A Temperature Monitor System

Based on Raspberry Pi3 B+ Piconet and DS18B20

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***Abstract*—In this project, we will use piconet as a network structure, and DS18B20 temperature sensors to build up a temperature monitor system to periodically test outdoor and indoor's temperatures. This project aims to help air conditioners know the difference between outdoor and indoor temperatures to save energy waste. Meanwhile, based on the piconet, we will also implement communication between different piconet nodes, so that the piconet master can manage the whole network structure. Besides, according to sustainable ideology, we plan to implement energy consumption digital virtualization only using the software. However, after implementing all functions, We found that energy consumption is hard to be computed only by software, so we only did some research on this field.**

***Index Terms*—Piconet, Energy consumption, Temperature, Sensor, Monitor.**

I. Abbreviations

RPI: Raspberry Pi
RSSI: Received Signal Strength Indication

II. Introduction

The project will investigate how to use Raspberry pi3 b+ to implement a temperature monitor system that can measure indoor and outdoor temperature through a piconet and transfer data to the master server. Besides, to better understand the system's energy consumption, we want to design a program to estimate the system's energy consumption for data transmission.

III. Problem Statement

A Temperature Monitor System that can help the air conditioner control temperature using minimum energy. Temperature control is essential when installing a central air conditioner in the building. To carry out the concept of environmental protection, the central air conditioner should use the least amount of energy to ensure a suitable temperature in the building. Hence, the temperature difference between indoors and outdoors is very important data for the air conditioner.

A. Delimitation

- The project is only working in the Electrum Building. The parameters we get from measuring only can be used in this location, such as the environmental factor.
- There are some barriers on the way when measuring path loss. Its effect can't be measured exactly.
- Both sending and receiving signal strengths are unstable on the RPI3 B+.

IV. Background and Related Work

Implementing the functions of monitoring temperature and collecting data manually is impractical. Raspberry Pi3 model B+ is an excellent device to implement real-time monitoring features and Bluetooth piconet is a suitable solution to collect data. According to lightweight standards, DS18B20 is the most appropriate sensor to be attached to the RPI3 B+.

A. Technology Intoduction

- Raspberry Pi3 B+: RPI 3 Model B+ is an upgraded version of RPI model B. There are several improvements compared to Model 3B. Model B+ increased CPU clock speed to 1.4GHz. Correspondingly, the heat spreader has been added, so that. It can improve thermal and power management. It also increased WiFi performance in two bands. [1]
- Piconet: Piconet is a mature technological network structure connecting devices through Bluetooth. A piconet consists of one master and up to seven slaves. It requires less energy and less cost. However, it has the disadvantage that each device only can keep the connection up to 10 meters. [2]
- DS18B20 Sensor: The DS18B20 is a digital temperature sensor with a built-in 12-bit ADC. It can be easily attached to an RPI. The sensor communicates with RPI over a single-wire bus and requires few components. [3]

B. System Design

This project referred to a smart home environment monitoring system based on Raspberry Pi [4]. Extracting some of the features from this article, we designed a system that can monitor indoor and outdoor temperatures. One slave RPI is installed at the exterior of the entrance of the Electrum building, to monitor the outside temperature. The other RPi is installed at the inside of the entrance, to measure the indoor temperature. One master RPi is installed at the service centre, to collect data from the two stated machines above.

C. Related Work

- Network Choice: WIFI also can be a good method to build up a network [5]. However, WIFI networks have higher power requirements. In contrast piconet, it is based on Bluetooth and used less energy. This feature is in line with the consensus on environmental protection. Hence, the Bluetooth piconet is suitable for this project.

- Network Communication Protocol Choice: There are two choices, Logical Link Control and Adaptation Protocol (L2CAP) and Radio Frequency Communication (RFCOMM). L2CAP is used in the Bluetooth standard that provides adaption between higher layers and the baseband layer of the Bluetooth stack. [6] RFCOMM is a simple transport protocol which is made on top of the L2CAP protocol. RFCOMM has a higher stable performance. [7] Hence, RFCOMM is the better choice.
- RSSI measurement tool: Hcitool is a built-in tool to measure RSSI, which is a part of BlueZ. It provides a simplified way of sending commands to the HCI device. The btmgmt is also a command-line version of the BlueZ Bluetooth utility. BlueZ is part of the official Linux Bluetooth stack and provides support for the core layers and protocols of the specification. [12]
- Establishment of Energy Consumption model Using External Devices [13]: PowerPi, a power model focusing on the power consumption of the Raspberry Pi to derive possible power-saving strategies. This article assumes that an accurate estimation of Raspberry Pi's power consumption can be obtained using system utilization only. The data this article used is gathered by some other external devices.

