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Monitoring a populated environment using single-row laser range scanners from a mobile platform

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***Abstract*— In this research, we proposed a system of detecting and monitoring pedestrians' motion trajectories at a populated and wide environment, such as exhibition hall, supermarket etc., using the horizontally profiling single-row laser range scanners on a mobile platform. A simplified walking model is defined to track the rhythmic swing feet at the ground level. Pedestrians are recognized by detecting the braided styles, which is a typical appearance that could discriminate the data of moving feet with other mobile and motionless objects. Two experiments are conducted. One is at the laboratory environment, the purpose of which is to examine the algorithm in details. Another is at an exhibition hall, a populated and wide environment, the purpose is to examine whether the system could be applied for practical needs. It is a big challenge, while the system did well. Pedestrians in the exhibition hall at the moment of measurement are detected. Their motion trajectories are extracted, and associated to the background map, which is made of the motionless objects, and covers the whole exhibition hall.**

I. INTRODUCTION

Analyzing or monitoring human activities, such as counting the number of passengers, measuring their trajectories, speeds, directions, or distributions, is considered very useful in various fields, such as security, planning and management assistant in shopping malls, railway stations, exhibition halls, public event sites, and so on. A system of tracking a large crowd of pedestrians using a network of single-row laser range scanners was developed in our previous research (Zhao and Shibasaki, 2005), the performance was evaluated through many experiments in the concourse of railway stations (Nakamura et al., 2006). An always met question is, how to locate the limited number of sensors, while efficiently cover a large area, such as the whole concourse of a large railway station. A conclusion finally came out that, if we do not increase the number of sensors, we have to let some of them patrol at the concourse. A static sensor can monitor a specific area continually, while leaving blind spots all the time. A mobile sensor can seamlessly cover a large area, while the measurement at each location is a sampling at a certain time interval. It is a balance between cost and accuracy. For the area of less importance, sensing from a patrolling platform should be a pratical way in many applications. Detecting and tracking pedestrians at a large and populated environment using mobile laser range scanners is the goal of this research. In the rest of this chapter, we first give a review to the existing researches, then briefly outline our methods.

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A. Literature Review

1) Visual-based methods:: So far, video camera has been used as the major device to sense the environments, and motion analysis from video data are widely studied to collect such a data. A good survey for visual-based surveillance can be found in Gavrila,1999. Followings are several examples that targeting at tracking a relatively large crowd in a large area. Regazzoni and Tesei, 1996 described a video-based system for people counting over time and detecting overcrowded situations in underground railway stations. Schofield et al., 1997 developed a lift aiding system by counting the number of passengers waiting at each floor. Uchida et al., 2000 tracked pedestrians on street. Sacchi et al., 2001 proposed a monitoring application, where crowd flow in an outdoor tourist site is counted from video image. Pai et al., 2004 proposed a system of detecting and tracking pedestrians on crossroad to prevent traffic accidents. Heikkila and Silven, 2004 developed a real-time system for monitoring cyclists and pedestrians. Davis and Keck, 2005 detected person from thermal image. Yan and Forsyth, 2005 studied people behavior in public space through video tracking. In order to cover larger areas, Kang, et al. 2005 and Stauffer, 2005 presented works of tracking through the regions of a number of cameras. Video-based methods suffer mainly on two problems: occlusion and sudden illumination change. If the region of a number of objects clung together, it is always difficult to discriminate them individually based only on intensity or color values. In order to reduce occlusion to achieve a better tracking to a large crowd, cameras' setting conditions are always highly restricted, e.g. they are always required to be set on high position so that the objects on ground could be monitored with less occlusion; while they could not be too far or too near to the ground so that moving objects on image are large enough for tracking and the whole targeting area could be covered. Still, the always change of illumination and weather condition is another major obstacle to the reliability and robustness of visual-based system.

2) Range-based methods:: In addition to video camera, laser range scanner is a new sensor technology, which profiles surroundings using eye-safe laser (class 1A, near-infrared spectrum), directly measure range distances to target objects according to e.g. time-of-flight at each controlled beam direction. Especially as the development of single-row laser range scanner, that profiles at a certain plane with high scanning rate, wide viewing angle and long-range distance, laser range scanner is getting more and more popular for the task of detecting and tracking moving objects, mapping and localization.

