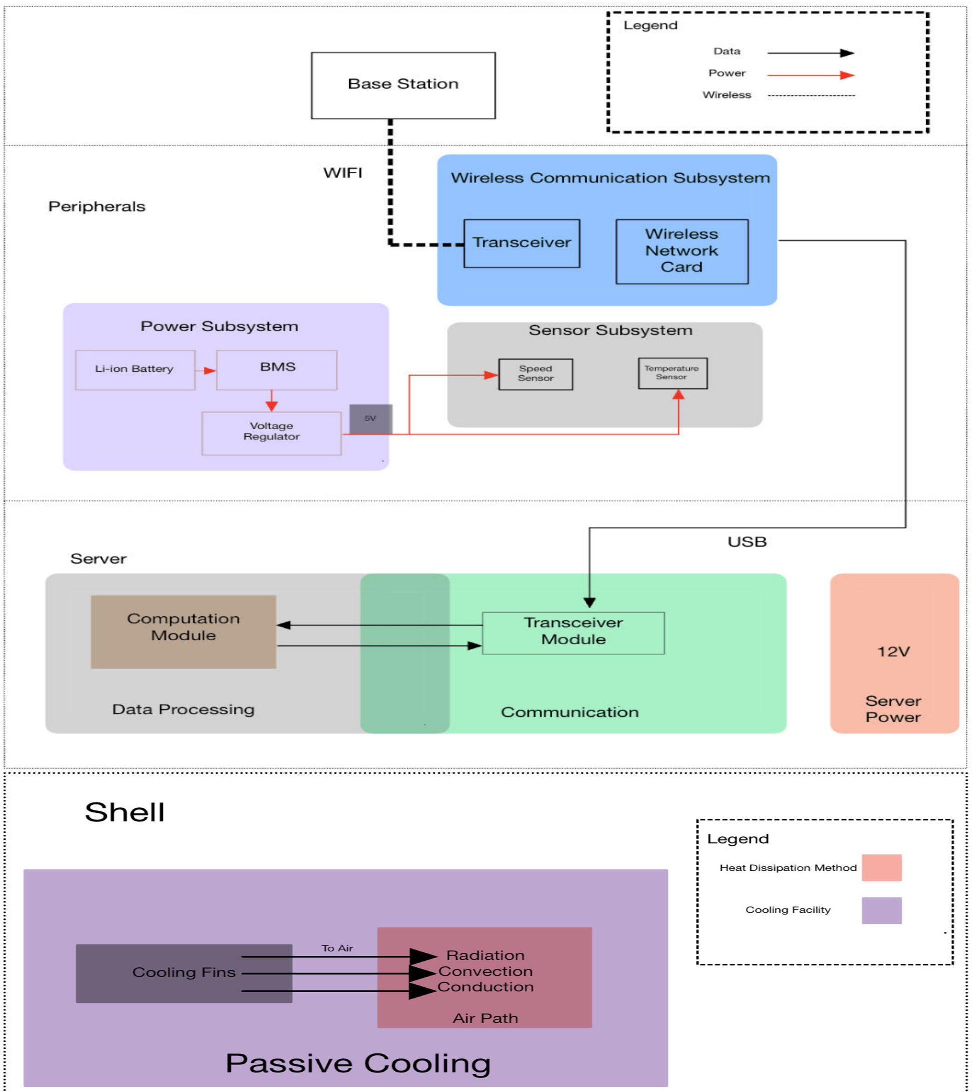

Figure 2: Block Diagram

2.2 Physical Diagram(part)

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.

