Implementation of the Real-Time People Counting System using Wireless Sensor Networks

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Abstract

In this paper, we describe an automatic people-counting system based on a wireless sensor network at a mountain area. Several people-counting systems have been proposed separately. However, these systems are not suitable to a place such as the mountain area because of a few problems. In this paper, we develop a system which can count the number of visiting people and sense environment information to protect an ecosystem of the mountain area. For people-counting in the mountain area, our system uses two photo-beam sensors, a big rechargeable power and a solar power. Our people-counting method can automatically count the number of incoming and outgoing people at a special point in real time. Moreover, the environment sensors measure environment information at the mountain area, and constitute the wireless sensor network with photo-beam sensors. To establish this system in Korea mountain, we did tests on the wireless communications range and the reliability of people-counting. By the testing results, we found that the developed system is suitable within 200 meters for effective wireless communications in Korea mountain. When the width of a path up a mountain is within 1.5m, the reliability of people-counting in our system is over 90%. The number of visiting people and the measured environment information are used to manage and control the mountain.

***Keyword**: People-Counting System, Sensor, Wireless Sensor Network*

1. Introduction

1.1. Motivation

An automatic people-counting system in real time is important in several application areas where the activity of people needs to be analyzed or monitored [3]. If we get the number of visiting people for a period, it is easy to manage and control people and special areas such a building, a park, and so on. Several systems [1], [2], [3], [5] have been developed for these purposes. Most of these systems are based on a camera, the existence network such as the Internet, and use an electric power including a wire power line. Also, these systems are for indoor such as at gates, at entrances of buildings and so on. Therefore, these systems are not suitable to outdoor because of the electric power device, the wire power line and so on.

On the other hand, a few monitoring systems [9], [12] have been developed to protect and manage a special land or a living thing including a natural monument. However, these systems cover just a narrow land or an open land. According to develop wireless communications technology and computer hardware technology, a small mobile node can be made. The small mobile node can communicate with other mobile nodes everywhere and constitute a wireless sensor network such as an ad-hoc network [4], [6]. Recently, many systems using a wireless sensor network and mobile nodes are applied to all industry area (e.g. military, monitoring for protection of an ecosystem, distribution, factory automation and so on).

We consider a mountain area which can not use the existence network and well receive a radio wave. A mountain area is a kind of national park, and is very important area for protection of an ecosystem. Mountain-climbing is a kind of popular hobby. However, the ecosystem of the mountain has been destroyed by many people. To recover the destroyed mountain, we should give a rest period to the mountain. For a rest period, no one goes up the mountain to protect the ecosystem of the mountain. The number of visiting people in the mountain is differs with mountains. To protect the ecosystem of the mountain, we develop a system which can do people-counting as well as environment monitoring based on photo-beam sensors and a wireless sensor network. The number of visiting people and the measured environment information are used to manage and control the mountain and visiting people. That is, the managers of the mountain can know the number of visiting people and environment information, and decide a rest period for the ecosystem of the mountain. Moreover, the managers can keep the safety of visiting people because the developed system is able to automatically count the number of incoming and outgoing people in real time. The developed system will set up in Korea mountain area.

1.2. Related Works

For counting and tracking moving people, several systems [1],[2],[3],[5] using image processing by a camera have been proposed, recently. To process image data, these systems were based on motion analysis of moving people. Rossi and Bozzoli [2] have developed a system to detect and track moving people using a fixed video camera. Their goal was only to count the number of people crossing a counting line. In their system, a motion detection module determines whether any person has entered the scene which is a tracking module combining prediction and matching then follows people until people reach the counting line. However, this system did not consider an area that electric power is not supplied or existence network is not constructed. Segen and Pingali [3] have developed a system for real-time tracking of people in video sequence. In their system, the input to the system is live or recorded video data acquired by a stationary camera in an environment and the output consists of trajectories which give the spatio-temporal coordinates of individual persons as they move in the environment. Terada et al. [5] proposed a counting method accurately for passing people by using stereo images. In proposed method, the stereo camera is hung from the ceiling of the gate and the optical axis of the camera is set up so that the passing people could be observed from just overhead. Masoud et al. [1] proposed a real-time system for pedestrian tracking in sequences of grayscale images acquired by a stationary camera. The objective is to integrate this system with a traffic control application such as a pedestrian control scheme at intersections. The proposed approach can also be used to detect and track humans in front of vehicles.