V. METHOD

A. Communication Network

The project involves building a piconet using raspberry pi. The aim is to connect up to 8 devices to form a small network that can communicate with each other. For this purpose, two C programs are designed and used to create the piconet that enables data transfer.

A piconet is a group of devices that can connect to each other. In a piconet, the terms master and slave are used to specify the role of devices. In our case, the term client is used instead of slave, the term server is used instead of master.

The process of forming a piconet is as follows. Firstly, all the clients started to listen to incoming connections. Then the server is started to initiate connections to each client. Once the connections are established, the server maintains the connections, and data transfer is possible among all nodes. The transfer between a client and the server is operated through the socket directly based on the RFCOMM protocol. However, the clients do not communicate with each other directly. The data transfer between two clients goes through the server, as the server forwards the data it received to the specific client.

B. Received Signal Power Measurement

Received Signal Power depends on Received signal strength indication (RSSI). This textbook [10] gives the calculation formula of Received Power Signal.

$$Receivedpower = RSSI - Pathloss - Sensitivity \quad (1)$$

RSSI can be measured by BlueZ. It provides two command tools. Hcitool and btmgmt.

Path Loss is the reduction of signal when propagating signal. Its calculation formula is shown in *Wireless Communication Networks and Systems* [11].

Sensitivity is the value that devices are able to receive minimum signal strength. Sensitivity is measured using a method of increasing the distance between two devices.

C. Temperature Monitor

The temperature monitor system is based on the piconet created previously and the temperature sensor DS18B20. One temperature sensor is attached to each Raspberry Pi through the breadboard and the GPIO interface. The Raspberry Pi is able to read the temperature from the sensor using the command line tool. The way to attach the sensor is shown in 1.

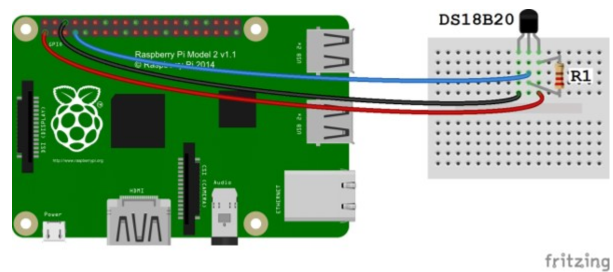

Fig. 1. Attaching sensor

To create a small network that collects temperature data to the central point, the command of reading data from the sensor is integrated into the client program. The Raspberry Pi periodically read data from the sensor and sends the data to the server through the piconet connection. By deploying multiple Raspberry Pi at different locations, A small temperature monitor system based on Bluetooth is created to measure the temperature of different places and automatically transfer the data to a central server.

D. Energy Consumption Model

Before we calculate the power consumption of a BLE device, we should first know about the current profile. With the current profile, we can easily estimate the situation of energy saving in BLE devices.

From reference [9], we found a possible current profile model that may be suitable for our project. The picture below shows a typical BLE slave device's current profile. Then we defined the basic parameters in the current profile.

- MPU(Micro Processing Unit)Running current: I_{MPU}
- Radio Transmission Current: I_{TX}
- Radio Reception Current: I_{RX}
- Sleep Current: I_{sleep}
- MPU running time: T_{MPU}
- Radio Transmission time: T_{TX}
- Radio Reception Offset: T_{offset}
- Radio Reception Time: T_{RX}

In general, when the master and the slave devices connect, connection events will occur repeatedly in BLE slave devices.

