Combining Multiple Laser Range Scanners and Sensor Networks for Real Time People Detection and its Application to An Energy Saving System for Air-Conditioning Control

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Abstract: Recently, a novel air-conditioning system, which can send a wind very locally and cool down or warm up only a target person, has been developed (it's called "spot-ventilation"). However, in a wide public area such as a station, airport, exhibition hall and others, the system has never been applied effectively because pedestrians change their location continuously. In this paper, combining multiple laser range scanners and sensor network technology, an energy saving system for the air-conditioning control, which sends a wind only to where and when pedestrians exist, is proposed. By using multiple laser range scanners, pedestrians' positions are detected extensively. This method has advantages against using camera or infrared sensors in terms of low occlusion and independence from lighting condition. Moreover, by scattering a lot of sensor network devices equipped temperature sensor within the target area, a temperature distribution is acquired. The sensor network devices are very easy to exploit because they use a wireless network and organize a network for themselves. In addition, the devices are robust for disconnection because the packets are relayed from node to node. Therefore, the network is composed like a "mesh". Moreover, it needs only very low energy. By integrating the two types of data, pedestrians' positions and temperature distribution, we can find where and when the spot-ventilation system should fan. Linking up with the proposed system and spot-ventilation system, the air-conditioning system will run very efficiently in a wide public area, and achieve decreasing useless energy consumption without spoiling comfort.
Keywords: Laser Range Scanners, Sensor Network, Pedestrians, Temperature Distribution, Data Fusion.

1. Introduction

By having ratified the Kyoto Protocol in February 2005, the campaign for CO_2 reduction is activating among many countries. In Japan, a policy for energy saving to reduce CO_2 emission is employed aggressively. However, actual air-conditioning systems have a lot of wastefulness because they fan also to empty area and where the temperature is sufficient. Recently, a novel air-conditioning system that can send a wind very locally by controlling the nozzle's angle flexibly has been developed (it's called "spot-ventilation"). For example, an air-conditioner for home use, which equips a temperature sensor, and monitors and reduces unevenness of temperature in a room, has been developed in Japan. In other cases, spectator's seats at Osaka city dome in Japan are ventilated very locally by monitoring audiences' positions and temperature using infrared camera. Although conventional systems are effective for home use or relatively small area, they will be not adequate to relatively wide area such as a station, airport, exhibition hall and others, because pedestrians is moving continuously. Truly effective air-conditioning system is still very few in the sense that can fan only when and where a target person exists and the temperature is unsatisfactory.

Accordingly, the goal of this study is to cut down on a waste of energy used in air-conditioning system placed in a wide public area. To that end, also in the wide area, a large number of pedestrians' positions should be detected and the temperature distribution is monitored simultaneously.

So far, to recognize and track multiple pedestrians, a lot of researches using CCD or stereo cameras have been conducted [1]. However, video-based approaches have some obstacles, such as narrow field of view, limited resolution and affection by illumination. Therefore, multiple cameras are often needed to cover a relatively wide area. Consequently, only few systems have been applied to the measurement of high-density crowds in a wide area, such as railway stations or exhibition halls. In recent yeas, single-row type laser range scanner with high scanning rate, wide viewing angle and long-range distance has been developed, and can be bought with rather than low price on market. The laser range scanner has some advantages against cameras, which is almost independent from lighting condition and obtains range distance from sensor to surrounding objects directly. It has been demonstrated of efficiency for detection of masses of pedestrians in relatively wide area [2].

On the other hand, a wireless sensor network technology, which measures some environmental information such as temperature, moisture, lightness, noise, and so forth, has been developed and become popular. It's very easy to construct a network, because it organizes a network autonomously. Moreover, the network is composed like a "mesh", i.e. the packets are relayed from node to node, so that it's robust for disconnection. Conventional researches applying the sensor network, for example, monitoring physiological information of livestock [3], air-pollution monitoring using gas sensor [4], temperature monitoring for shellfish catches [5], and so on, are conducted.

In this research, we propose a novel system, which detects a lot of pedestrians' positions using multiple laser range scanners, derives temperature distribution in a target area using a wireless sensor network technology, and the two types of data are fused in the same coordinate system in real time. Finally, we detect the positions where to fan.