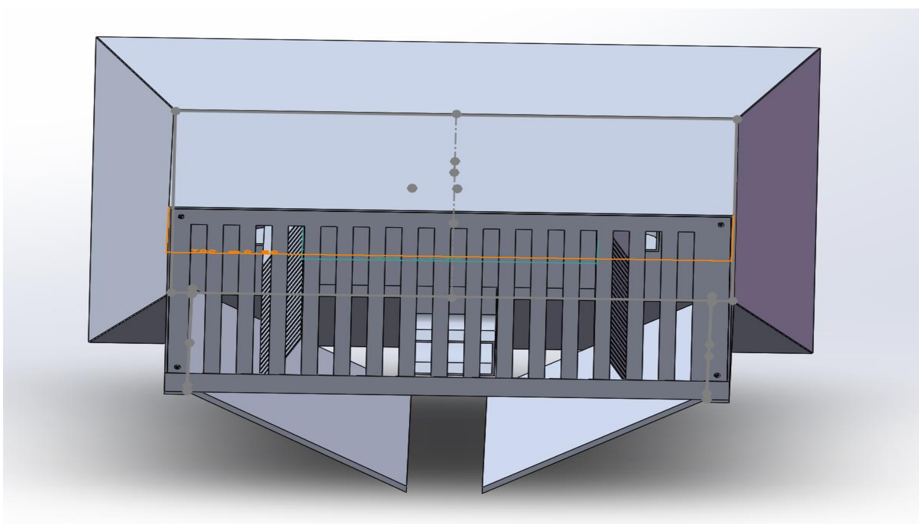

Figure 3: Physical Diagram(1)

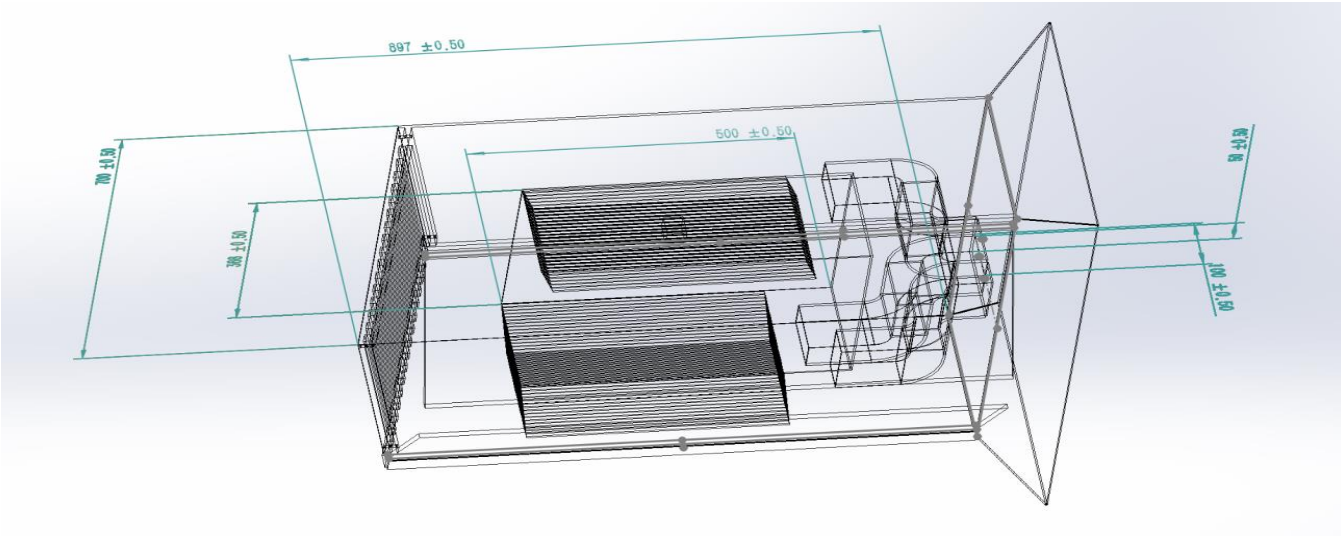

Figure 4: Physical Diagram(2)

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. The server will be configured as if it's practically used in edge computing.

• 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.

• Under this condition, we will settle the server on-board a moving platform, and test whether the cooling system is functioning well or not, i.e. effectively cool the server under the safe temperature.

