CROWDS FLOW DETECTION AND INDOOR TEMPERATURE MONITORING FOR ADVANCED AIR-CONDITIONING CONTROL

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ABSTRACT: In this paper, we propose a novel air-conditioning system that will be effective for wide public space such as a concourse of railway station, exhibition hall or museum. In these spaces, conventional air-conditioners are not enough, since the air-conditioner sends a wind to also empty area and where the temperature is already sufficient. Generally, it is difficult to ventilate effectively to the extensive coverage. On the other hand, our proposed system monitors people-flow and temperature distribution simultaneously, so that the system detects an optimum location to send a cool/warm wind, i.e. where the population density is relatively high and the temperature is insufficient. In order to track a number of pedestrians, we exploit multiple laser range scanners, since they are not only independent from lighting condition, but also can measure a range data directly with wider coverage. Additionally, we attempt to extract a crowds-flow or stream of confluences within lots of trajectories. This approach has seldom researched. While, by using wireless sensor network technology, a temperature distribution in the target space is calculated with IDW spatial interpolation. Finally, by integrating these two types of information, crowds-flows and temperature distribution, the proposed system detects a position where should be fan, and then, it controls the nozzle's orientation on the real-time basis. The availability is tested by conducting an experiment at railway station in Japan. By applying the proposed system, a ventilator can aim at more persons for longer period to fan each person than conventional air-conditioning system.

1. INTRODUCTION

Recently, novel air conditioning systems that control a wind temperature and the nozzle's direction depending on the room temperature have been developed (it's called "spot-ventilation"). Conventional air conditioning systems may be effective for relatively small space (e.g. home-use). In a wide public space, however, such as railway station, airports, exhibition hall, it's difficult to ventilate effectively, since almost people do not keep them location, also the population density or crowds flow changes continuously. Therefore, if the air conditioner can control the fan direction dynamically adapting on the situation, i.e., only where and when

population density is relatively high and temperature is insufficient, it must be more effective system as a kind of context-aware service. In this paper, we propose a novel air-conditioning system by combining two types of sensing technology, people tracking system using laser range scanners and monitoring temperature distribution using wireless sensor networks. By integrating the results of people tracking and temperature monitoring, we automatically detect the optimum location to ventilate effectively. Conventional researches that deal with tracking pedestrians are mainly exploited a CCD or stereo camera (T. Zhao, *et al*., 2004). However, video-based approaches have some limitations, such as narrow viewing angle, occlusions with each pedestrians, and affection by lighting condition. On the contrary, laser range scanner has advantages in terms of relatively wide viewing angle, direct range measurement and almost independence from lighting condition. Additionally, by scanning at the height of pedestrians' feet, multiple pedestrians are detected with low occlusion. In conventional reports, it had demonstrated that approximately 120 persons are tracked simultaneously using 8 laser scanners with over 80% accuracy by conducting an experiment at a railway station in Japan (H. Zhao, *et al*., 2005). Also, a personal privacy or "right of portrait" can be relatively secured rather than taking a picture by CCD. Additionally, we attempt to extract a principal crowds-flow or tendency of confluences based on lots of individual trajectories as the upper layer information of trajectories. So far, this approach has seldom researched. On the other hand, using lots of networked temperature sensors, which are elaborately placed in the target area, temperature distribution is calculated with IDW interpolation method, and overlaid onto the laser coordinate system. Finally, the proposed air-conditioning system determines where cool/warm wind is necessary rather than any places, which direction of fan nozzle is optimum, or how much intensity or temperature of the wind should be sent.

2. METHODOLOGY

2.1 Outline of Sensors

2.1.1 Laser Range Scanner: In order to detect multiple pedestrians' positions, single-row type laser range scanner (briefly called "laser sensor" in the followings), LMS200, by SICK corp. is exploited (Figure 1(a)). It measures a time of flight of a laser pulse reflected from surrounding objects, and calculates the distance. It scans horizontal plane of 180 degrees by rotating an inner mirror. The laser sensor has high angle resolution (0.5 degree) and scanning rate (37.5Hz). It uses an eye-safe beam (safety class 1) with 905nm wavelength.
In order to cover a wider area and mitigate occlusions, multiple laser sensors are set on a floor at the height of 20cm to aim at pedestrians' feet. Accordingly, obtained cross sectional data coincide with same horizontal level. Each laser sensor is controlled by a client computer that is connected to a server using LAN. The obtained range data are gathered to the server through the network real-timely.