2. Method

2.1 Outline of the Sensors

In this research, to detect a lot of pedestrians' positions, single-row type laser range scanner, LMS200, produced by SICK corp. is exploited (Fig. 1). It measures a time of flight from shot of a laser pulse to reflection against surrounding objects, and calculates a range distance. It has a wide viewing angle of 180 degrees on the scanning plane by rotating inner motor fast. Accordingly, high angle resolution (0.5 degree) and profiling rate (37.5Hz or 26 msec/scan) are equipped. It can be easily converted to rectangular coordinates in the sensor's local coordinates system. Maximum measurable distance is about 30m and an average distance error is 4cm. A wavelength of the laser beam is 905nm, and it's used "eye-safe" beam (safety class is 1A).

Moreover, to measure a temperature distribution, a wireless sensor network device, MOTE™/MICA2, produced by Crossbow Technology Inc., is employed (Fig. 2). Even if it's very small (55x32x25mm), multiple sensors are installed such as temperature, light, noise, acceleration, and so on. The temperature sensor has an error within about 1.0 degree Celsius. Moreover, the devices are very easy to exploit because they organize a network autonomously (it's also called "ad hoc" network). Moreover, they relay a packet from node to node, so that the network is like a mesh. Therefore, the network is robust against disconnection. The signal reaches about 30m per a hop. The radio frequency is 315 MHz. The power voltage is 3 V, and current is about 15mA when it's active. Consequently, the device lives over few weeks with a battery. The sensors' data are gathered to a central node (it's called "sink") every other second. The sink is connected a server computer with RS-232C. The server computer must be installed a "TinyOS" previously, which is an open-source operating system designed for wireless sensor networks.

Figure 1. Laser Range Scanner

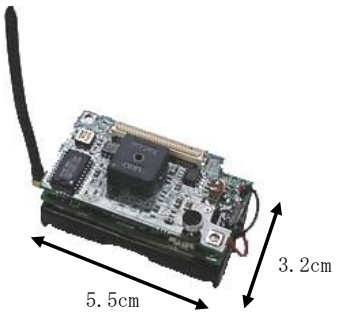

Figure 2. Sensor Network Device

2.2 System Architecture

In this research, a number of laser range scanners are set on floor for horizontal scanning at a height of about 20cm above the ground. Accordingly, cross sectional data at the same horizontal level are obtained, which containing both moving objects (e.g. pedestrians' legs) and static objects (e.g. walls, poles, desks, chairs and so on) in a rectangular coordinate system of real dimension. Locations of the laser range scanners are elaborately planned in order to cover a wide area, while occlusions and crossing problem could be solved to some extent. To integrate the coordinate system from each sensor's coordinate system to global (common) one, they should be having some overlapping area. Each laser range scanner is controlled by a client computer. All client computers are connected to a server computer using LAN. It's used UDP/IP protocol in order to prioritize a communication speed. Thereby, the range measurements derived from the all laser range scanners are gathered to server computer.

In addition, to measure a temperature distribution, a lot of sensor network devices are distributed in the target area avoiding crowding the positions. In order to overlap laser point data and temperature data, the sensor network devices should be placed at obvious positions for laser range scanners such as a pillar, edge of wall, immediate position of laser range scanner. Alternatively they should be surveyed the positions. A sink node is connected a server computer with RS-232C.

