ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

A mmWave Breath Monitoring System for Smart Vehicle Applications

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Team #20

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1 Introduction

1.1 Problem

Forgetting children in a hot car has always been a problem needed to be solved since 21st century. According to data statistics, more than 900 children have died in hot cars since 1998 and more than half of them were left behind unknowingly by their caregivers. When these accidents occurred, people would blame their parents for their carelessness. However, David Diamond, a professor of psychology at the University of South Florida in Tampa pointed out that leaving children in cars is not a negligence problem but a memory problem and it could happen to anyone [1]. Therefore, this problem will still exist in the future and it is urgent to develop a kind of device that helps caregivers to detect children in the car. We hope to design a system that detects the breath of children left in the car. And if children are detected, the system will send an alarm to their parents.

1.2 Solution

These years, radar technology has been developing swiftly and it gradually turns from the military field to the civilian fields such as applications for aircraft, ships and automobiles [2][3]. This project aims to design a system using mm-wave radar and radar signal processing methods to detect children's breath in the car. For the basic principle of a breath detection system using radar, our radar will transmit periodic linearly-increasing frequency chirps known as Frequency-Modulated Continuous Wave (FMCW) towards the object. In order to measure small-scale vibrations such as breathing, we will measure the change in phase of the FMCW signal with time at the object range bin and it can be derived by taking the FFT of the beat signal.

In practice, our team decided to use TI-60GHz mm-wave radar development board IWR6843ISK-ODS and CP210 driver to finish the hardware link and data collection. Data collected will be then sent to the software Matlab for the application of millimeter wave radar range detection and micro-doppler detection.

To be specific, after generating the FFT graph in Matlab, we will use the peak detection algorithm to judge the possible objects and the phase time domain graph should be analyzed to select the starting point of breathing and determine the breathing rate. With the breathing rate we calculate from Matlab, we will do further signal processing and improve our algorithm to detect the children's breath in complex and diverse environments. Finally, we plan to design a UI to allow users to know the breathing status of children in the car.

1.3 Visual Aid

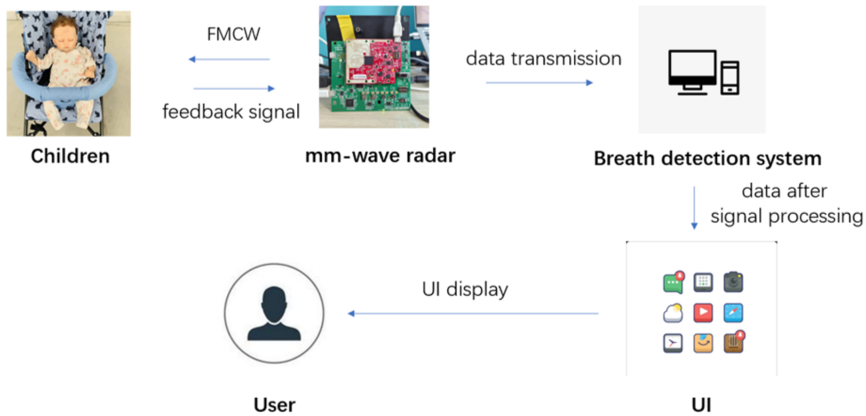

Figure 1: Visual Aid.

1.4 High-level requirements list

1. Since we care more about younger children such as babies stuck in the car, so our system should manage to distinguish the respiratory waveform of children of different ages.
2. In different weather, children may wear various clothes which may have some influence on detection, our system should be able to work well under the circumstance of different shielding materials.
3. In a car, children may stay in different postures and it could be a factor affecting the detection result. Our system needs to detect children's breath under different postures.
4. Sometimes, there will be more than one kid in the car and we hope our system to be capable of detecting multiple persons.