2.1.2 Wireless Sensor Network: In order to monitor a temperature distribution, wireless sensor network, MOTE^{TM}/MICA2, produced by Crossbow Technology Inc. is employed (Figure 1(b)). This sensor network device (briefly called "MOTE" in the followings) organizes wireless ad-hoc network autonomously, while the packets are relayed from node to node. Therefore, the network

is robust against disconnection. MOTE measures an atmospheric temperature at that site by a temperature sensor embedded on the MOTE. The obtained temperature data are gathered to the base station, and then, they are imported to a server computer at every second. Actually, a number of MOTEs are placed in the target area at the height of 160-180cm (the height of person's face). In order to overlap MOTE positions to laser coordinate system, MOTEs should be placed at "obvious" positions for laser coordinate system, e.g. pole or edge of walls, moreover, those positions should be dispersed, since a temperature distribution is calculated.

(a) LMS200 (b) MOTE

Figure 1 Dimensions of laser range scanner(a) and sensor network device(b)

2.2 People Tracking

2.2.1 Background Subtraction: The obtained laser data contains both moving objects (e.g. pedestrians' legs) and static objects (e.g. walls, poles, desks). When a certain level of frames are stored (e.g. 512 frames), a histogram of the range value at each sampling angle is created. Since a mode value in the histogram can be regarded as static objects, the mode value is registered as a background object at that sampling angle. By iterating this process for all sampling angle, a background image is generated. In order to extract only moving objects, range data near from background value (e.g. within 30cm) are subtracted.

2.2.2 Calibration: In order to integrate each laser sensor's coordinate system to common one, Helmert transformation is conducted, which deals with a shift and rotation. The integration is achieved by overlapping common features in the each background image by manual operation.

2.2.3 Tracking: Multiple pedestrians are tracked by conducting spatio-temporal clustering. Firstly, based on a certain laser point of moving objects, the nearby points are searched (e.g. 15cm thresh.). Similarly, based on the searched point, same process is iterated until nearby points are not found. Moreover, in a previous frame, nearby points are searched as well. If clustered points are found in a previous frame, previous cluster's ID is inherited to the current cluster, else not, new cluster ID is allocated to the new cluster. By extending same cluster's centroid from previous frames, the time-series of people positions, i.e. trajectory, are obtained.

2.3 Crowds Flow Detection

Based on the lots of trajectories obtained by tracking process, we extract several information such as crowds flow's places, orientation, degree of broadening, traffic volume, and density of

trajectories. Since crowds flow changes at every moment, it is necessary to adjust the time interval flexibly from now to some previous frames (e.g. a minute, an hour or a day). In order to detect main streams of people flow, we calculate a traffic volume at each direction of trajectories' vectors. At first, the measurement area is divided to grid by equal width. At the certain grid cell, a histogram of the angle of trajectory vector that passed on that cell is calculated (this histogram is called as "angle histogram" in the followings). The angle histogram composes a 3-dimensional (x, y, angle) structure. The angle histogram is updated when trajectories passes on the cell. The mode of the angle histogram can be regarded as the principal direction of crowds flow at that site, moreover, the histogram value corresponds to the traffic volume. By calculating the angle histogram at all grid cells, crowd flows are extracted. However, the obtained shape of the histogram depends on the grid width (both spatial and angle width). Therefore, we apply a kernel density estimation to calculate the angle histogram to be independent from the grid width. As the kernel function, 3-dimensional (x, y, angle) Gaussian kernel is adopted. The center of kernel is the node of trajectory, which has (x, y, angle) coordinate. Besides, the kernel size is determined empirically.

On the other hand, in order to adjust a time interval (from now to some previous frames) to calculate an angle histogram, we apply the leaky bucket algorithm. For example, if we need to assess the trajectories in the past 10 seconds, an additional value should be 10, and the angle histogram is subtracted 1 value at every seconds. Therefore, the histogram value will be zero after 10 seconds, so that we can adjust the time interval by controlling the additional value or subtracting value. This calculation cost is very low, since it is not need to memorize past trajectories. Accordingly, if pedestrians pass at same position and same orientation, the angle histogram value is higher than other places.