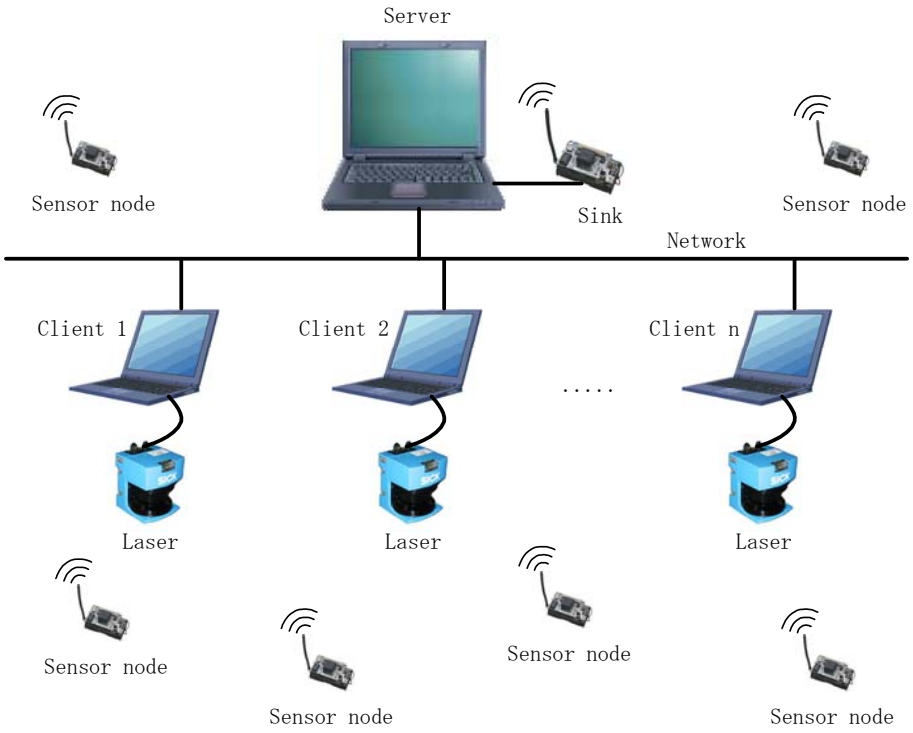

Figure 3. System Architecture

2.3 Detection of Pedestrians

2.3.1 Background Subtraction

Obtained range data contain both moving objects and static object (i.e. background), so that we generate a background image and extract only moving objects. A background image is generated when a certain level of range data are stocked (e.g. 512 frames). In each sampling angle of range scanning, a histogram is generated using the range values from stocked range frames. A maximum value above a certain threshold (e.g. 5% of the number of stocked frames) is found out from the histogram, which tells that the peak value is continuously measured at the identical range distance, or the static objects. By calculating it at all sampling angles, the background image is made up. If the difference between newly measured range value and background image's value is larger than a given threshold (e.g. 30cm), the new range value is extracted as a moving object. Whenever a new range frame is recorded, background image subtraction is conducted.

2.3.2 Clustering

We use multiple laser range scanners in order to cover a relatively large area, and reduce occlusions as well. Integration between the sensor's local coordinate system is conducted by Hermart transformation that deals with a horizontal shift and rotation because of horizontal scanning. Specifying one sensor's local coordinate system as the global one, range data from each laser range scanner is transformed to the global coordinate system (Fig. 4). Transformation parameters are calculated by matching the laser points of common objects such as walls or poles by manual operation.

In the subtracted and integrated laser points, some points hit pedestrians' feet because the laser range scanners are set at a height of about 20cm above the ground. Therefore, close-by points, which have a radius less than a normal foot (e.g. 15cm), are clustered. We assume a number of points gathering within 15cm distance as a leg, so that the center point of which is treated as their foot coordinate. Consequently, neighboring two detected clusters or feet (e.g. within 30cm) are treated as one person.

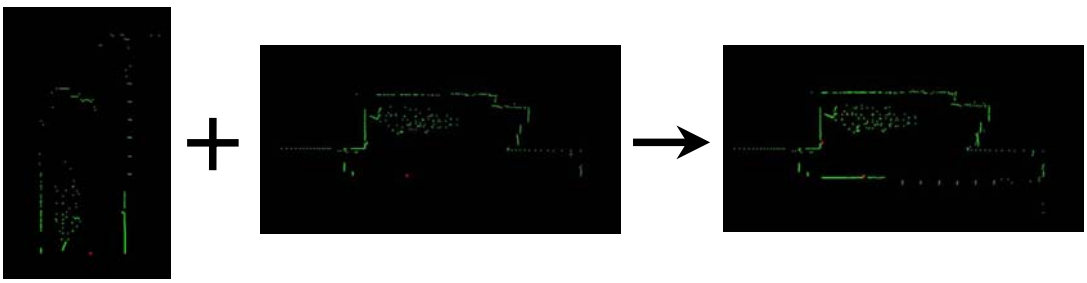

Figure 4. Integration of Background Images to Global Coordinate System

2.4 Data Fusion

Next, we fuse two types of data between the observed laser points and temperature data from sensor network devices. The background images obtained by laser range scanners can be treated as a floor map of the measurement area because they include only static objects such as walls, poles, chairs. Using this map, positions of the sensor network devices are arranged on the map compared with real dimension.