2 Design

2.1 Block Diagram

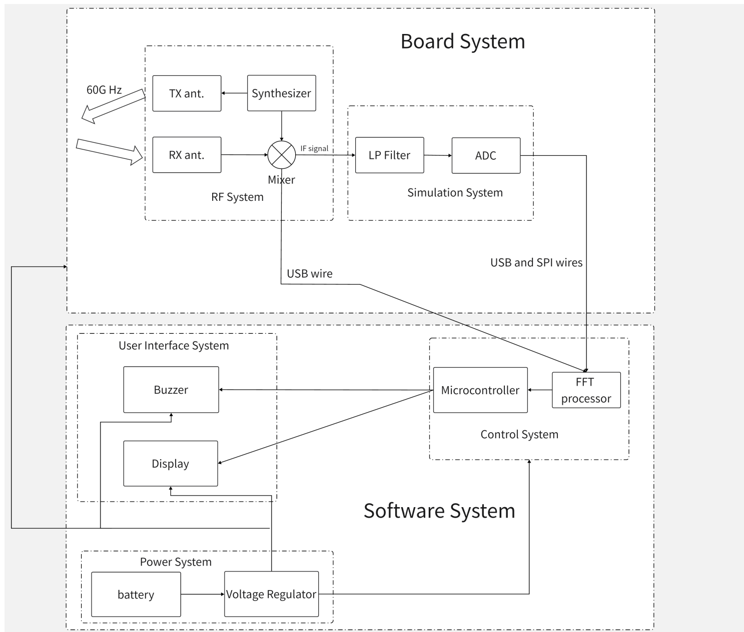

Figure 2: Block Diagram.

2.2 Subsystem Overview

Radio Frequency(RF) system: TI-60GHz mmWave Radar Development board: IWR6843ISK-ODS. A sensor to work on Millimeter wave radar range detection and micro-doppler detection technology. It has 2 TX antennae and 4 RX antennae. We can choose the working mode to turn on the specific antenna.

Simulation system: Use DCA1000 Board to collect the data of the radar board. The Intermediate Frequency(IF) signal consists of multiple tones, and the frequency of each tone is proportional to the distance of the corresponding object. So this system uses a Low-pass(LP) filter to filter the noise and Analog to Digital Converter(ADC) to convert the IF signal to an analog-digital signal. And ADC must support an IF bandwidth of S2d/c. It is connected to the Control system with the transmission line.

Control system: The control system is based on Raspberry Pi 4b. It consists of two parts: Signal processing algorithm and Microcontroller. The algorithm gives the breath detection result, and the Microcontroller gives a signal to the buzzer and displays screen based on the result as shown in Fig.3.