Also, there are some systems for a habitat monitoring using sensor network. The Intel Research Laboratory at Berkeley, the College of the Atlantic and the University of California at Berkeley has jointly developed a habitat monitoring kit that enables researchers worldwide to engage in the non-intrusive and non-disruptive monitoring of sensitive wildlife and habitats

[9]. These networks monitor the microclimates in and around nesting burrows used by the Leach’s Storm Petrel. Another system is Redwood Park Forest Ecosystems [12]. This research has been enforced by the University of California at Berkeley [12]. They are extending the fog input data to the ecosystem scale and asking how the water inputs and the nutrients within these inputs are influencing the ways in which water, carbon and nitrogen cycles within the Redwood forest.

1.3. Contribution

We develop a system which enables automatic people-counting as well as environment monitoring using photo-beam sensors and a wireless sensor network. Our goal is to maintain the safety of people through the number of incoming and outgoing people, and to protect the ecosystem of the mountain. Usually, the managers of the mountain manage and control visiting people, a forest fire, and an ecosystem. In fact, there is no virtue in such measures, and the managers are impossible to control and to manage all over the mountain. Most of mountain areas are not set up the existence network and can not well receive a radio wave. To manage and control the mountain, we develop a new system based on photo-beam sensors and a wireless sensor network.

First, we develop an automatic people-counting system to count the number of incoming and outgoing people in real time using photo-beam sensors. As mentioned in Section 1.1, the existence people-counting systems have the problems of power (including a wire electric power) and network connection to be established at a mountain area. We solve the problem of a power through a big rechargeable power and a solar power. Moreover, the developed hardware system was designed to operate in a low-power. To solve the problem of the network, our system constitutes the wireless sensor network using photo-beam sensors and the environment sensor. This wireless sensor network can be used everywhere without the existence network.

Second, Most of the existence systems operate in only indoor and can not use without the existence network. Also, communication costs are high because of using of the existence network. The developed system can use in indoor and outdoor and communication costs is lower than those of the existence systems. Our system counts the number of incoming and outgoing people at a counting line or a turning point. Therefore, the managers of the mountain can not only control and manage visiting people in real time, but also know the number of visiting people between turning points. In addition, if the visiting people are injured at the path up a mountain, the manager can suppose the injured location.

Third, our system can verify the total number of visiting people and manage the ecosystem of the mountain by its results. That is, the number of visiting people is differing with mountains. The managers of the mountain can manage and control the mountain by the counted number. This is a very effective method.

This paper is organized as follows: In Section 2, we describe briefly configuration of the developed system. We present results of the previous tests to establish the developed system. Conclusion and future works are presented in Section 4.