Furthermore, a spatial interpolation of the temperature data collected from each sensor network device is conducted. As interpolation method, IDW (Inverse Distance Weighted) method is employed as shown in Eq. (1,2). IDW is one of the most commonly techniques used for spatial interpolation of scatter points. The method is based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. The interpolating surface is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases. An estimated value at certain point is calculated as follows.

$$\hat{z} = \sum_{i=1}^{n} w_i z_i \tag{1}$$

$$w_i = \frac{d_i^{-r}}{\sum_{j=1}^{n} d_j^{-r}} \tag{2}$$

Where, $\hat{z}$ is an estimated value at certain point, n is the number of measurements, w_i corresponds to the weighting factor, z_i consists each measurement value, d_i consists a distance between the estimating position and measurement position and r is a real plus number (ordinarily 2.0). For actual time-series measurement, w_i is calculated at every grid interval (e.g. 1m), and derived only first one because the positions of sensors are constant. Therefore, IDW is relatively fast interpolation method.

On the other hand, temporal integration at each data is unnecessary in real time measurement because the newest data are always processed. However, for post-process, the computers' internal clock should be calibrate in advance, and each client computer must record the time when obtains each data. After measurement, each data can be integrated by finding the nearest record time of a server's common time, so that the experimented situation is duplicated at any time.

2.5 Detection of Positions Where to Fan

Here, we define a spot-ventilation machine has functions such as swinging the nozzle, controlling the wind force and wind temperature. As described in previous section, temperature values at pedestrians' positions derived from range data can be estimated. If a density of population is relatively high and the temperature at that position is unsatisfactory, the area should be fan. An angle of nozzle is determined from a relative angle between the insufficient position and ventilation machine's position. A wind force is determined from the distance of the two positions as well. A wind temperature depends on the difference of temperature between the unsatisfactory temperature value at the pedestrian's position and a reference temperature value (e.g. 26.0 degree Celsius in summer or 22.0 in winter). Applying this system, we can aim at real-timely monitoring of temperature and pedestrians' positions, and cutting down on waste of energy used in air-conditioning system when a target area is empty or the temperature is sufficient.

3. Experimental Result

We conducted an experiment at a small hall on the front of our laboratory, which has a dimension of 6m by 15m (Fig. 5, 6). Some windows are aligned as shown in the under part of figure 5 and the right part of figure 6. Two laser range scanners (LMS1, LMS2) and ten sensor network devices (1-10) are arranged as shown in figure 5. Three computers are exploited in the experiment, where two control laser range scanners, and one works as the server computer. The computers are connected using 10/100 Base LAN. Background images are generated previously by each client computer. The mages are used in order to obtain a floor map in the measurement area integrating each sensor's coordinate system to a global one, and extract only moving objects that are recorded in each scanning. The experiment is conducted at noon and evening in summer.

Figure 7 and 8 show the fused image of laser points and temperature distribution. Whitish color corresponds to relatively warmer area, and blackish color corresponds to relatively coldish area. Two clusters as shown in figure 8 show pedestrian's legs. In these images, we can understand the under part of these figures are relatively warm, because the windows reside, and the sensors are exposed to the sunlight. In addition, figure 7 was captured when an air-conditioner had been turned off. On the other hand, figure 8 shows a situation after the air-conditioner was turned on. Although we cannot operate an actual spot-ventilation system, we confirmed that the proposed system performs in real time and is efficient for an energy saving of air-conditioning.