In each scan of single-row laser range scanner (simply called ”laser scanner” in the followings), a cross section of the surrounding objects at the scanning plane is directly sampled as a sequence of range values at each angle interval, which can be easily converted into a rectangular coordinate system of real dimension. Suppose they are the measurements to motionless objects, as long as the laser scanner profiles at the same plane, sensor’s motion can be estimated by matching the stream of laser scans (localization), meanwhile, a 2D map at the scanning plane can be obtained by integrating the laser scans to a global coordinate system (mapping). This is always called SLAM (Simultaneous Localization and Mapping). The concept was first proposed by Leonard and Durrant-Whyte, 1991. The power has been perfectly demonstrated after the appearance of single-row laser range scanner.

In addition to mapping and localization, single-row laser range scanner is well accepted as an effective sensor in detecting obstacles, tracking moving objects in order to prevent collision or follow people. Applications can be found in Streller et al., 2002, where a laser scanner is set on a car to monitor surrounding vehicles; in Prassler et al., 1999, where a laser scanner is set on a wheel-chair to help handicapped person traveling through a crowded environment without collision; in Topp and Christensen, 2005, where a laser scanner is set on a service robot to follow a specific person.

There are still few research efforts in monitoring the moving objects in an environment using mobile sensors. In order to detect and track moving objects from the data of a mobile sensor, one and almost the most important thing is to discriminate the data between moving and motionless objects. Montemerlo, et al. 2002 and Schulz, et al. 2003 assumed that the environment is fixed without any change, so that the data of moving objects can be subtracted out by comparing with a previously generated map. While, in a populated environment, it is always a dangerous thing to assume that the environment is fixed. For example, chairs and other small/light objects can be easily moved. If do not assume a previously generated map, Wang and Thorp, 2002 proposed a method of summarizing previously extracted stationary objects and moving objects into maps, SO-Map and MO-Map, and characterizing a newly appeared object by comparing with the maps. Still, the problem is if an object appear at an undeveloped area, it might be difficult to say exactly at the moment whether it is a moving or stationary object, and whether the data is a partial or total measurement to the object. A classification process for the newly appeared object is required.

Through the above research efforts, efficiency of laser scanner serving as the major sensor in moving objects’ detection and tracking, mapping and localization has been demonstrated. Whereas, comparing with visual-based methods, it has also limitations and disadvantages that has to be figured out to make it more powerful. As has been addressed in previous section, laser scanner directly measures object geometry as a sequence of laser points, which are sampled every angular interval within a scanning range. For an object far from sensor’s location, the laser points sampled of the object will become sparse, so that 1) it might be confusing in clustering process whether the laser points belong to the same object or not, 2) estimation to the object’s state parameters, such as location, speed, size, shape and so on, might be fluctuated, especially when the sensor’s location and orientation changes. On the other hand, as laser scanner samples object geometry only, it is always difficult to discriminate the objects that have similar geometry at the scanning plane. For example, in the case of a horizontal scanning at an elevation of 1.0m above the ground, a tree, a telegram pole, a person and a cart might looks quite similar in a laser scan of limited resolution and accuracy. A spatial-temporal processing of the data is required to discriminate the objects.

B. Outline of the Method

One of the basic difference that could discriminate a people from other objects is, people moves in a non-rigid body. In this research, we pay special attention to people’s moving feet for the following reasons: 1) no matter a child, an adult or an eld people, as well as it is a normally walking people, its feet can be catched by a horizontally scanning laser scanner at the ground level, and their rhythmic swing can be modelled in a uniform pattern. 2) continuous occlusion caused by moving feet is much less than the other level of a body.

In this research, we propose a method of detecting and tracking pedestrians at a large and populated environment using mobile single-row laser range scanners. Laser scanners profile at a ground level, catching the data of rhythmic moving feet. A simplified model is defined to track the rhythmic swing feet at the ground level. Pedestrians are recognized by detecting the braided styles, which is a typical appearance that could discriminate the data of moving feet with other mobile objects, and motionless objects. In the followings, we will first have a look at the data of pedestrian’s walking feet and define a simplified walking model for pedestrians’ detection and tracking. The algorithm for monitoring a populated environment, i.e. measuring pedestrians motion trajectories and associate them with a certain map using mobile laser scan data is addressed in Chapter 3. Two experiments are addressed subsequently. One is conducted at laboratory environment. The purpose of which is to examine the algorithm in details. Another is conducted at an exhibition hall, a populated and wide environment. The purpose is to examine whether the system could be applied for practical needs. Conclusion and future studies are addressed finally.