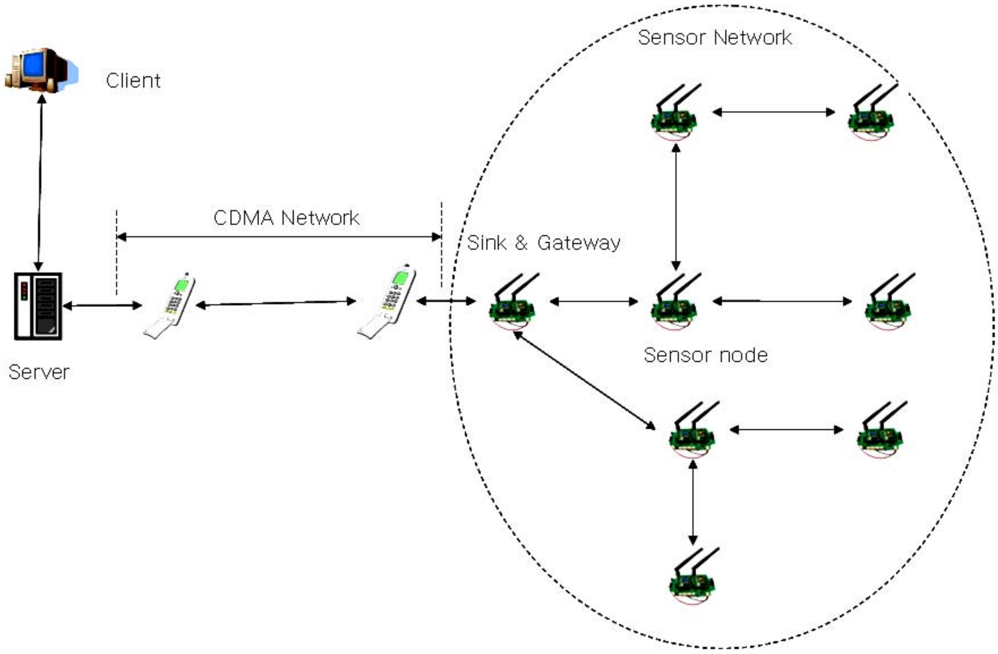


Figure 1. system configuration

2. System configuration

In this section, we introduce the system architecture of the developed system. Our system consists of Sensor Node, Sink Node or Gateway, Server and Client. The sensor node consists of a people-counting sensor and an environment sensor. The people-counting sensor is counting and tracking visiting people through the path (e.g. a path of mountain) using photo-beam sensors. The environment sensor is sensing environment information such as temperature, humidity and illumination in real time at a special point. The people-counting sensor is deployed at an entrance and exit and each turning point of a path of mountain, and the environment sensor is deployed at important environment points. Then, these sensor nodes are counting the number of visiting people and measure environment information at deployed places in real time. Also, these sensor nodes constitute a wireless sensor network and make an exchange with each other's information. The exchanged data by these sensor nodes is sent to a gateway through the wireless sensor network.

The gateway is a role that connects between the wireless sensor network and other network (e.g. CDMA network, the Internet). That is, the gateway connects with existing CDMA network using a CDMA module, and sends data to a server. To provide data to a client, the server analyzes the received data. The client accesses to the server, he identifies the analyzed data in real time. Figure1 shows our system configuration.

2.1. Motivation

In the Mountain area, requirements are several. The sensor networks at mountain area must be accessible via the Internet. An essential aspect of people-counting monitoring applications is the ability to support remote interactions with in-situ networks.

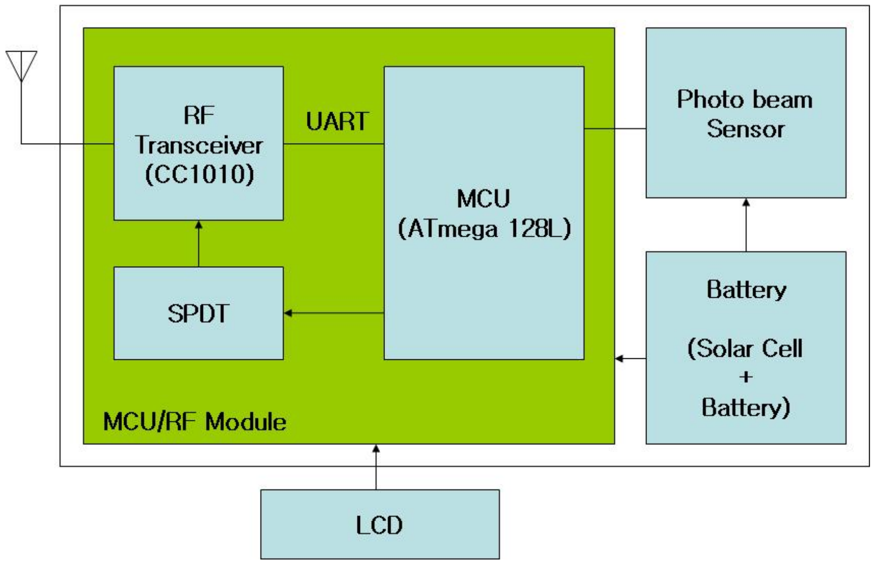


Figure 2. People-counting Sensor node block diagram

The field station at mountain area needs sufficient resources to host Internet connectivity and database systems. However, the mountain areas of manager interest are located up to several kilometers further away. A second tier of wireless networking provides connectivity to multiple patches of sensor networks deployed at each of the areas of interest. Three to four patches of 100 static nodes is sufficient to start.