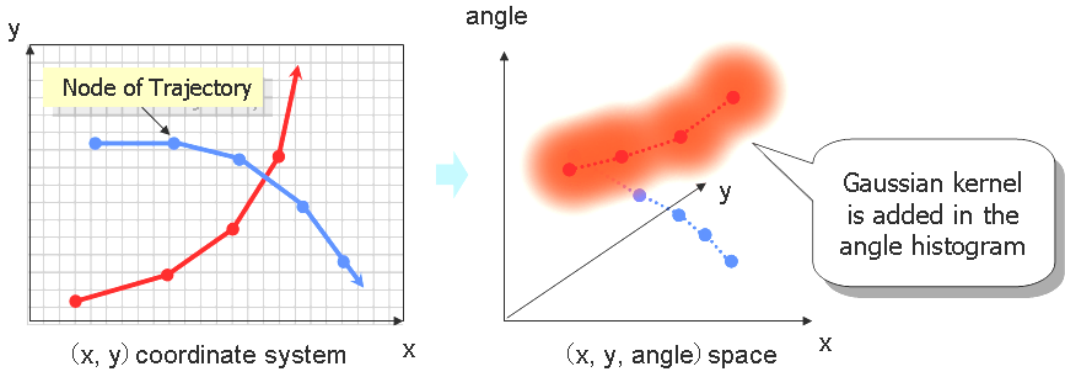

Figure 2　Calculation of the angle histogram by 3-dimensional Gaussian kernel

2.4 Monitoring Temperature Distribution

Temperature data obtained by each MOTE are gathered to a server computer through wireless network at every second. Each MOTE's spatial location on a laser coordinate system is determined by comparing the real positions of MOTEs with laser background image manually. Temperature distribution is calculated with IDW (Inverse Distance Weighted) interpolation method. By overlaying the calculated temperature distribution onto the laser coordinate system, we obtain an estimated temperature value at each pedestrian's site.

2.5 Detection of Optimum Location for Ventilation

At final step, by integrating two types of information of crowd-flow and temperature distribution, we detect an optimum location to send a cool/warm wind for effective ventilation. Here, we define an index that indicates a degree of demand for ventilating, which is calculated at every nozzle's angle. The optimum angle of the fan nozzle corresponds to the angle that maximizes an index of demand for ventilating. The demand index is calculated as follows.

1) An angle histogram discussed above is calculated with the obtained trajectories of last 10 seconds interval from now.
2) Estimated temperature values are calculated at all cells of angle histogram included in a triangular ventilating area (Figure X) that is determined by nozzle's angle, and absolute difference value between the estimated temperature and target one (e.g. 26.0 deg C in summer or 22.0 deg C in winter) is calculated.
3) The value calculated above process is weighted by the angle histogram value (i.e. traffic volume) at each site.
4) The summation of the weighted value included in a ventilating area calculated above process is defined as a demand index at the nozzle's angle.

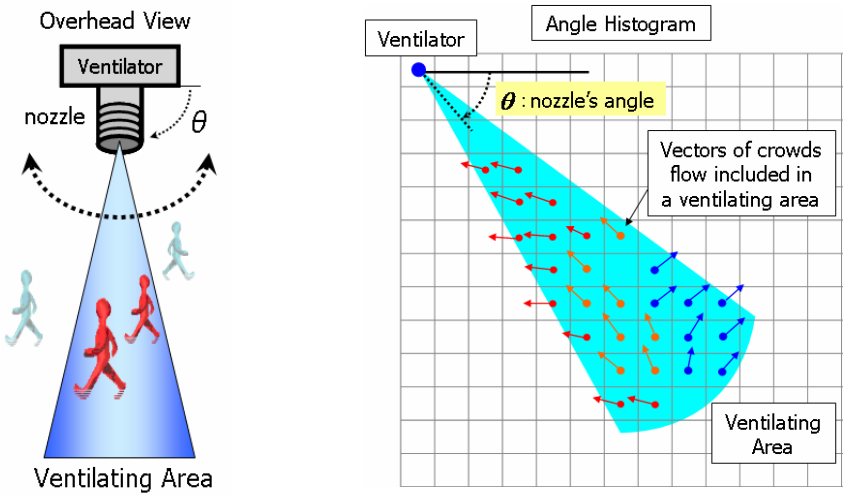

Figure 3 A ventilating area defined by the nozzle's angle and calculation of an index that indicates a degree of demand for ventilating