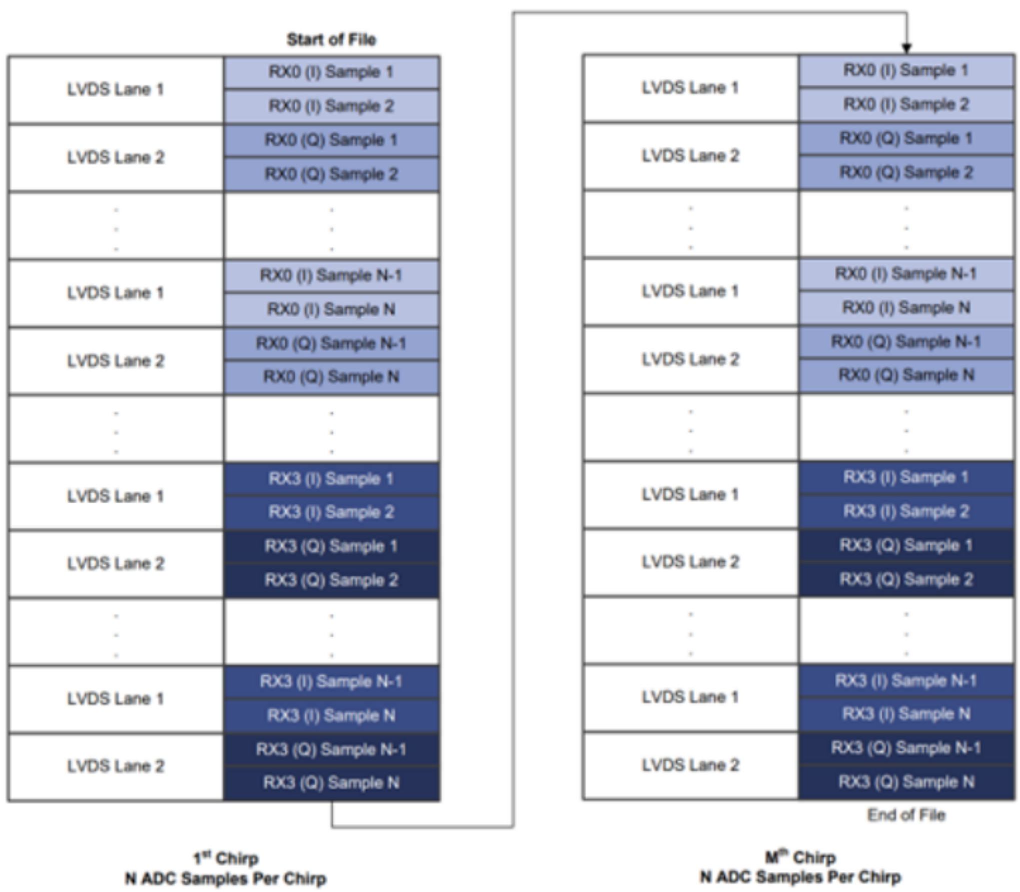

Figure 3: IWR6843 Complex Data Format Using DAC1000[4]

User interface system: it receives the signal from the control system. And Display screen can show whether there are people breathing in the car or not. The received data should be visualized in this system to be shown. The buzzer will ring if breathing is detected.

Power system: generate proper voltage to supply those systems. This power system always provides 5v to the DCA1000 and 60GHZ mmwave studio which are the RF and simulation system. It is powered by the Li-ion battery. And when the battery runs out of charge, it should be changed to power the system again. The current through DCA1000 and 60GHZ mmwave studio radar board need to under 2A. And the voltage and current should be regulated all the time

2.3 Subsystem Requirements

2.3.1 RF system

Requirement:

1. It consists of three components: Mixer, synthesizer, and Antenna. The synthesizer generates a chirp and passes the chirp to the mixer and TX antenna. TX antenna transmits the chirp to the environment. And RX antenna receives the delayed vision of this chirp. The mixer is used to mix the original chip and delayed chirp to get the IF signal.

2. We have 2 TX and 4 RX antennas. Choose the Working mode of the radar Board to generate mm-wave. The mmwave should be 60GHZ. The chirp slope is 60MHZ per microsecond. The voltage of this system is 5V and the current is 1A. There are 32 chirps in one frame. The working time of this system should be under one hour to ensure accuracy. This system should connect with the Control system by USB port.

Verification:

1. Once the USB connection to the board is intact, Select the SOP Mode and Click the Set button. Set the SOP2: Development Mode, which should be used for RF evaluation. Connect it over RS232. Select the Operating frequency and Device variant if the auto selection is incorrect.

2. Collect the data received by the RX antenna and use Matlab to analyze the frequency. It should be around 60GHZ and increase by 60MHZ per microsecond.

3. Use a voltmeter to measure the voltage of this system and a Current meter to measure the current. The result of 5v and 1A is allowed.

4. Use the clock to measure the working time. It should work at most 1 hour.

2.3.2 Simulation system

Requirement:

1. The mmWave radar device communicates with the external host processor using the SPI interface. The mmWave device is configured and controlled from the external host processor by sending commands to the mmWave device over SPI. The control system

should turn off the firewall to connect SPI. Ethernet should be set. IP address and subnet mask should follow the instruction. The Ethernet adapter is a Realtek PCIe GBE Family Controller (Gigabit network), and the DCA1000 works properly. If the Realtek PCIe FE Family Controller Ethernet adapter does not work, replace the PC that supports the Gigabit network

2. Connect with the RF system to collect data. Connect with the control system using a USB port. Work with 5V and 1A.

3. The LVDS data captured by the DCA1000 EVM is packetized and transferred over the Ethernet interface as UDP datagrams. Make sure to provide at least 2 seconds gap between DCA1000 ARM and Trigger Frame. Else, no LVDS data would be captured and there would be a timeout for 30 secs.

Verification:

1. Once the MSS firmware boot-up is complete, Click SPI Connect. The SPI Connect button becomes SPI Disconnect indicating a success. If SPI connect does not succeed we need to erase the serial flash and try again using the Uniflash tool. Set the Ethernet IP address to 192.168.33.30 and the subnet mask to 255.255.255.0.

