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Visible Light Communication Based Wide Range Indoor Fine Particulate Matter Monitoring System

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요 약 PM 2.5로 불리는 초미세먼지는 인간의 건강을 해치는 2.5 μm 이하 직경의 입자크기를 갖는 공기 중의 미세먼지를 말하며, 미세먼지 집중도는 공기 질 정보로 사용할 수 있다. 사람은 일반적으로 90% 이상을 실내에서 거주하며 실내에 대한 공식적인 먼지 집중도 자료는 제공되지 않기 때문에, 본 연구는 실내의 관점에서 공기 질 측정에 초점을 두었다. 실내 먼지데이터 모니터링은 병원과 같은 환경에서 매우 중요할 뿐만 아니라 교실, 시멘트 공장, 컴퓨터 서버 룸, 석유화학 저장고 등의 장소에서도 유용하게 사용할 수 있다. 본 논문에서는 전자기파로부터 자유로운 실내 먼지 모니터링을 위해 맨체스터 코딩기법을 이용한 가시광 통신 시스템을 제안한다. 넓은 범위의 먼지 집중도를 포함한 중요한 실내 환경정보가 가시광 채널을 통해 전송된다. 강력한 주변광 및 저주파 잡음 제거를 위해 평균전압트레킹 기법을 사용한다. 입력광은 광다이오드에 의해 수신되고, 동시에 수신 마이크로콘트롤러에 의해 신호처리 한다. 사용자는 실시간으로 실내 공기 질 정보를 모니터링 할 수 있으며, 공기 질 정보에 따라 미리 적합한 대처를 할 수 있다.

• 주제어 : 가시광통신, 미세먼지, 맨체스터코드, 평균 전압 트래킹, LED

Abstract Fine particulate matter known as PM 2.5 refers to the atmospheric particulate matter that has a diameter less than 2.5 micrometer identified as dangerous element for human health and its concentration can provide us a clear picture about air dust concentration. Humans stay indoor almost 90% of their life time and also there is no official indoor dust concentration data, so our study is focused on measuring the indoor air quality. Indoor dust data monitoring is very important in hospital environments beside that other places can also be considered for monitoring like classrooms, cements factories, computer server rooms, petrochemical storage etc. In this paper, visible light communication system is proposed by Manchester encoding technique for electromagnetic interference (EMI)-free indoor dust monitoring. Important indoor environment information like dust concentration is transferred by visible light channel in wide range. An average voltage-tracking technique is utilized for robust light detection to eliminate ambient light and low-frequency noise. The incoming light is recognized by a photo diode and are simultaneously processed by a receiver micro-controller. We can monitor indoor air quality in real-time and can take necessary action according to the result.

• Key Words : Visible Light Communication, Particulate Matter, Manchester Code, Average Voltage Tracking, LED

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Ⅰ. Introduction

With the advancement of industrial revolution, the amount of air pollution is also increased day by day. According to World Health Organization (WHO), 9 out of 10 people are breathing polluted air which contains harmful substances to human body. The main causes of air pollution are burning fossil fuels, chemical gases, smoke from fires, volcanic aches and dust particles. WHO declares Particulate Matter (PM) as potentially harmful, for its injurious effect on human health. Both short term exposure and long term exposure have harmful effects in the human body [1]. Inhalable particle whose diameter is less than 2.5μm is called fine Particulate Matter or PM 2.5 and is the most harmful element for human health [2]. The PM 2.5 can cause premature death in people from heart or lung disease, nonfatal heart attacks, irregular heart bit, aggravated asthma and breathing problem.

Different methods have proposed to monitor the PM 2.5 in the environment specially in outdoor [3]. In our study, we are more focused on measuring the PM 2.5 in indoor environment. Because multiple reports say that human spends more than 90% of their daily life in indoor environments [4], so the quality of indoor air is our primary concern. Indoor PM 2.5 checking is very important in patient room and hospital environments, beside that this can be useful in public places, cement factories, mining areas, classroom or other indoor places. Several methods have been proposed for PM 2.5 monitoring such as [5] but not covering wide range, also not utilizing visible light communication.