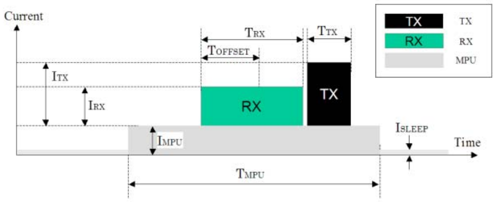

Fig. 2. Consumptive Current in one connection event

Therefore, we only need to measure the current profile in one effective connection interval. The equation of the average consumptive current I_{AVG} for BLE slave in connection is given.

$$\begin{aligned} I_{AVG} = (&T_{MPU} \times I_{MPU} + T_{RX} \times I_{RX} + T_{TX} \times I_{TX} \\ &+ (EIntv - T_{MPU} \times I_{sleep}))/EIntv \end{aligned} \tag{2}$$

EIntv is the Effective Connection Interval. To compatible fast response time with low power consumption, BLE slaves may be allowed to skip some connection events and stay asleep if no data to send to their master. Therefore, the effective connection interval is several times the actual connection interval.

VI. Result

A. Communication Network

The experiment of the piconet is conducted using three Raspberry Pis. One node acts as the server and the other two act as the clients. In the experiment, messages are successfully delivered to server specified client. The result in 3 and 4 shows establishing a piconet and sending a message from a client to the server. It is proved that data transfer between any two nodes within the piconet is viable.

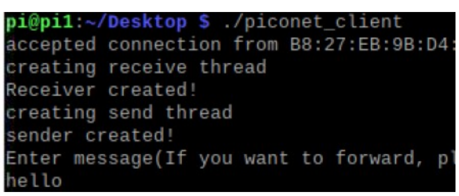

Fig. 3. Sending data from client

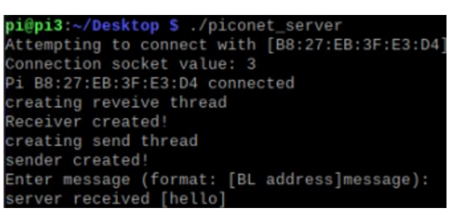

Fig. 4. Receiving data from server

B. Received Signal Power Measurement

Under the Temperature System Scenario, we get the data:

$$\begin{aligned} RSSI &= -37\ dbm \\ Distance &= 5\ meters \end{aligned}$$

According to the data, we can calculate the **Path Loss** is -36.4 dbm. We get the **Sensitivity** of RPI is Sensitivity is equal to -95 dbm. Received power can be calculated as:

$$\begin{aligned} ReceivedPower &= -37\ dbm - 36.4\ dbm\ +\ 95\ dbm \\ &= 21.6\ dbm \\ &= 144.5\ mW \end{aligned}$$

Meanwhile, we measured the relationship between distance and RSSI value when testing the sensitivity.

Distance/m	RSSI Values/dbm
0	-38.4
1	-62.2
2	-65.5
3	-73.1
4	-73.6
5	-77.3
6	-79.1
7	-81.3
8	-82.9

TABLE I
Relationship between Distance and RSSI

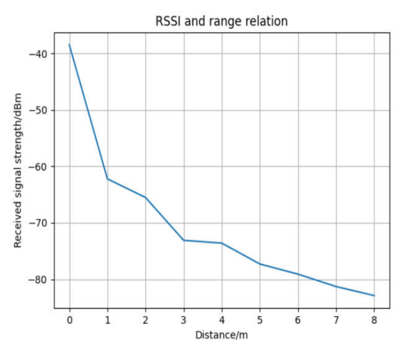

Fig. 5. Relationship between Distance and RSSI

C. Temperature Monitor

A small network with three nodes in the experiment is used to verify the temperature monitor function. The sensor is attached to the raspberry pi as sown in 6. The result is shown in 7. The server terminal receives the periodic temperature data from the client. The unit of temperature is celsius degrees and the last three digits are decimals, so the temperature here is between 20 and 30 degrees which is the temperature inside the room.