II. PEDESTRIAN’S WALKING MODEL

When a normal pedestrian steps forward, one of the typical appearances is, at any moment, one foot swings by pivoting on the other one. Two feet interchange their duty by landing and moving shifts at a rhythmic pattern. If we let a scanner profile at ground level, as the left or right foot swings from

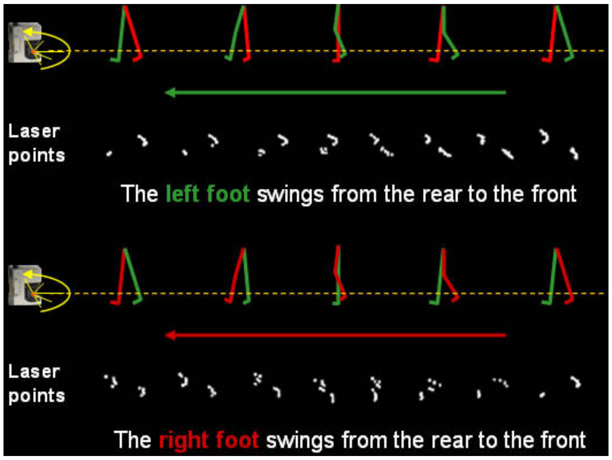

Fig. 1. Laser scanning of walking feet

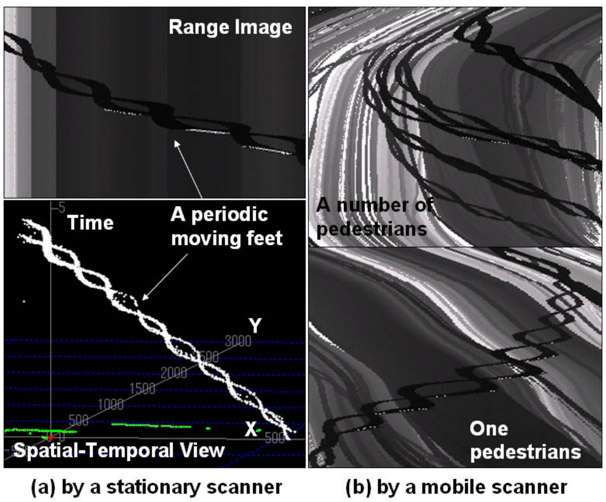

Fig. 2. The briaded style of walking feet

the rear to the front, the moving feet are captured by a sequence of laser scans as shown in Figure 1. From the range image of either a stationary sensor or a mobile one, we can see in Figure 2 that the braided style of periodic moving feet are clearly captured. This is an essential difference that could discriminate a pedestrian from other motionless and mobile objects.

In this research, we use a simplified walking model that was defined in our previous research (Zhao and Shibasaki, 2005) to estimate the feet parameters. Here we model feet movement at the plane on ground level. So that points and vectors in the following definitions are restricted to a two-dimensional coordinate system, which will be addressed in the next section.

As shown in Figure 3, we divide a walking cycle into four phases, modeling the status change by using a loop of eight Markov modes, i.e. $M0 \rightarrow M7$. Let v_L and v_R, a_L and a_R denotes the speed and accelection of the left and right foot respectively. All of them are scalar values associated to the normal vector of walking direction V_{dir}. Let p_L and

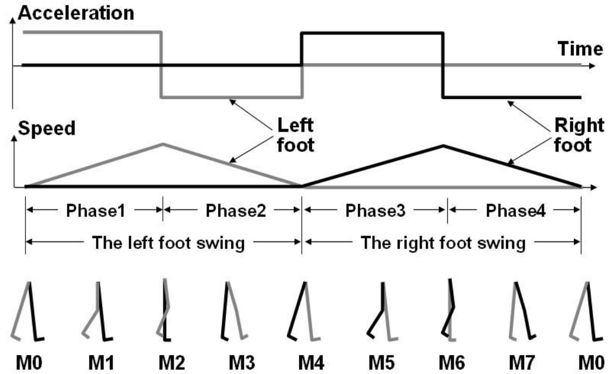

Fig. 3. An example of the simplified walking model

	M0	M1	M2	M3	M4	M5	M6	M7	M0
a_L	Turn Point	A →	Turn Point	-A →	Turn Point	0	0	0	0
a_R	0	0	0	0	Turn Point	A →	Turn Point	-A →	Turn Point
v_L	0	↗	V	↘	0	0	0	0	0
v_L	0	0	0	0	0	↗	V	↘	0
d_{LR}	S	↘	0	↗	S	↘	0	↗	S