The system is implemented with Visible Light Communication (VLC), the reason behind this is that it is free from harmful radio frequency (RF) and the wavelength cover 480 nm to 780 nm. So almost 400 nm spectrum is unlicensed and can be used without any license or regulation in contrast to RF. So this large bandwidth can be utilized for many different application, such as Indoor data transfer, traffic control system, vehicle to vehicle communication etc. Beside that the VLC transmission can be controlled and prevented from unauthorized access to network[6]. Another aspect of VLC communication is that it is free from harmful electromagnetic interference(EMI) and LED can be a potential candidate for application in human health concerned area[7].

PMS 5003 dust sensor manufactured by Plantower, China is used to get the PM data from the laser scattering data of the particles in the environment and this data is transferred to the VLC channel. The light signal is transferred by using one LED illumination and in the receiving part we use photodiode to receive the data. For modulation of data, we use the Manchester encoding technique for synchronization and bit recognition. Using Manchester encoding in transferring data through VLC channel and receiving data using average voltage tracking system will be implemented. The use of Manchester coding as modulation scheme and adopting the average voltage tracking system circuit makes the system more robust, beside that our goal is to achieve wide distance VLC communication.

Ⅱ. System Model

2.1 Dust Sensor Module

For acquiring PM 2.5 data from the indoor environment, we use dust sensor PMS 5003. This sensor can provide accurate real time PM 2.5 data and minimum response time for single data[8]. We can get the dust concentration information for different diameter size including PM 2.5 from this sensor. The sensor uses laser scattering principle to capture particulate matter presence in the air in a certain angle. This sensor has the ability to measure different diameter particles from air and we can get the desired particulate matter data. In the method for getting data from PMS 5003, we need to send some specific code to the sensor and in response to that the sensor generates data which contains dust related information. Here MCU generates the request to send the PM data and the sensor sends data in replay. This data can be stored in a 1D array and PM 2.5 data can be extracted from this stored array. This data represents real-time dust concentration information of the observation area. For this paper, we have experimented in various places in indoor to measure the PM 2.5 concentration level.

2.2 Manchester Code

Manchester encoding is an algorithm used in computer networking to encode data digitally. In ordinary VLC system, the bit sequence is generated by high and low pulses. Which can cause bit loss if the string of 0s or 1s is long. Manchester code can give better solution to this problem. The main advantages of this scheme are ensuring that the signal never remain at logic low or logic high for an extended period of time and converts the data signal into a data-plus-synchronization signal. Some of the reasons for considering this scheme are as follows: It dose not require a separate clock. It can mitigate low-frequency background noise. It dose not have DC component. It has high ambient light performance. It has low LED optical noise.

In Manchester coding, the duration of each bit is divided into two halves. The voltage remains in one level during the first half and moves to another level in the second half. The transition at the middle of the bit provides synchronization [9]. For experimental data we use a transition from low voltage to high voltage is 1 and a transition from high voltage to low voltage represents 0. In the Fig. 1 the code scheme is demonstrated.

2.3 Transmitter with Dust Sensor

In the transmitting side, we used Atmega 128 MCU and PM 5003 sensor for generating and sending PM 2.5 data. To get the real-time PM 2.5 data from the dust sensor, UART (Universal Asynchronous Receiver-Transmitter) communication is used to request the data. The received 32-bit real time data is transferred using in the VLC (Visible Light