3. EXPERIMENTAL RESULTS

An experiment was conducted at railway station in Japan, which has a dimension of 60m by 30m. In this experiment, 8 laser sensors and 12 MOTEs are arranged. As tracking result, about 180 persons are detected simultaneously on the real-time basis (Figure 5). The result of crowds-flow detection is shown in Figure 6. The overlapped image of temperature distribution and tracking result is shown in Figure 7. We evaluate the availability of the proposed system by calculating how many persons are received the air-conditioning wind, and the average ventilating time for each person. In case of applying proposed system, the number of persons

who received a fan-wind is 709 persons within 10 minutes, whereas 554 persons are received by conventional systems (it has a static nozzle). The average ventilating time for each person is 3.01 second in case of proposed system, against 2.89 second by conventional systems.

Figure 4 A photo of the experimental site

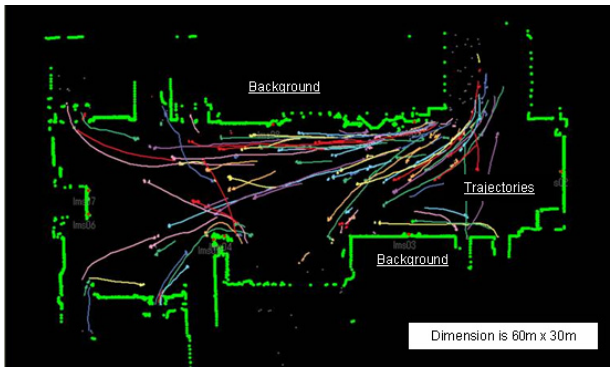

Figure 5 Tracking results

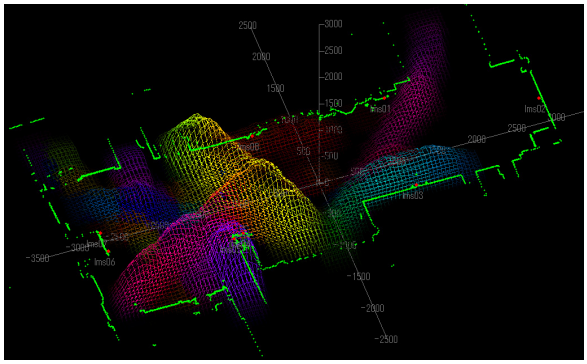

Figure 6 A result of crowds-flow detection as 3-dimensional image (z-axis corresponds to the traffic volume)

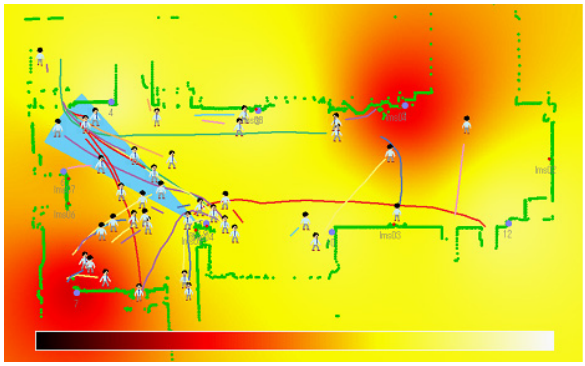

Figure 7 A screen copy of the system that displays a temperature distribution, tracking results and ventilating area

4. CONCLUSION

In this paper, an adaptive air-conditioning system is proposed, which monitors crowds-flow by using laser sensors and temperature distribution by using sensor networks. The availability is evaluated by conducting an experiment at a concourse of railway station. As a result, the proposed air-conditioning system is capable that more persons will be ventilated for longer periods than conventional air-conditioning. In future works, we will consider a convection of the wind from a ventilator more strictly. A combination of multiple ventilators will be arguable.

References

[1] T. Zhao, R. Nevatia, 2004. "Tracking multiple humans in complex situations", IEEE Trans. Pattern Anal. Mach. Intell., vol.26, no.9, pp.1208-1221.

[2] H. Zhao, R. Shibasaki, 2005. “A real-time system for monitoring pedestrians”, Proceedings of IEEE Workshop on Applications of Computer Vision (WACV), CD-ROM.

[3] W.E.L. Grimson, C. Stauffer, R. Romano, L. Lee, 1998. “Using Adaptive Tracking to Classify and Monitor Activities in a Site”, cvpr98, pp.22.