Fig. 4. Typical parameter change during a walking cycle

p_R denotes the position of left and right foot, d_{LR} denotes the distance between them. Here V_{dir} represents the motion direction of the center point of p_L and p_R. In order to make the story clear, we define "initial position" to the situation where swinging foot and standing foot cross, i.e. the M2 and M6, "standing position" to that where both feet stand on the ground, i.e. the M0 and M4.

In the turn that left foot swings, it starts from standing position $M0$, where both feet stand on the ground with $v_L = v_R = 0$. At the begining half of swing (phase 1), the left foot shifts from the rear to the initial position at an acceleration $a_R > 0$, which comes from muscle strength for walking movement. During this period, the speed of left foot v_L is accelerated from 0 to its maximum, while the distance between two feet d_{LR} is reduced from its maximum, i.e. stride size, to 0. During the rest half of swing (phase 2), the left foot shifts from the initial position to the front at a deceleration $a_R < 0$, which comes from the forces, such as those to keep the moving body in balance. During this period, the speed of left foot v_R is decelerated from its maximum to 0, while the distance between two feet d_{LR} is enlarged from 0 to its maximum. During the period of left foot swings, the right foot serves as a pivote, standing on the ground. So that $v_R \approx 0$, $a_R \approx 0$, and $v_L > v_R$. In the same way, we can deduce the status when right foot swings forward by pivoting on left foot.

In this research, we simplify the problem by assuming that the absolute value (A) of acceleration and deceleration on either of the swing feet are equal. They are kept constant during the period of each phase. Also we assume that the swing period (T) of both feet are equal. So that the maximal speed of swing foot and the maximal distance between two feet, i.e. stride size, are calculated as $V = A * T$ and $S = 0.5 * A * T^2$ respectively. In summarizing the definitions, we have the following parameters to address the current status of the pedestrian. $\theta_1 = \{S, T, A, V_{dir}\}$ are the parameters that do not change in the middle of each swing phase. $\theta_2 = \{v_R, v_L, p_R, p_L\}$ are the parameters that change at each frame.

The status change of the parameters in θ_1 during a walking cycle is summarized in Figure 4. From the figure, it is clear that at the initial position, d_{LR} reaches its minimum, i.e. ≈ 0, while at the standing position, d_{LR} reaches it maximum, i.e. $\approx S$. By detecting the picks and valleies on the sequence of d_{LR}, swing phase are located. Meanwhile, stride size S can be assigned by the d_{LR} at the pick, while phase period T is the time interval between a subsequent valley and pick. So that the absolute value of acceleration and deceleration is assigned by $A = 2*S*T^{-2}$. In this research, the parameters S, T, A are initialized and updated whenever the start and the end of a swing phase is detected. As for V_{dir}, it is updated when a pair of subsequent valleies are located. If valleies could not be reliably detected for a long period, it is assigned to the motion direction of the center point of p_L and p_R during the last few frames.

On the other hand, the parameters in θ_2 are predicted and updated during the tracking process whenever a new laser scan is measured. The predicting and updating processes are summarized as follows.

Algorithm *Prediction of θ_2 at frame k*
Input $\theta_{2,k-1} = \{v_{R,k-1}, v_{L,k-1}, p_{R,k-1}, p_{L,k-1}\}$
Output *Predicted* $\theta^-_{2,k} = \{v^-_{R,k}, v^-_{L,k}, p^-_{R,k}, p^-_{L,k}\}$