Table 1. Specification of interface board

Class	Feature
MPU	- ATmega 128L 8MHz - EEPROM : 4KByte - internal SRAM : 4KByte - Two 8bit Timers and Counters - Two external 16bit Timers and Counters - Active Power (DC 2.7 ~ 5.5V) - internal Flash Memory : 128KByte - external Flash Memory : 128KByte - 10mW, 0dBm
Communication	- IEEE 802.15.4 compatible - ZigBee compatible - Multi-hop routing
RF module	- RF chip : Chipcon CC1010

	- Low current consumption : 9.1mA in RX - Data rate : Maximum 76.8Kbps - Fast PLL, RSSI - MCU : 8051 compatible microcontroller - Flash Memory : 32KByte - SRAM : 128Byte - 3 Channel 10bit ADC - 4 Timers - supply voltage : DC 2.7 ~ 3.6V - 64-lead TQFP
Antenna	- Helical Antenna, 1500m - Connector type : Male reversed SMA - Frequency range : 433MHz or 477MHz - Impedance : 50 Ohms
Sensors	- Temperature - Humidity - Photo-beam - Illumination

Sensor networks that run for several months from non-rechargeable power sources would have significant audiences today. Although people-counting measures at mountain areas span multiple field seasons, individual field seasons typically vary from 9 to 12 months. Seasonal changes as well as the plants and animals of interest determine their durations. We installed power supply as big rechargeable battery and solar power supply.

2.2. Sensor Node Specifications

Here, we introduce the developed sensor node (See Figure 2 and Figure 3). The developed sensor node consists of two nodes; people-counting sensor node and environment sensor node. The main characteristic is a power-supply part. If sensor node is set up at a mountain area, this should operate for at least several years without exchanging the power. So, we use a big rechargeable power and a solar power supply which can be rechargeable. If the sun shines brightly, the solar-power supplies power to sensor node and the big rechargeable battery. If the sun isn't shines, the sensor node uses the big rechargeable battery.

Sensor node consists of Interface board and RF board (see Figure 3). The sensor node drives RF board, stores data, and communicates data. The sensor node is used for this system. The sensor node is shown in Figure 3. The main components of the sensor node are the microcontroller, RF board, and external data storage. The microcontroller is

ATmel ATmega 128L. It has 128KB of program memory, 4KB of RAM, and runs at 8MHz. The radio chip is the Chipcon CC1010. Its data rate is maximum 76.8Kbps. We used a radio frequency of 433MHz and 477MHz. The sensor node also has an external 128KB EEPROM for data storage. The sensor node interfaced to sensors digitally using I2C and SPI serial protocols and to analog sensors using the on-board ADC.

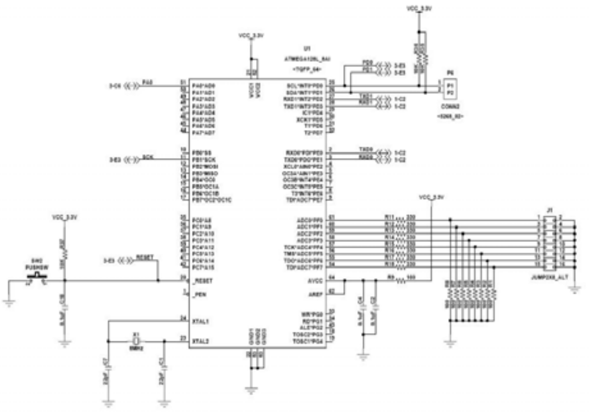
Table 1 shows specifications of the interface board the RF board. The interface board is based on ATmega128 [7] which is known as a low-power processor, and uses MAX1674 [11] and LP2981 [10] to optimum the efficiency of energy. Figure 4 shows a circuit diagram of developed hardware system.

Our sensor nodes have such as sensors: BEN5M MFR photo-beam sensor, LM61

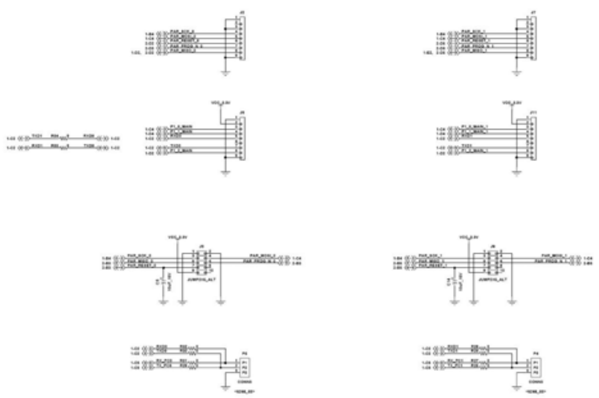
Figure 3. Developed interface board and RF board

temperature sensor, HS1101 humidity sensor, and A9060 illumination sensor. The BEN5M MFR photo-beam sensor uses a pair of photo-beam sensor. This sensor is slim-type photoelectric sensor with free power voltage. The BEN5M MFR is selectable light ON / Dark On by the DIP switches (DC power). Also, The BEN5M MFR has built-in protection circuit against reverse power polarity (DC power) and NPN and PNP output to be applied at the same time in DC power type relay output. The photo-beam sensor used to measure incoming and outgoing people counting. The people-counting line is 5m.