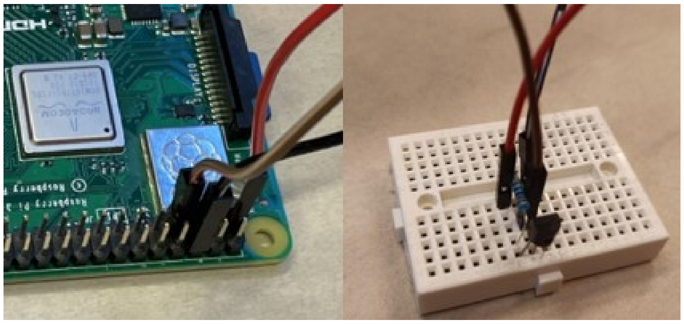

Fig. 6. Attaching sensor

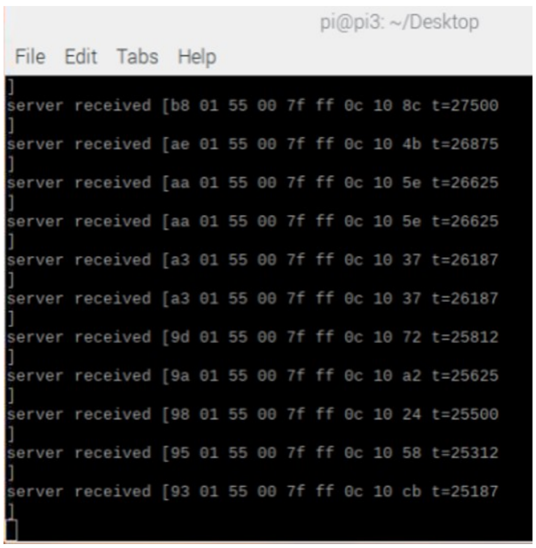

Fig. 7. Monitor system server output

D. Energy Consumption

Since it is hard to measure the current of raspberry Pi without hardware tools. By just using software tools, the measured results are not accurate. Therefore, according to the reference [9], we can get and calculate relevant reference values of basic parameters for I_{AVG}, which is relatively close to practice BLE devices in the market.

Parametets	**Values**
I_{MPU}	7mA
I_{TX}	12mA
I_{RX}	12mA
I_{sleep}	0.001mA
T_{MPU}	4ms

TABLE II
BASIC PARAMETER VALUES FOR BLE SLAVE DEVICES

Suppose the data rate of BLE transmission is 1000 kbps. Besides, the values of T_{TX} and T_{RX} depend on the size of BLE packets transmitted, which may be variable. We suppose that the size of the BLE packet is 20 bytes, then $T_{TX} = 0.16ms, T_{RX} = T_{offset} + 0.16ms$, where the value of T_{offset} depends on the Effective Connection Interval according to the reference [9];

We estimated the BLE average consumptive current I_{AVG} with the values in Table 1, and we obtained the results shown below. They represent the BLE Average Consumptive Current (I_{AVG}) values depending on different Effective Connection Intervals (EIntv).

EIntv	I_{AVG}
7.5ms	4.246mA
100ms	0.320mA
200ms	0.161maA
500ms	0.065mA
1s	0.033mA

TABLE III
BASIC PARAMETER VALUES FOR BLE SLAVE DEVICES

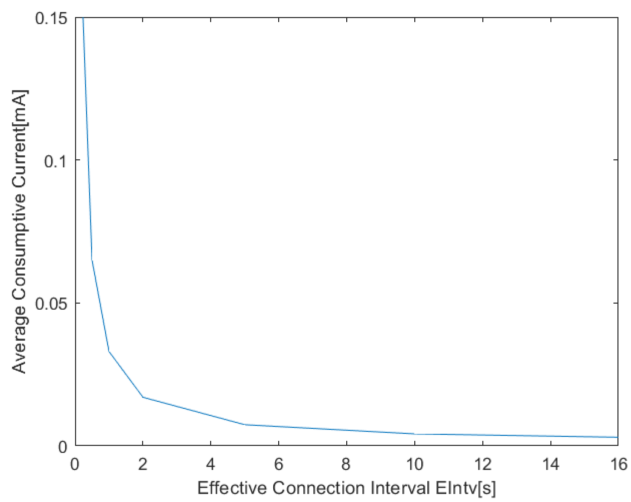

Fig. 8. The current estimation results

Table 3 and Figure 8 show the current profile estimation of BLE slave devices. When the Effective Connection Interval becomes longer, the Average Consumptive Current decreases gradually, which means the device can save more energy and last more running time. But at the same time, the slave device would response to the master's request more slowly. Therefore, there is a tradeoff between energy saving and response time, which needs to be considered in future work.