1: *Locate the swing foot as the one that has larger v*
2: *if $v_L > v_R$, # the swing foot is the left one*
 a) *Locate the rear foot by comparing p_R and p_L with V_{dir}*
 b) *If the rear foot is the left one*
  # the left foot is moving at an accelerated speed
  # and the right foot is kept still
  i) *Let* $v^-_{L,k} = v_{L,k-1} + A * \delta t$
  ii) *Let* $p^-_{L,k} = p_{L,k-1} + 0.5 * (v_{L,k-1} + v^-_{L,k}) * \delta t * V_{dir}$
  iii) *Let* $v^-_{R,k} = v_{R,k-1}$
  iv) *Let* $p^-_{R,k} = p_{R,k-1}$
 c) *else*
  # the right foot is moving at an accelerated speed
  # and the left foot is kept still
  i) *Let* $v^-_{L,k} = v_{L,k-1} - A * \delta t$
  ii) *Let* $p^-_{L,k} = p_{L,k-1} + 0.5 * (v_{L,k-1} + v^-_{L,k}) * \delta t * V_{dir}$
  iii) *Let* $v^-_{R,k} = v_{R,k-1}$
  iv) *Let* $p^-_{R,k} = p_{R,k-1}$
3: *else if $v_R > v_L$, # the swing foot is the right one*
 ...

Algorithm *Update of θ_2 at frame k*
Input $\theta_{2,k-1}$ *and* $\theta^-_{2,k}$
Input *A measurement to feet positions* $\{p'_{R,k}, p'_{L,k}\}$
Output *Updated* $\theta_2 = \{v_{\hat{R},k}, v_{\hat{L},k}, p_{\hat{R},k}, p_{\hat{L},k}\}$

1: *Let* $p_{\hat{L},k} = p'_{L,k}$
2: *Let* $p_{\hat{R},k} = p'_{R,k}$
3: *If the left foot is swing*
 a) *Let* $v_{\hat{L},k} = 2 * (p_{L,k} - p_{L,k-1}) \cdot V_{dir}/\delta t - v_{L,k-1}$
 b) *Let* $v_{\hat{R},k} = v_{R,k-1}$
4: *else*
 a) *Let* $v_{\hat{R},k} = 2 * (p_{R,k} - p_{R,k-1}) \cdot V_{dir}/\delta t - v_{R,k-1}$
 b) *Let* $v_{\hat{L},k} = v_{L,k-1}$

III. DETECTING AND TRACKING PEDESTRIANS

Now let's discuss the algorithm for monitoring a populated environment, i.e. measuring pedestrians motion trajectories and associate them with a certain map, using the data from mobile laser scanners. In order to detect and track moving objects from the data of a mobile sensor, one and almost the most important thing is to discriminate the data between moving and motionless objects.

If we use a stationary sensor to monitor the environment, this problem can be easily solved, as at each controlled beam angle, if the laser beam is not contantly blocked by any mobile objects, the laser scanner should be able to get the same range return at most of the scan from the nearest motionless object at the direction. So that a map of the motionless objects (called "background map") can be generated by looking for the most often happened range returns at each beam angle. Subquently, the data of mobile objects can be subtracted out, if the range value is in between of the sensor and a motionless object that is suggested by a previously generated background map.

The problem got complicated if the sensor is a moving one. We need to do two things: 1) locate the sensor's position and orientation at the moment of each laser scan, so that all data measurement can be processed at a global coordinate system; 2) update the background image as the sensor exploiting unknown area. The problem of simultaneous localization and mapping (SLAM) has been widely studied in existing researches, as has been addressed in literature review. In this research, we do not focus on SLAM. It is conducted to serve for pedestrians' detection and tracking at the coordinate system of a simultaneously generated background image.

Figure 5 summarize the processing flow whenever a new laser scan (frame) is measured. Three databases are maintained. The background map is a grid image, which is made of the data of motionless objects. It suggest to an unobstructed view from the sensor's locations to the nearest motionless objects. At the begining of measurement, the sensor is required to keep static for a few minutes, so that an initial background map can be generated in the way as that for a stationary sensor. The background map is a growing one as the sensor moves and exploit new areas. If an object is detected that do not belong to any registered objects or background map, it is add to the database as a newly developed seed. At the process of each frame, a classification is conducted for each registered seed. If a seed is recognized as a motionless object, it is removed from seed database, while the data will be reflected to the background map. If a seed is recognized as a kind of moving object, more specifically, a pedestrian in this research, it is moved from