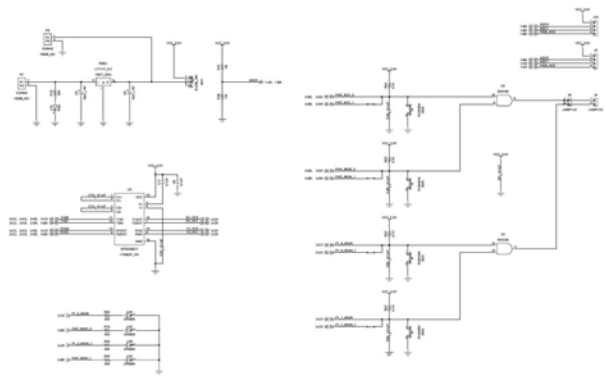
The LM61 is a precision integrated-circuit temperature sensor that can sense a -30℃ to +100℃ temperature range while operating from a single +2.7V supply. The LM61's output voltage is linearly proportional to Celsius (Centigrade) temperature (+10mV/℃) and has a DC offset of +600mV. The HS1101 is relative humidity sensor. The HS1101 Based on a unique capacitive cell, these relative humidity sensors are designed for high volume, cost sensitive applications such as office automation, automotive cabin air control, home appliances, and industrial process control systems. They are also useful in all applications where humidity compensation is needed. Their main features same as: Full interchangeability with no calibration required in standard conditions,



(Figure 4-1)



(Figure 4-2)



(Figure 4-3)

Figure 4. A circuit diagram of developed sensor node

Instantaneous desaturation after long periods in saturation phase, Compatible with automotive assembly processes, including wave soldering, reflow and water immersion, High reliability and long term stability, Patented solid polymer structure, Suitable for linear voltage or frequency output circuitry, Fast response time, and Individual marking for compliance to stringent traceability requirements.