References

[1] Matt, M. (2018, November 15). Introducing the Raspberry Pi 3 B+ Single Board Computer. Raspberry Pi Spy. Retrieved January 12, 2023, from https://www.raspberrypi-spy.co.uk/2018/03/introducing-raspberry-pi-3-b-plus-computer/

[2] Wikipedia contributors. (2021, May 16). Piconet. Wikipedia. https://en.wikipedia.org/wiki/Piconet

[3] Learn — OpenEnergyMonitor. (n.d.). https://learn.openenergymonitor.org/electricity-monitoring/temperature/DS18B20-temperature-sensing?redirected=true

[4] X. Wen and Y. Wang, "Design of smart home environment monitoring system based on Raspberry Pi," 2018 Chinese Control And Decision Conference (CCDC), 2018, pp. 4259-4263, doi: 10.1109/CCDC.2018.8407864.

[5] N. S. Ismail, N. A. Rashid, N. A. Zakaria, Z. I. Khan and A. R. Mahmud, "Low Cost Extended Wireless Network Using Raspberry Pi 3B+," 2020 IEEE Symposium on Industrial Electronics Applications (ISIEA), 2020, pp. 1-4, doi: 10.1109/ISIEA49364.2020.9188215.

[6] Logical Link Control Adaptation Protocol (L2CAP). (n.d.). https://www.tutorialspoint.com/logical-link-control-adaptation-protocol-l2cap

[7] List of Bluetooth protocols. (2022, October 18). In Wikipedia. https://en.wikipedia.org/wiki/List_of_Bluetooth_protocols

[8] F. Kaup, P. Gottschling and D. Hausheer, "PowerPi: Measuring and modeling the power consumption of the Raspberry Pi," 39th Annual IEEE Conference on Local Computer Networks, 2014, pp. 236-243, doi: 10.1109/LCN.2014.6925777.

[9] R. Tei, H. Yamazawa and T. Shimizu, "BLE power consumption estimation and its applications to smart manufacturing," 2015 54th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE), 2015, pp. 148-153, doi: 10.1109/SICE.2015.7285303.

[10] Rappaport, T. S. (2002). Wireless Communications: Principles and Practice (Subsequent). Prentice Hall.

[11] Beard, C., and W. Stallings, Wireless Communication Networks and Systems, Pearson Education, 2016

[12] Bluetooth - Tizen Wiki. (n.d.). https://wiki.tizen.org/Bluetooth

[13] F. Kaup, P. Gottschling and D. Hausheer, "PowerPi: Measuring and modeling the power consumption of the Raspberry Pi," 39th Annual IEEE Conference on Local Computer Networks, 2014, pp. 236-243, doi: 10.1109/LCN.2014.6925777.

Appendix

Division of Responsibilities

- Arrangement Design: R.K. He (50%), Y.H. Zeng (30%), Z.Y. Lin (20%)

Piconet Establishment

- Literature Research: R.K. He (40%), Y.H. Zeng (40%), Z.Y. Lin (20%)
- Application Analysis: R.K. He (50%), Y.H. Zeng (50%)
- Function Implementation: R.K. He (50%), Y.H. Zeng (50%)

Received Power Signal Measurement

- Literature Research: R.K. He (60%), Y.H. Zeng (30%), Z.Y. Lin (10%)
- Application Analysis: R.K. He (50%), Y.H. Zeng (40%), Z.Y. Lin (10%)
- Function Implementation: R.K. He (60%), Y.H. Zeng (30%), Z.Y. Lin (10%)

Temperature Monitor System

- Literature Research: R.K. He (100%)
- Application Analysis: R.K. He (100%)
- Function Implementation: R.K. He (60%), Y.H. Zeng (40%)

Energy Consumption Modeling

- Literature Research: R.K. He (20%), Z.Y. Lin (80%)
- Application Analysis: R.K. He(10%), Z.Y. Lin (90%)
- Function Implementation: Z.Y. Lin (100%)

Presentation

- Slides: R.K. He (70%), Y.H. Zeng (20%), Z.Y. Lin (10%)
- Statement: R.K. He (40%), Y.H. Zeng (30%), Z.Y. Lin (30%)

Report

- Writing: R.K. He (60%), Y.H. Zeng (20%), Z.Y. Lin (20%)