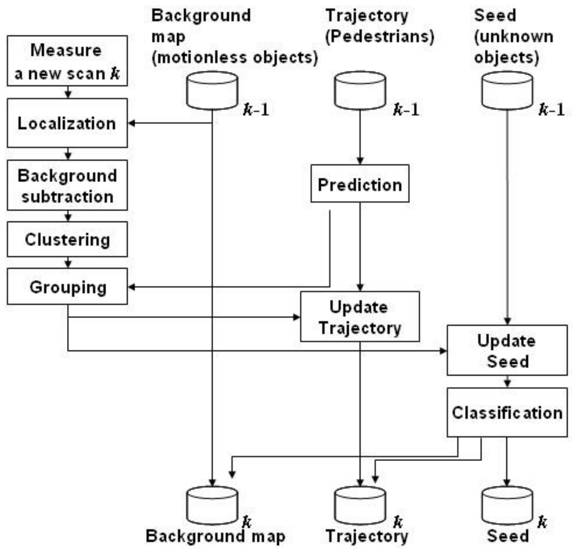

Fig. 5. Flow of the process

the seed database to trajectory database. If it is difficult to tell the characteristics of the seed at the moment, it will remain at the database to wait for further observation data. So that the basic difference of three databases is, background map contains the data of motionless objects, trajectory database is composed of the moving objects that have been recognized as (a) certain class(es), seeds are those waiting for classification.

Whenever a new laser scan is measured, it is matched with the background map to locate the sensor's position and orientation at the moment. As our focus is not the SLAM in this paper, we leave the process "localization" as a black box, but make its input and output clear here. After backgroud subtraction, the laser points that do not belong to the background map are extracted and segmented into clusters according to the range values' continuity. The next step is called "grouping". The purpose of the process is to group the clusters that might belong to the same objects. In this research, the function is more specific: 1) looking for the clusters that suggest to feet candidates, e.g. small clusters with a radius less than 30cm; 2) for the registered pedestrians, predicting their feet positions at the current frame, looking for their matches from the feet candidates and making them as a group; 3) for the rest of feet candidates, pairwise those that has a distance within a normal step size; 4) for the rest clusters of either large size or isolated ones, groups that contains one cluster are generated. In this research, the extracted "groups" are treated as the new measurements to either moving objects or the motionless objects that has not been registered at the background map. Recognition of pedestrian is conducted by detecting the braided style of feet data. More specifically, we calculate d_{LR} as the distance between the two clusters in the same group. We examine the sequence of d_{LR}s of the seed to find whether it appears as periodic wave from a certain minimum (≈ 0) to a certain maximum (with in the size of a normal stride).

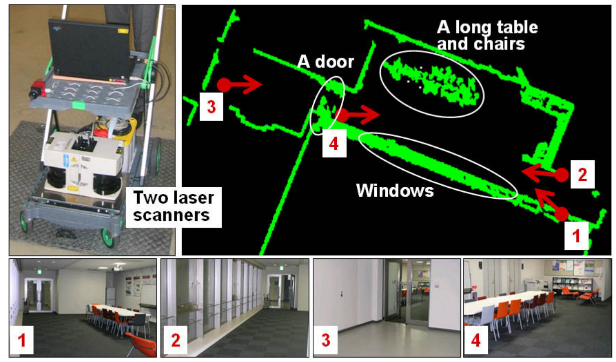

Fig. 6. The measurement system and the experimental site at laboratory environment

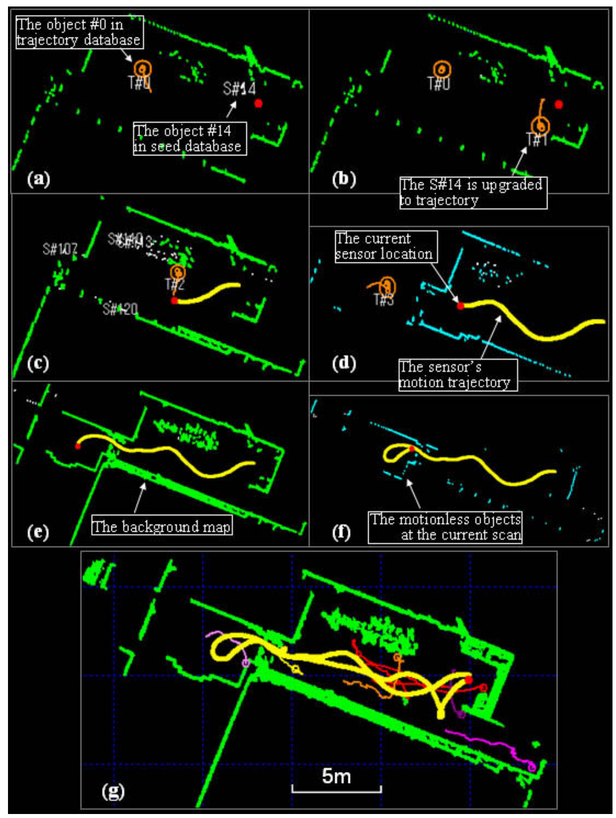

Fig. 7. Experimental results at laboratory environment

Fig. 8. Pictures of the exhibation hall

Fig. 9. Experimental results at the exhibition hall: background map, sensor's motion trajectory, and all detected pedestrian trajectories