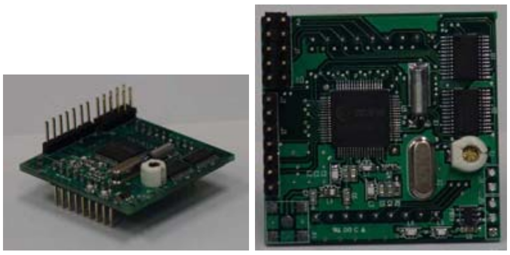


Figure 5. Developed RF Module

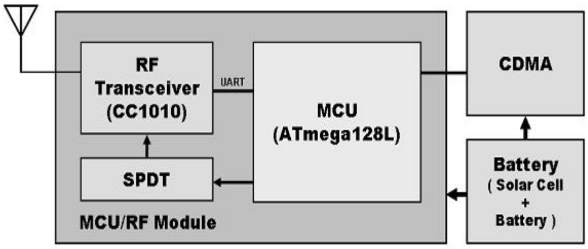


Figure 6. Gateway block diagram

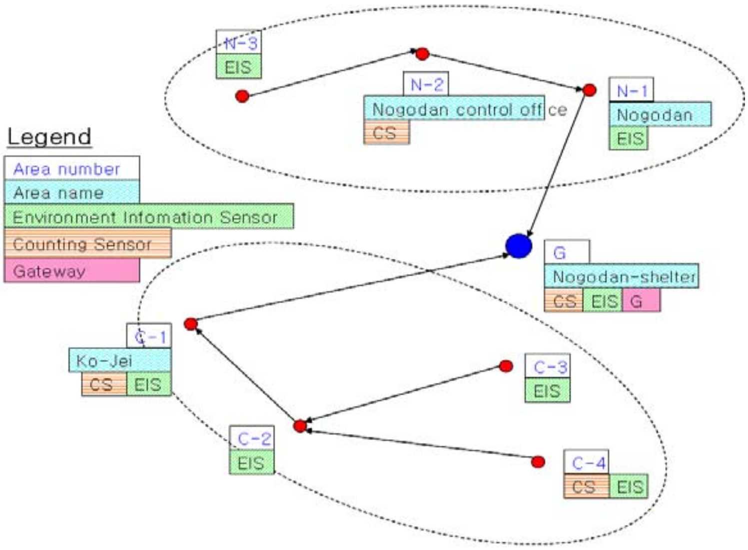


Figure 7. Deployment of established system at Nogodan area

However, the only receptions in this protocol occur at the base station, so if either the base station is close to the sensor nodes, or the energy required to receive data is large, this case may be an acceptable (and possibly optimal) method of communication.

We used MAC and routing protocol. In the standard of IEEE 802.15.4 of a sensor network, PHY layer operates in three frequencies (868MHz, 915MHz and 2.45GHz). However, our sensor node uses 433MHz by Korea's frequency-law and the previous testing results to maintain effective wireless communications. Although this frequency is not the standard of

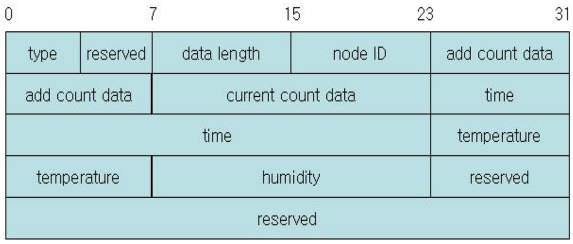


Figure 8. Packet Format

Table 2. Type value

Type value	Description
0000	Counting information
0001	Sensing information
0010	Counting + sensing information
0011~1111	Reserved

IEEE 802.15.4, it is suitable to Korea's mountain areas. For the RF communication module, we choose a CC1010 transmitter-receiver chipset of Chipcon [8] and make a programming to be operated in 433MHz. Our sensor node uses GFSK (Gaussian filtered FSK) and Manchester encoding. The maximum speed of data transmission is 76.8Kbps.

The routing protocol of our system is based on multi-cluster tree and static routing protocol. All sensor nodes have configured a routing table and send directly its data to sink & gateway or a neighbor node. After the sensor nodes configure a network of tree structure, they maintain the routing table which is required in communications.

2.4. Directional People-Counting Algorithm

Figure 9 shows a situation of the path up a mountain for people-counting. To count visiting people, we set up a pair of photo-beam sensor node. Each photo-beam sensor node is established on the photo-beam sensor 1 and the photo-beam sensor 2 of the interface board. If it is checked on the photo-beam sensor 1 to the photo-beam sensor 2, that means 'incoming'. If it is checked on the photo-beam sensor 2 to photo-beam sensor 1, that means 'outgoing'. Therefore, the photo-beam sensors automatically are able to count the number of incoming and outgoing people in real time. Usually, a width of a path up a mountain is narrow. When people are walking in a narrow path up a mountain, our system counts the number of visiting people in real time. If this system is established at each turning point of a path up a mountain, we can know the number of visiting people between two turning points as well as the number of incoming and outgoing people at a turning point in real time. This will be a help to the safety of visiting people at passing prohibition time (from 18:00 to 06:00). To enhance the reliability of the photo-beam sensors, we limit a width of a path up a mountain within 1.5m.

The computation of maximum number assumes the definition of a person model. Figure 11 illustrates the people model: H=tallness, W=shoulder width, T=chest depth, D=head diameter, h_h=head height, h_l=leg length, a=arm length [13]. Our system use T (chest depth) and h_l (leg length). When people pass path line, width (K) of counting line K estimated by T. Figure 10 show directional people-counting algorithms. This algorithm explains counting method and store method. Each counting sensor node programmed at memory and operate algorithm.