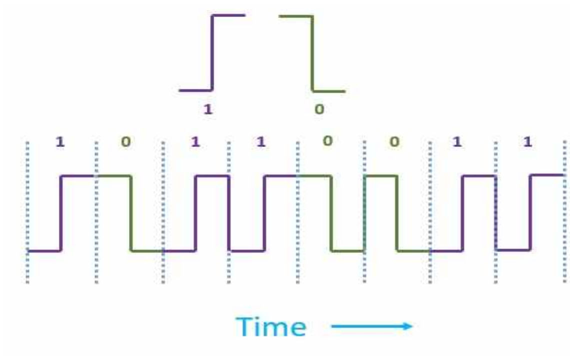

Fig. 1. Manchester code example for data 10110011

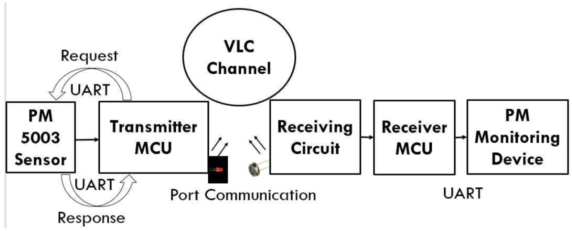

Fig. 2. Overall communication schematic diagram

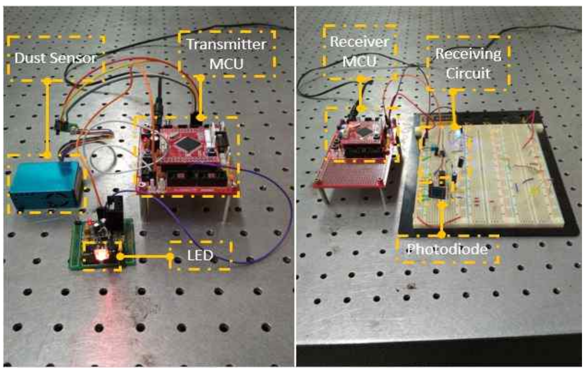

Fig. 3. Transmitter and receiver circuit

Communication) channel using port communication. The Atmega 128 development board has six I/O ports(A-F) for communication. In the port communication we have to provide proper time synchronization scheme and frame format to receive the data successfully. In our experiment, 10 Kbps transmission speed is employed for proper synchronization and recognition of data frames. Figure 2 shows the data transmission process between dust sensor, transmitter and receiver. Because the dust information is not big, channel data rate will not effect the performance of the system.

After getting data from dust sensor, MCU generates corresponding binary data stream and make entire frame. The data frame is than transmitted using 0 and 1 signal to the LED. MCU code is implemented in a way that it generates the corresponding Manchester encoding signal to transfer the data. The signal pattern will be rising edge when the bit is one and falling edge when the corresponding bit is zero. The frame format for sending data to the receiver consists of 56 bits. Figure 4 shows the frame format. The 0xFF and 0x80 are used as synchronization and header information. Then 32 bits data are transferred and followed by end byte. Therefore the total frame length is 56 bits.

LED light cannot illuminate in long distance and its light can not be propagated without lens. To solve this problem, we used Plano-convex lens at the transmitter end[10]. To achieve long distance communication we need good optical intensity and proper focusing to the receiving diode. These two important points can be handled easily by Plano-convex lens. This will help to transfer data in long range about 12m, which can be used in hospitals, schools or baby care centers.

2.4 Receiver Module

In the receiver module, Atmega 128 processor and optical signal detection circuit are employed. The photodiode generates voltage when the light signal illuminates its sensing area. But the voltage is very low to recognize as digital data, so we need additional circuit to amplify the received voltage to make data recognizable. This circuit consists of a buffer (IC1), amplifier (IC2), average voltage tracking (AVT) bock (IC3), differential amplifier(IC4), and comparator (IC5). Here, an AVT block (IC3), which was recently introduced to eliminate ambient light and low-frequency noise under 100 Hz. This enables strong light detection even when the light source is weaker than ambient light, where the cutoff frequency is set to 160 Hz [11], adopting the equation of the RC filter cut-off frequency $f_c=1/(2\pi RC)$ (R= 10KΩ and C= 100 nF are used). At the end of optical receiver circuit we can get binary signal, which is then connected to Atmega 128 for further processing. The incoming signal from AVT circuit is received in port communication in the Atmega 128. UART communication is employed to connect with Atmega 128 and PC as shown in Fig. 2.

Table 1. Experimental parameters

Value	Parameter
Experimental Space	Indoor (Night-time)
Ambient light Intensity	150-200 lux (PD field of view)
Adopted lens types	Plano-convex lens
Experimental Distance	1-14 m
Light Source	Hyper Flux 5 pie (Red)
LED's viewing angle	0-100°

Sync. Byte	Header Byte	Data Byte	Data Byte	Data Byte	Data Byte	End Byte

Fig. 4. Data transmission frame format

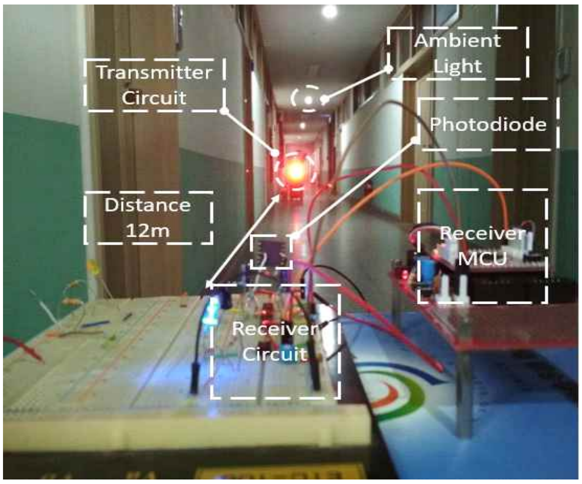

Fig. 5. Experimental setup

Ⅲ. Experiment Result

The experiment setup is made two parts. One is a transmitter part with a single LED for light illumination, Plano-convex lens and MCU. The other part where a photodiode, receiver circuit and receiver MCU is placed as shown in Fig 5. The experimental conditions are listed in Table 1. The detection