2. Use the clock to wait 3 secs to ensure the LVDS data can be fully captured.

3. Connect with the Personal Computer(PC) using the USB port. Select the COM port to ensure the connection.

2.3.3 Control system

Requirement:

1. The Fast Fourier Transform(FFT) is performed on the ADC data. Since the IWR6843 board has 2 Tx antenna and 4 Rx antenna, the data from sampling must be reshaped for later analysis. The location of peaks in the frequency spectrum directly corresponds to the range of objects.

2. The Extend DACM algorithm can give the detailed phase at the selected position. The phase changes indicate the breath information.

3. The signal which tells the microcontroller to turn on the buzzer or not. The microcontroller receives the data representing the breathing and distance of objects and can control the buzzer and display screen.

Verification:

1. The algorithm should give the breath detection results including distance and phase changing rate. Examine whether the result matches the truth.

2. If there is human breathing, the on signal should be sent to the buzzer.

3. the data on the screen should be in the right format.

2.3.4 User interface system

Requirement:

1. Process the data to form visualized graph about the result. The output graph must be in the proper size to fit the monitor.

2. If there are people, for example, the children, in the car, the buzzer will start to ring and give the warning signal. Otherwise, the buzzer will not ring.

Verification:

1. Able to know the breath rate and distance from the screen

2. The buzzer rings if and only if there is a person breathing in the detection area.

2.3.5 Li-ion battery

Requirement:

This Li-ion battery will provide the voltage and current, which then be regulated by the voltage regulator. The battery's capacity should be larger enough so that the running lifetime of the total system can be at least 5 hours. Based on that the capacity should be at least 5*2.5AH.

Verification:

we connect a fully-charged Li-ion battery with a nominal voltage of 5v. The positive port is connected with VDD and the negative port is connected with the ground. We need to measure the capacity of the battery by discharging it at 2.5A for 5 hours. If it can survive for at least 5 hours, then we can ensure the capacity. During the process, we also need to use the voltmeter to ensure the voltage is always approximately 5v.

2.3.6 voltage regulator

Requirement:

1. Because the voltage of the battery may exceed 5v, we need to use the voltage regulator to control the maximum voltage to be 5v. It should be able to work within the range from 0A to 2.5A. We can choose the TLVM13610 regulator with the output voltage mode at 5v, and output current at 1A.

2. Raspberry Pi needs 5V Voltage and 3A current. The voltage regulator is needed to control the 5V voltage. The TLVM13610 regulator allows 0 to 8A current output. It can be used to provide a 3A current.

Verification:

We connect the output channel to other systems' VDD. And select the current mode to be 1A and 3A. After that, use the oscilloscope to measure the output voltage and ensure the error is within 1% of 5v.

2.4 Tolerance Analysis

At the beginning stage of our project, we decide to use our radar board to measure the distance between the radar board and the object. During this process, there is one critical tolerance we need to concern is the range resolution d_{res} that refers to the radar's ability to resolve two closely spaced objects. Generally, the smaller d_{res} is, the higher the detection accuracy. For a distance of around 3m in our experiment, we hope that d_{res} is no more than 10cm. Our radar board consists of four basic elements as shown in the graph below: synthesizer, TX antenna, RX antenna, and mixer.

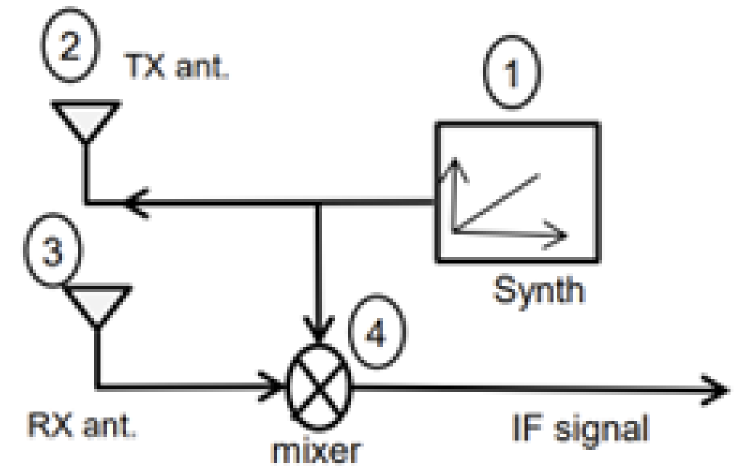

Figure 4: Basic components of FMCW radar.