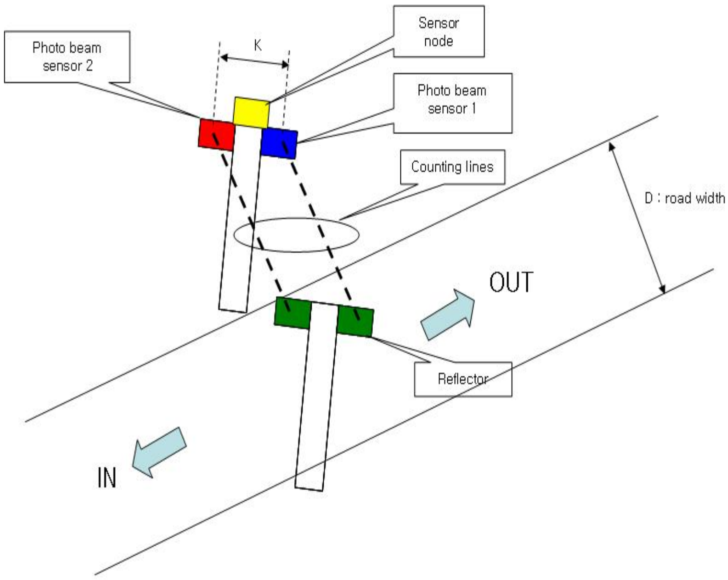


Figure 9. A situation of the path up a mountain for people-counting scene

```
// People pass time (ms)
#define MINPASSTIME        100
#define  NORMALPASSTIME    150
#define MAXPASSTIME          250

main()
{
// Counting buffer (current people number)
        unsigned long counting;
// input time buffer
        unsigned long time_CH1;
        unsigned long time_CH2;
// If Ch_1 check, incoming
// If Ch_2 check, outgoing
        int CH_Seq;
do
{
```

```
if (CH_Seq == 1)
{
if (time_CH2-time_CH1>= MINPASSTIME && time_CH2-time_CH1 <=
NORMALPASSTIME)
        counting++;
else if (time_CH2 - time_CH1 > NORMALPASSTIME && time_CH2 - time_CH1 <
MAXPASSTIME)
        counting = counting + 2;
        }
        else if (CH_Seq ==2)
        {
if (time_CH1 - time_CH2 >= MINPASSTIME && time_CH1 - time_CH2 <=
NORMALPASSTIME)
        counting++;
else if (time_CH1 - time_CH2 > NORMALPASSTIME && time_CH1 - time_CH2 <
MAXPASSTIME)
        counting = counting + 2;
            }
        }while(1)
    return 0;
```

3. Testing Results

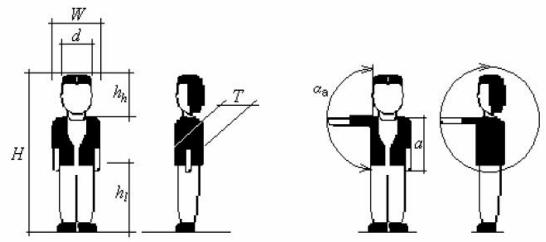
In this section, we introduce testing results for the developed system.

3.1. Testing Results of Wireless communications range

First of all, we tested the range of wireless communications using our system in four Korea's Mountain which are Mt. Ju-wang, Mt. Kyer-yong, Mt. Pal-gong and Mt. Ka-ya. As mentioned in Section 2, we used 433MHz frequency. We tested the range of wireless communications by the 50m at each mountain area. To test the communication reliability, we send 100 packets and check the number of the received packets. With this test results, we

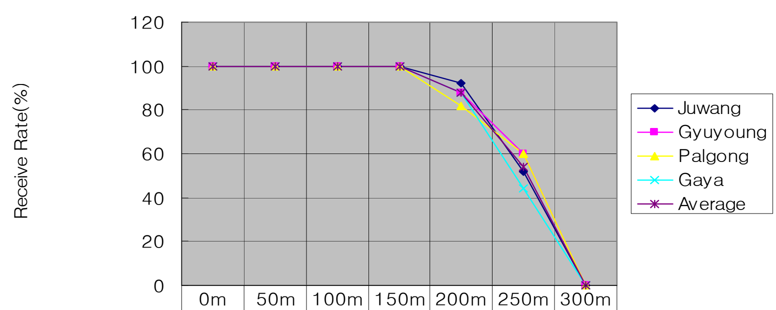
found that a wireless communication is suitable within 150m~200m in Korea's mountain area, if Line of Sight is impossible by many tree, hill, and stony Mt. When Line of Sight is possible as flatland, the range of wireless communication is up to 500m. Figure 12 shows test results on wireless communications ranges and the reliability in Korea's mountain area. In Figure 12, the horizontal axis is test range and the vertical axis is the receive rate. The communication

range 150m under show 100% receive rate and the communication range 200m show about 80% upon. But, the communication range 200 more than show about 80% under. Figure 14 show test place in Mt. Kyer-yong.