• We will enhance its ability of wireless communication, so that it can get access to the user ends through the Internet. In Linux OS, we install a driver for USB wireless network card. The USB wireless network card will be further described in the subsystem of peripherals.

• The CPU computational intensity and the operation condition of the fans(embedded in the server) is adjusted according to the temperature of CPU. There's a block of code to control the hardware resources of the server. The document in "/etc" directory in Linux is modified.

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 cooling method is the adoption of threee 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 fins. The second 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. While the inner shelter provides fins and container to the server, the outer shelter blocks away direct sunlight on the server. Creating a stable temperature environment in the shelter.

• 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.

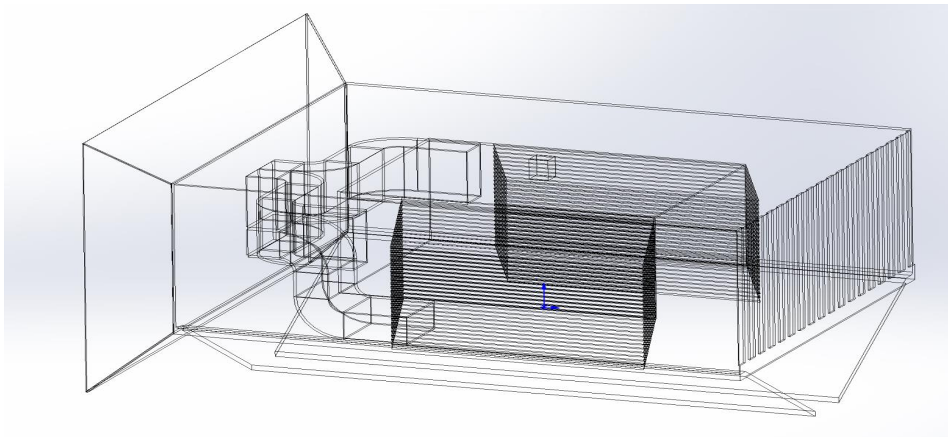

Figure 5: CAD Model for Double-Deck Shelter

2.3.3 USB Wireless Network Card

It adopts wireless connection with the nearby WiFi or hotpot with reliable accessibility through certain protocols. And it is easily connected to the server via USB protocol. AS for its structure, it uses a high-gain transceiver antenna to realize stable data sending and receiving. Also it's very convenient for the communication with the server by the USB. Only the software for a driver provided by the company is needed to be downloaded to the Linux system is enough for the wireless network card to work well.