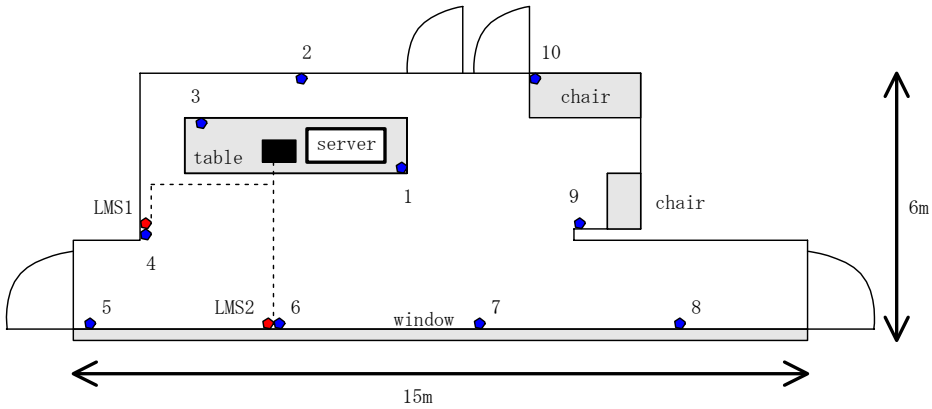

Figure 5. Layout of Laser Range Scanners and Sensor Network Devices

Figure 6. Experimental Site

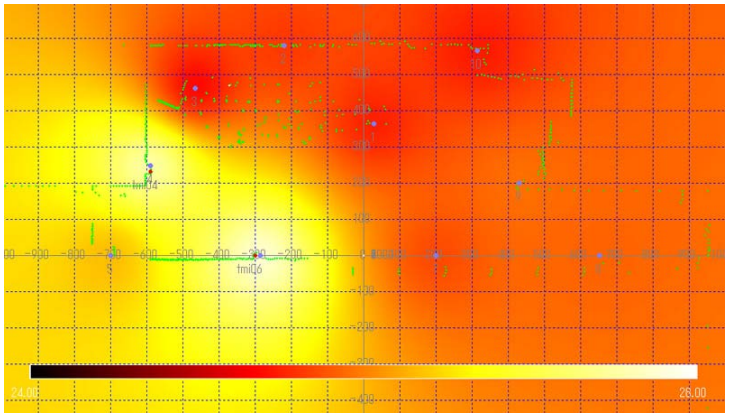

Figure 7. Integrated image (Before Air-conditioner Turns on)

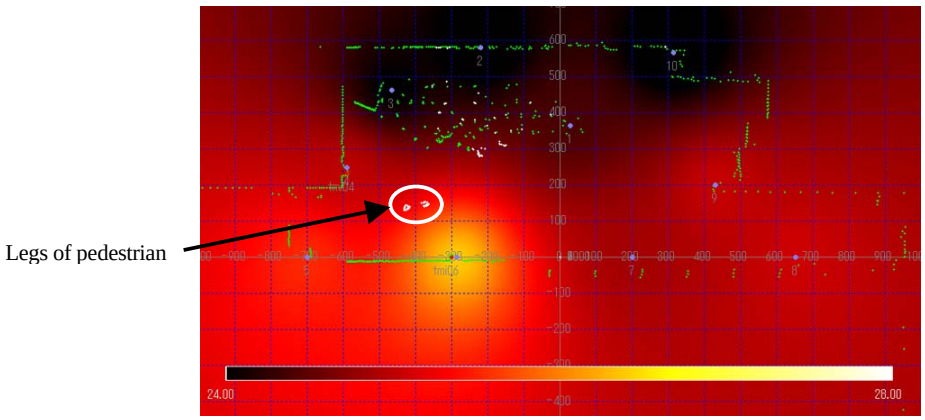

Figure 8. Integrated Image (After Air-conditioner Turns on)

4. Conclusion

In this research, an energy saving system for air-conditioning control by using multiple laser range scanners and sensor network technology is proposed. As a result of an experiment, we found the proposed system performs in real time and is efficient for an energy saving system of air-conditioning. Using multiple laser range scanners is very effective in terms of detection of pedestrians in relatively wide area, because it's simple to calibrate multiple laser range scanners and integrate the distributed data to one global coordinate system. In addition, background image is also used as a floor map in the measurement area. More specifically, it's available for alignment of sensor network devices to global coordinate system in server computer. By linking up the proposed system with a spot-ventilation machine, it will be possible to reduce some energy waste according to send a wind to where pedestrians are close up and that position's temperature is insufficient.

In future works, a function of tracking pedestrians will be added, and the trajectories will be used to determine more effective angle of nozzle and wind force, for example, a wind may be able to send against the direction of walking. Furthermore, the proposed system will be linked up with an actual spot-ventilation machine, and verified how the system make a difference for energy saving without spoiling comfort.

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