Table 2. Comparison of dust monitoring systems

Feature	Proposed System	Ref1[5]	Ref2[12]	Ref3[13]
Transmission of PM data	VLC	No Transmission	Wi-fi	Cable Connection
Sensor for PM 2.5	PMS 5003	OPC-N2	DSM501A	OPC-N2
Sensor Interface	UART	ISP	I2C	ISP
MCU	Atmega 128	SAM3X/A	Raspberry pi	Raspberry pi
Data Monitor	Visual Studio Program	TFT display	Web-based	Web-based

capability of the receiver circuit is tested in different distance. To ensure light transmission across a room space, e.g., a medical center, a longer-distance transmission is required (transmission coverage over 2 m), where Plano-convex lens has employed at the transmitter-end. These lenses are very useful to focus the light source and extend the transmission distance without the need for an additional power supply or LED. In Table 2, the characteristics of the proposed system are compared with those of recent PM2.5 monitoring systems [5], [12], [13]. The proposed system provides accurate PM2.5 information with simple hardware in terms of indoor monitoring and VLC is utilized for long-term transmission with EMI-free characteristics.

According to our experiment, we can achieve 12m VLC communication without error, which signifies long distance communication. The output of the oscilloscope of one data frame is shown in Fig. 6, the test transmission bits are shown for understanding the manchester coding. The test bits include 0xAA(10101010) and 0xBB(10111011) which were transmitted over the VLC channel. After getting the data from different distance, the packet error rate is calculated to measure the transmission performance.

3.1 Indoor Dust Monitoring

To test the proposed system, we have collected and stored the PM 2.5 data using the PM 5003 sensor. The measured data is then compared with the data

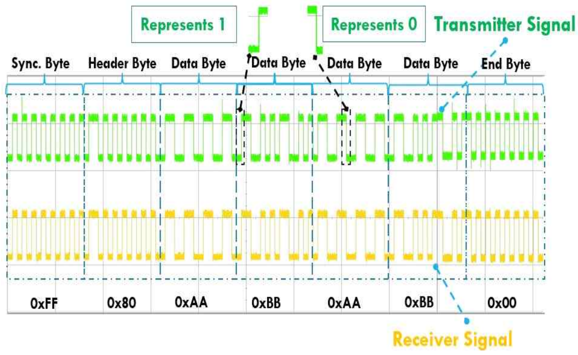

Fig. 6. Oscilloscope output at 11m distance

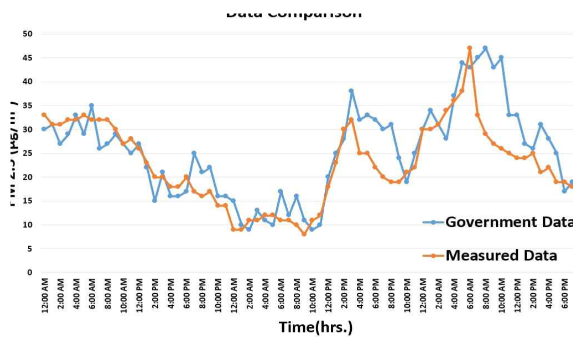

Fig. 7. Dust data comparison

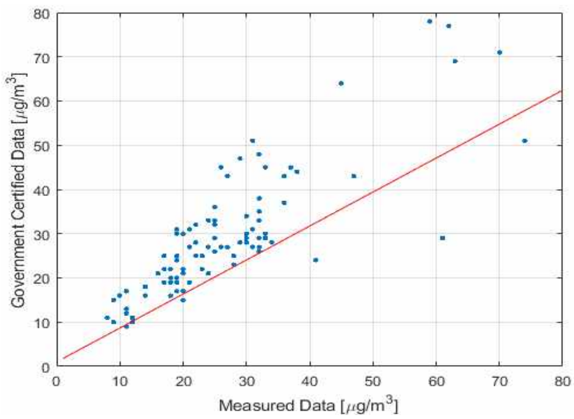

Fig. 8. Correlation between Government data and measured PM 2.5 data

supplied by the Korean Ministry of Environment. The trend of three days data is shown in the Fig. 7.