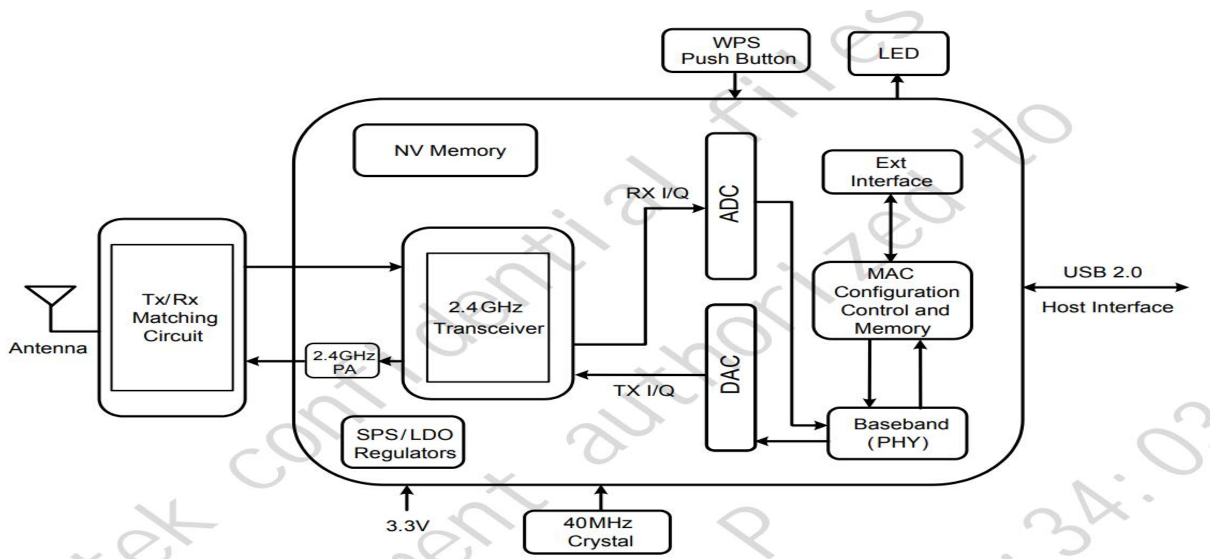

Figure 6: The block diagram of USB Wireless Network Card

2.3.4 The sensor subsystem

• A temperature speed 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

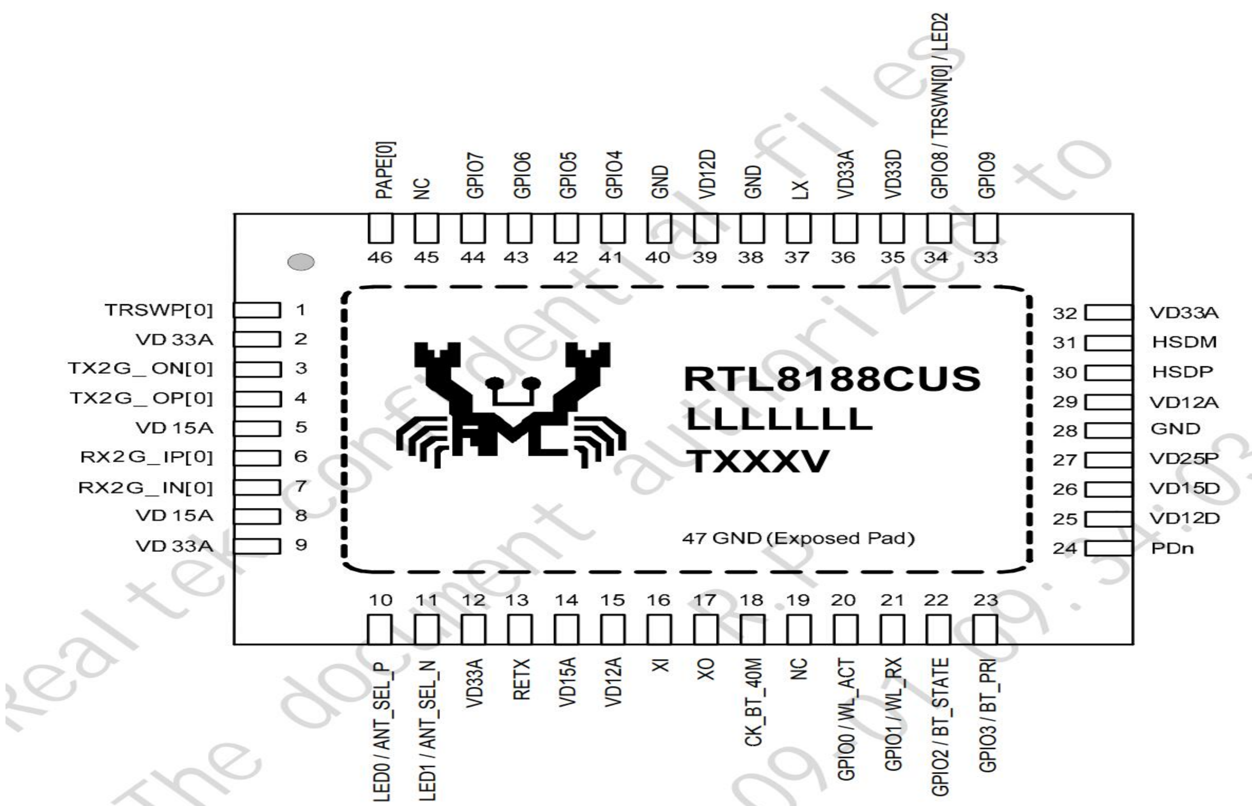

Figure 7: USB Wireless Network Card(2)

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].