First of all, the synthesizer will generate a chirp and then the chirp will be transmitted by the TX antenna. Next, the chirp is reflected off an object and the reflected chirp will be received by the RX antenna. Finally, the RX signal and TX signal will be mixed by the mixer to generate the IF signal which will be processed later to get the result distance. For the working principle of the mixer, it generates a sinusoid output signal with 1. Instantaneous frequency equal to the difference of the instantaneous frequencies of the two input sinusoids; 2. Phase is equal to the difference in the phase of the two input sinusoids. Based on the definition of FMCW radar wave, TX chirp, RX chirp, and IF signal, we could draw the frequency-time plot as shown below in Fig.2.4.

Recall that the frequency of the signal at the mixer's output is the difference between the instantaneous frequency of the TX-chirp and RX-chirp. Therefore, the IF signal is a straight horizontal line in the f-t plot, which means a single object in front of the radar produces an IF signal that is a constant frequency tone. Furthermore, this frequency tone S_T can be represented as:

$$S_T = S * T = S * \frac{2d}{c} = \frac{2Sd}{c}$$

(where S is the slope of the chirp,d is the distance and c is the speed of light)

When doing the Fourier Transforms of the IF signal, we notice that two objects that stay too close may result in a single peak in the frequency spectrum. To separate the two

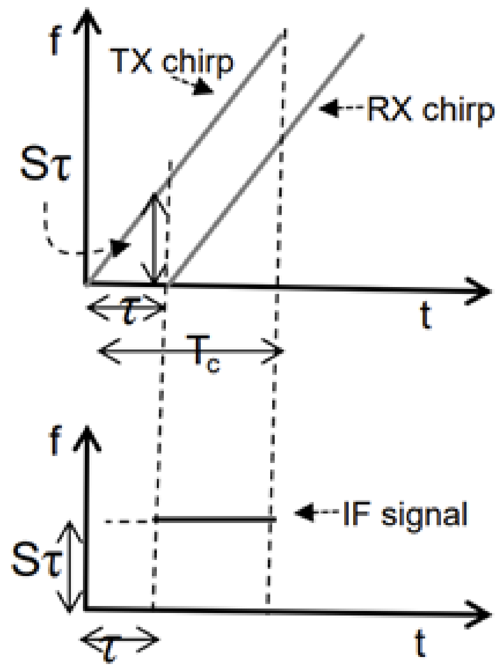

Figure 5: The frequency-time plot of TX chirp, RX chirp, and IF signal.

different tones in frequency, we should ensure that their frequency difference is larger than the reciprocal of chirp duration, $\triangle f \geq \frac{1}{T}$. In addition, T can be represented with ADC sample rate f_s and maximum number of samples N: $T = \frac{N}{f_s}$

Thus, we could get: $\triangle f \geq \frac{1}{T} \rightarrow 2S\triangle d/c > 1/T \rightarrow \triangle d > c/2ST \rightarrow \triangle d > (cf_s)/2SN$

Finally, we have the relation: $d_{res} = (cf_s)/2SN$

In our experiment, we set the parameters as:

$$f_s = 10000ksps$$
$$S = 60MHz/s$$
$$N = 500$$

In practice, since the radar board and ADC sampling are of high precision, it is reasonable to assume that the slope of chirp S and ADC sample rate f_s vary up to 0.01% from the set value. In the worst case, S will be the minimum 60*(1-0.01%)=59.994 MHz/s, while f_s will be the maximum 10000*(1+0.01%)=10001ksps. Under this condition, the overall estimation is $d_{res} = (cf_s)/2SN \approx 0.05001 = 5.001cm$. Apparently, the d_{res} is smaller than 10cm which satisfies our requirement even in the worst case. Therefore, the tolerance in radar board and ADC sampling is allowed.