The Blue color line represents Korean Government data and the yellow line represents the data measured in our lab using the PM 5003 sensor. The data shown here is collected from 6th January 2019 to 8th January

2019. We can see from the figure that the measured data follows the trend that of the government data.

Figure 8 shows the correlation between the two data set and the derived value is R^2 = 0.7. The value is comparable with the outside dust information, although there are some other factors which can create variation in the PM concertation level in indoor. It includes the number of people inside room, space of the room and type of the room like living or store room. We have collected data from various places of different rooms.

The Fig. 9 shows the correlation of two sensor data measured in different rooms and has a correlation of (R2 = 0.938). Which signifies that different indoor position air concentration data is similar but is different from outside data.

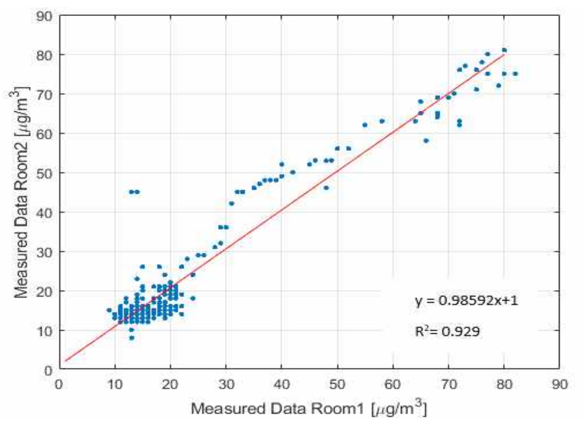

Fig. 9. Correlation between two sensor data measured in indoor

3.2 Optical Experiment

The light intensity of the experiment is measured in different situation, where a digital lux meter (MS 6612) is used to measure the light intensity. For the main noise light source, a fluorescent lamp was used, and is supplied by 220-V AC supply with a 60-Hz frequency. From the packet error rate figure, we can observe that there is no error untill 12m, after that distance the error rate is going high as the distance increases. The error rate is increasing from $3x10^{-2}$ to 0.5 in the range of 12.5m to 14m, respectively. The overall experimental result is seen in Fig. 10.

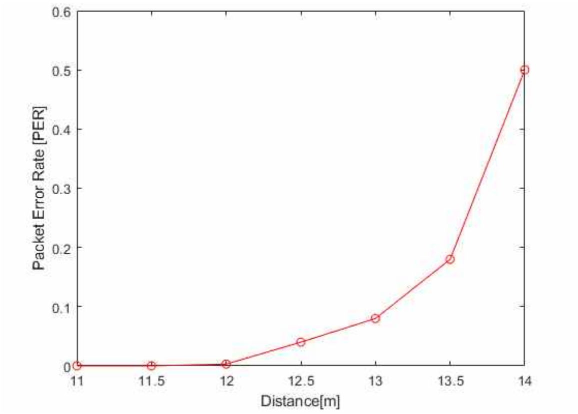

Fig. 10. Packet error rate vs. distance curve

3.3 Real-Time User Interface

The user interface was designed using Microsoft Visual Studio tool (monitoring indoor air quality) for the PC environment. Figure 11 shows the designed indoor air-quality monitoring screen that was used to observe PM 2.5. By pressing the start button after selecting the port number, indoor dust concentrations are displayed in real-time, and are recoded for further analysis. In the user interface we first need to select the correct port number and then start the process the PM 2.5 data can be observed in the text-box. A corresponding graph is also drawn which is changed dynamically as the received value changes.

Ⅳ. Conclusion

In this study we have adopted the Manchester encoding technique through VLC channel for transferring the PM 2.5 data. AVT circuit is employed to reduce the effect of ambient light for error free data in the receiver end. To keep the system simple we have adopted a single LED and photodiode based communication. This system can send PM 2.5 data at wide range (12m) with the help of visible light communication having a reliable error rate. It is expected that the proposed system will work efficiently to monitor the indoor air quality.

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