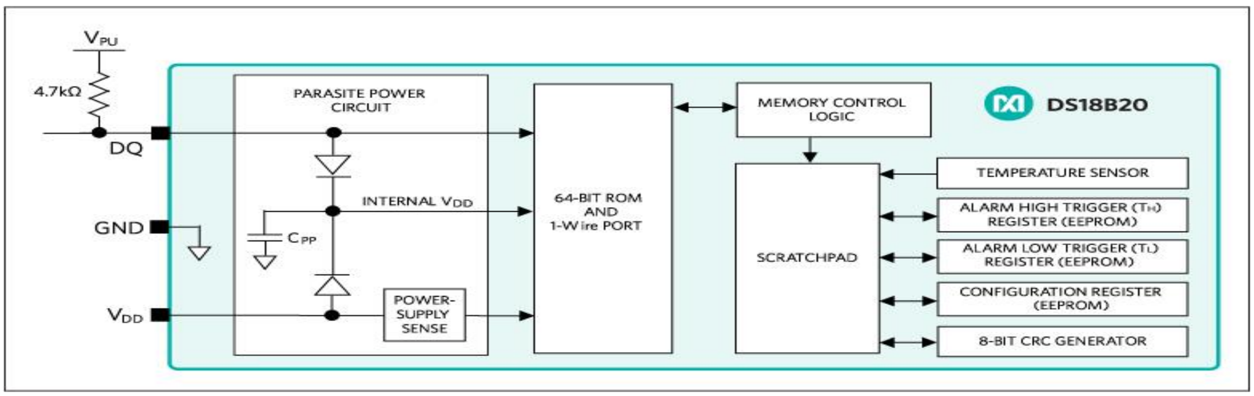

Figure 8: Temperature Sensor

• A wind speed sensor.
Input: Li-ion battery.
Output: wind velocity [m/s].
We use Duct wind speed transmitter. Sensing the speed of the wind, it transmits the data to the server by USB protocol. Then the server makes use of the data to adjust the use of the fans and also anticipates how to adjust the operating intensity of the CPU.

Figure 9: Wind Speed Sensor

2.3.5 The power subsystem

Li-ion battery. It must be able to supply to the sensors continuously at 5V.