For further study, we will focus on calculating the chest undulation and breathing rate based on the Fast Fourier Transform(FFT) graph analysis of the IF signal. However, tolerance in some factors may cause a large overall error when calculating chest undulation. For example, people of different ages have various skin types with different absorption and scattering. What's more, various materials of clothing may also result in different absorption and reflection of millimeter waves. Our group assume that chest undulation we calculate $A_{calculate}$ and the real data A_{real} have the following relationship:

$$\mathrm{A}_{real} = a_{age} * A_{calculate}$$
$$\mathrm{A}_{real} = a_{clothing} * A_{calculate}$$

In our further study, we will collect data results from testing people of different ages and people in different clothing. Then, we plan to work on the analysis of data and calculate a_{age} and $a_{clothing}$.

3 Ethics and Safety

3.1 Ethics

According to [5], we promise to uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities. To be more specific, we will ensure all data is from legal sources and that all our actions including data collection and data management won't cause any harm to anyone. Also, we will ensure the privacy of all data and volunteers.

Furthermore, according to [5], we promise to treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others. To be more specific, we will treat every person fairly regardless of their race, age, social status, etc. And we will respect all their intention and protect their safety.

3.2 Safety

We will use 60GHz mmWave Radar. Unlike much higher frequency ultraviolet, X-ray, and gamma radiation, mmWave radiation is non-ionizing because the photon energy is not nearly sufficient to remove an electron from an atom or a molecule, so it is less harmful. Thus, the main safety concern is the heating of the eyes and skin caused by the absorption of mmWave energy in the human body. Searching the potential biological effects of mmWave radiation on the human body, [6] supposes that under skin's protection, mmWave radiation won't be absorbed much by our bodies and most radiation will be reflected. The eyes are vulnerable to radiation-induced heating, however,[7] supposed that mmWave radiation won't cause detectable ocular damage even after being exposed to the radiation for a long time. So under our careful instruction, the data collection process won't cause harm to volunteers.

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4 Cost

Each team member's labor is estimated to be $\$7$/hour, 10 hours/week for three people. We consider the project would last for 9 weeks, so the cost of member's labor would be:

$$4 * \frac{\$7}{hr} * \frac{10hr}{wk} * 9wk * 2.5 = \$6300$$

Our estimated costs for hardware are listed in the tabular below:

Part	Item(manufacturer)	Price per unit	Amount	Total Price
RF System	IWR6843ISK-ODS mmWave ODS(Texas Instruments)	$175	1	$175
	Internet Cable(Amazon)	$5.75	1	$5.75
	USB Type C Cable(Amazon)	$6.49	2	$12.98
	5V 1A Barrel Connector(PERFEIDY)	$13.99	1	$13.99
Control System	Raspberry Pi 4 8GB(GeeekPi)	$279.99	1	$279.99
UI System	Portable Touchscreen(ELECROW)	$43.99	1	$43.99
	Buzzer(QMseller)	$0.79	1	$0.79
Power System	AAA battery(Duracell)	$1.22	2	$2.44
Grand Total				$534.93

Table 1: The estimated hardware cost for our project

Another part of the cost would be the bonuses and reception expenses for volunteers in our data collection. The estimated cost for one volunteer is $\$15$, and there will be approximately 10 people each for 10 different age periods. So the total expected cost would be:

$$\frac{\$15}{person} * \frac{10persons}{group} * 10groups = \$1500$$

In a nutshell, the approximate grand total cost for all our project would be $\$8334.93$

5 Schedule

Week	He Chen	Kangning Li	Bowen Song	Keyu Lu
2/20	Project Selection			
2/27	Working on request for approval and searching for an applicable way for our thesis.			
3/6	Study the theory of our project. Purchasing the necessary hardware component.			
3/13	Connecting all hardware elements together.		Download the related software.	
3/20	Collect the data from members.	Understand the form of how the return signal is being recorded.	Writing the code for close-range object detection.	Working on raspberry.
3/27	Study the theory and determine the radar's parameter for our particular use.	Writing the code to analyze a single person's breath in the signal.		
4/3	Collect data from volunteers		Search waveform under different shielding materials.	Search waveform under different postures.
4/10	Search waveform of children for different ages.		Adjusting code for muti-person detection.	
4/17	Do the environment test.	Design the user interface.		Connect radar, signal management process, and user interface to allow them to work together.
4/24	Create the shell using 3D printing.		Packaging the process onto the raspberry.	
5/1	Prepare for final presentation.		Start writing final report.	

Table 2: The schedule for each of the members.

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