- H: tallness
- W: shoulder width
- T: chest depth
- D: head diameter

Figure 11. People Model



	0m	50m	100m	150m	200m	250m	300m
Juwang	100	100	100	100	92	52	0
Gyuyoung	100	100	100	100	88	60	0
Palgong	100	100	100	100	82	60	0
Gaya	100	100	100	100	88	44	0
Average	100	100	100	100	88	54	0

Distance(m)

Figure 12. Testing results on wireless communication range and reliability

Figure 13. Test Picture in Mt. Kyer-yong

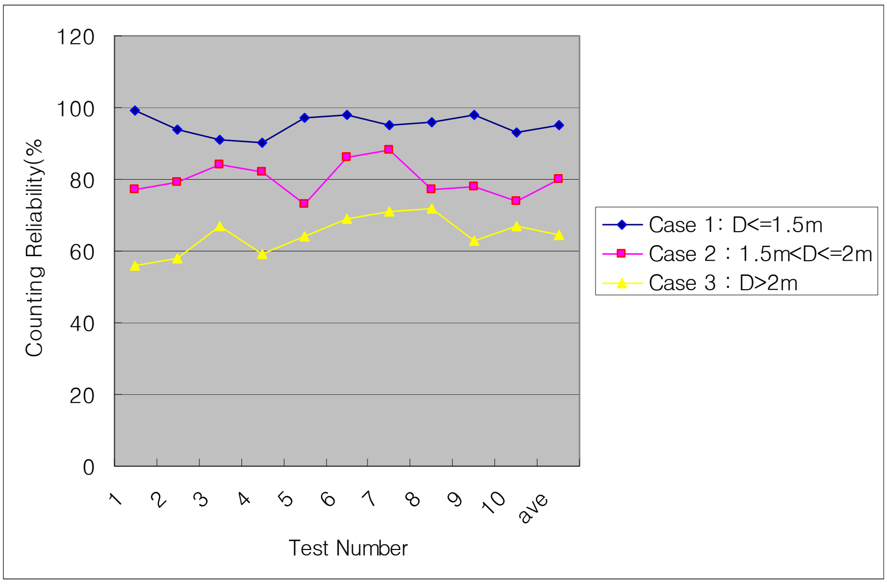


Figure 14. people counting reliability

Figure 15. people counting test place at Nogodan

3.2. People counting reliability

We tested the developed system at Mt. Ji-ri which is one of Korea national mountains. The testing area is Nogodan area which is one of summits at Mt. Ji-ri, including Nogodan-Shelter, Nogodan Control Office and Ko-jae which is one of hills at Nogodan. Figure 7 shows the established system at Nogodan area for testing. For the effective testing, we have some assumptions as follows;

Assumption 1. The number of people (N): 100

Assumption 2. A width of a path up a mountain (D): $D \leq 150cm$, $150cm < D \leq 200cm$, $200cm < D$.

Assumption 3. Average of walking speed (S): 4km/s.

Assumption 4. The passing time at counting line (T): 100msec.

Assumption 5. People can pass freely at counting line.

For this testing, 100 persons passed through the counting line 10 times (See Fig 9). Figure 14 shows the test results. In Figure 13, the horizontal axis is test number and the vertical axis is the reliability of people-counting. When the width of a path up a mountain is within 1.5m, the reliability is over 90%. When the width is larger than 2.0m, the reliability is about 65%. When the width is large than 1.5m, the improvement of reliability is one of our future works.

4. Conclusion and Future Work

For an effective manage a mountain area including national parks, we developed an automatic people-counting and environment monitoring system based on a wireless sensor network in real time. For an electric power of the developed system, we used a big rechargeable power and a solar power. Also, the power of our system is very effective system because we designed the hardware system and the routing protocol based on the low-power. The people-counting sensors and the environment sensors constitute a wireless sensor network and make an exchange with each other information. So, our system can be established everywhere.

Our system can count the number of incoming and outgoing people and measure environment information at a special point in real time. Therefore, the managers of the mountain can control and manage visiting people as well as the ecosystem of the mountain. However, when the width of the counting range is up to 1.5m, the reliability of people-counting in our system is under 65%.

In the future, we will extend the width of the counting range. Also, we will apply the developed system to count the number of running cars.

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