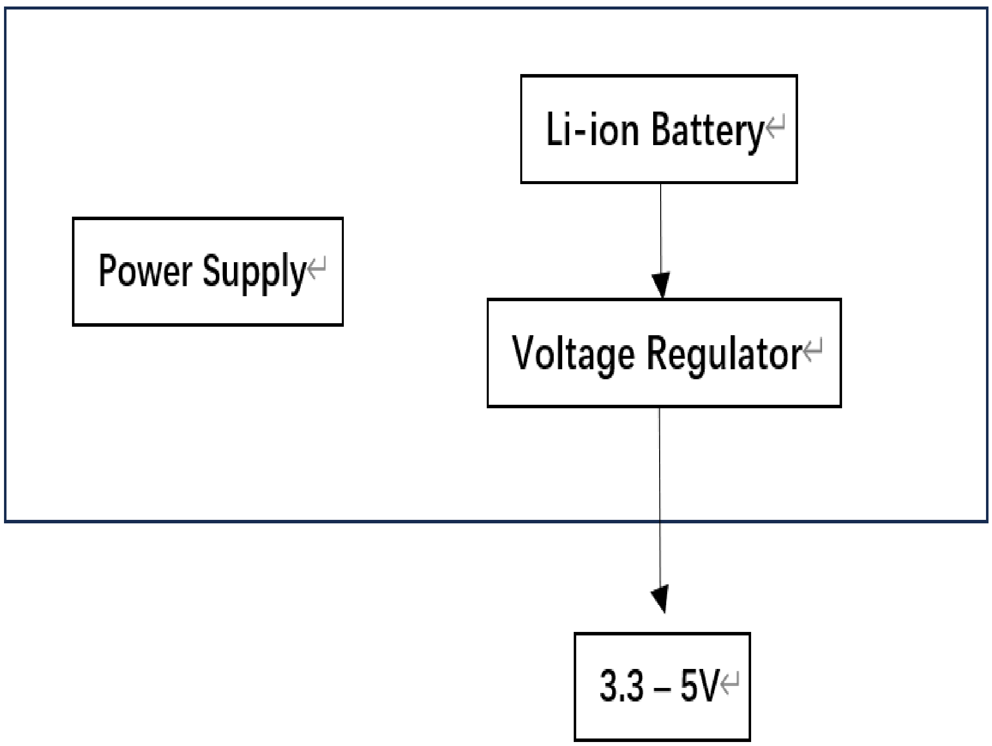

Figure 10: Li-ion Battery

2.4 Requirements and Verifications

2.4.1 Shelter

Table 1: Shelter

Requirement	**Verification**
1) The shelter is required to adapt itself in different rainfall environments, most extremely, it has to protect the server from being moistened by typical rainstorms while the vehicle is driving on the highway.	1) Use wind tunnel experiments to test the water-proof effects and heat exchange effectiveness. Additionally, use a spray head to simulate rainfall. If the server can sustain from being moistened by extremely large water sprays and wind, the shelter meets its waterproof requirement.
2) The shelter is required to cool the server effectively so electric devices wouldn't fail. Most extremely, the shelter has to avoid the server from being heated while the vehicle is driving slow (no sufficient air cooling)	2) Place the shelter under the sun in a regular sunny and windless day. Keep a low operating speed (a requirement of speed sensor).

2.4.2 Server

Table 2: Server

Requirement	Verification
1) The server is required to run deep learning algorithm normally.	1) Running a block of code to test whether it can finish as expected.
2) The server can send and receivedata through 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 75°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.
4) The server has a better performance compared with the condition without the wind cooling.	4) Test the time needed to run the DL algorithm in both of the server staying static and moving at the speed of 30m/s. Check whether it saves time when the server is moving.

2.4.3 Sensors

Table 3: Sensors

Requirement	Verification
1) The speed sensor is required to correctly measure wind speed in the wind tunnels of the shelter.	1) Use wind tunnel experiments to test the speed sensor effectiveness and correctness. Place the speed sensor at the outlet and compare measured speed and wind tunnel panel speed. If within 5%error, the speed sensor is verified.
2) The temperature sensor should correctly measure the transient temperature in the shelter. the server effectively so electric devices wouldn't fail. Most extremely, the shelter has to avoid the server from being heated while the vehicle is driving slow (no sufficient air cooling)	2) Put the temperature sensor in iced water, if panel temperature is within 5 % from 0 Celsius's, then the temperature sensor is verified

2.5 Tolerance Analysis

For the given server shelter with dimensions of 1m x 60cm x 60cm, 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 400 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 $Q = 400$ W and $\Delta T = 50$ K (from $25°C$ to $75°C$):

$$\dot{m} = \frac{Q}{c_p \cdot \Delta T}$$

$$\dot{m} = \frac{400\,\mathrm{W}}{1005\,\mathrm{J/kg \cdot K} \times 50\,\mathrm{K}}$$

$$\dot{m} = \frac{400\,\mathrm{W}}{50250\,\mathrm{J/kg}}$$

The volumetric flow rate of air required is:

$$\dot{m} = \frac{400}{50250}\,\mathrm{kg/s}$$

We can also convert this mass flow rate to a volumetric flow rate using the density of air (which is approximately $1.225\,\mathrm{kg/m^3}$ at sea level and at $25°C$):

$$\dot{V} = \dot{m} \cdot \frac{1}{\rho}$$

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 raindrops are blocked by gravity and are navigated to the drainage. For cooling, to reach the maximum heat transfer efficiency, the air flow should be laminar. To perform a tolerance analysis for the shell roughness to ensure that the air flow over the shell remains laminar (with a Reynolds number Re $< 10,000$), we need to first relate the Reynolds number to the roughness of the shell.

The Reynolds number is defined as:

$$\mathrm{Re} = \frac{\rho u L}{\mu}$$

where:

- ρ is the fluid density (kg/m^3),
- u is the flow velocity (m/s),

- L is the characteristic linear dimension (m) (in this case, it could be considered as the roughness height or a length scale related to the geometry of the shell),
- μ is the dynamic viscosity of the fluid (Pa·s or N·s/m²).

For air at room temperature (approximately 25°C), the density $\rho \approx 1.225$ kg/m³, and the dynamic viscosity $\mu \approx 1.85 \times 10^{-5}$ Pa·s.

Given:

- The air velocity $u = 10$ m/s,
- The desire to keep Re $< 10,000$ for laminar flow,

We can rearrange the formula to solve for L as a function of the maximum allowable Reynolds number, using the properties of air:

$$L < \frac{\text{Re}_{\text{max}}\mu}{\rho u}$$

The maximum characteristic dimension, which corresponds to the surface roughness of the shell made of aluminum to maintain laminar flow conditions over the shell is approximately 0.0151 meters (or 15.1 mm). This means that to ensure the air flow remains laminar with a Reynolds number less than 10,000, the shell's surface roughness should be kept below this value. For instance, if the shell is machined with a process that leaves tool marks or grooves, each groove's depth and width should be significantly less than 15.1 mm to avoid triggering the transition to turbulence.

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:

The sum of costs would be $23182.

2.6.2 Schedule

Week / Team Member	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Shaohua Sun	Improve Shelter Design	Manufacture Shelter	Conduct Wind Tunnel Experiment	Improve Shelter Design	Manufacture Better Shelter	Conduct Wind Tunnel Experiment
Mingjun Wei	Configure Server	Deploy a deep learning framework	Improve deep learning algorithms	Design algorithms for sensor communication	Test algorithms for sensors	Conduct wind tunnel experiment
Yinjie Ruan	Purchase sensors	Adjust CPU threads	Control CPU computational intensity	Deploy docker for Linux	Configure docker environment	Conduct wind tunnel experiment
Ye Yang	Finish pretreatment part in simulation-SCDC	Mesh generation	Use Fluent solver to iterate to generate nephogram	Iterate design to assist shelter design improvement	Manufacture Better Shelter	Conduct Wind Tunnel Experiment

Figure 11: Schedule

Table 4: Cost of Parts

Parts	**Cost**
1) Aluminum Shelter and manufacturing (Manufacturer: ”A 90” Hardware Manufacturer)	$100
2) Air Speed Sensor (Part: SN-3009TH-FS; Manufacturer: Puruisenshe)	$20
3) Server (Part: 1U Black; Manufacturer: Hankong)	$128
4) Arduino Board (Part: UNO R3; Manufacturer: Youchuangxiang)	$2
5) Temperature Sensor (Part: DS18B20; Manufacturer: Risym)	$0.5
6) PCB Three-proof Paint (Manufacturer:Qijialin)	$2

3 Ethics and Safety

We admit that we must try our best to guarantee the safety during our 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 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.

• Our project is related to vehicle so we must pay attention to the driving safety. We must ensure that the computing system does not interfere with the vehicle's electronic systems, which could affect navigation, communication, or other critical functions.

• Also, we make sure that any modifications do not negatively impact the vehicle's safe running or emergency handling.

• Since our server is fixed on the car, we must make sure that the fixation is reliable.

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].

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