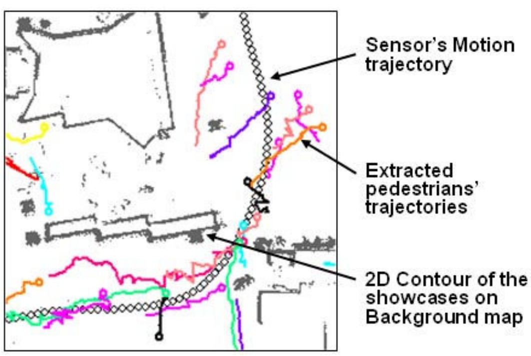

Fig. 10. Enlarged figure of the area A

IV. EXPERIMENTAL RESULTS

Here we present two experimental results. The first is conducted at the laboratory environment. The purpose is to look at the algorithm in detail through experimental results. The second is conducted at an exhibition hall with an area of 100m*150m, and near 30,000 visitors came during the three exhibition days. A picture of the measurement system is shown in Figure 6, where two single-row laser range scanners, SICK LMS291, are fixed on a cart, profiling at an elevation about 16cm above the ground. Here are some of the specification of a LMS291. When scanning within a range of 180^o at a resolution of 0.5^o, a scanning rate of about 37.5Hz is reached. In each scan, 361 range values are equally sampled on the scanning plane, with a maximum range distance of 80m, and range error of $4 \sim 10cm$. We let two LMS291 sit back to back on the cart, so that a wider view ($\approx 270^o$) could be covered. In experiments, pedestrians' tracking is conducted in an offline mode, while the computation cost is near realtime. This will be presented later with other results. In the experiments, we did not use other motion sensors, such as GPS, IMU, wheel encoder etc. Location and orientation of the cart is estimated by matching the laser scan data with background map, as addressed in previous section.

A. Experiment 1

The experimental site at laboratory environment is shown in Figure 6. It covers a student lodge and an elevator hall. The area of the experimental site is not wide, people are not crowded. While it has special difficulties: 1) There is a long table and many chairs, which cause occlusions, split the measurement to the backward wall into pieces, and create confusions with feet; 2) There is a door in between of the lodge and elevator hall, which heavily blocks the vision field of laser scanners, makes the matching of laser scans with background map sensitive to the disturbance from mobile objects; 3) The bottom of the window is a flat frame at almost the same level with sensors' scaning plane, so that range returns are much unstable over there. Data are processed in the flow of Figure 5. The whole processing is screen captured (see the attached AVI). A number of the scenes are picked up in Figure 7. Now let's discuss them in detail. At the begining sensors start measurement, the cart (the red dot) stopped at the lodge for a few minutes. As there are not a lot of moving objects in surroundings, the first 100 laser scans are used to initialize the background map (the green dots of (a)). The detected objects are denoted by ”T” or ”S”, representing for the database they are registered, as well as their ID. At the moment of (a), there are two pedestrians walking in around. One is recognized as a pedestrian, i.e. T#0, while another, i.e. S#14, is still a seed as it has just appear to the sensors. After a few frames' observation, in (b), S#14 is successfully recognized as a pedestrian, so that upgraded to a new trajectory T#1. When the cart starts moving, in (c), many objects are measured at the newly exploiting area. They are registered as seeds at the first appearance. In order to make the results clear, we do not show all the seeds but only those last for more than three frames. So that the seeds that do not make confusion in classification are not shown here, as they are upgraded to background map directly. The cart's motion trajectory is shown in bold yellow line, the cart's current position is denoted by a red dot. In (d) and (f), the water-blue dots represents the current measurement to the motionless objects. It can be seen that when the cart go throught the door, sensor's vision fields are heavily narrowed, measurement to the objects on the other side of the door are limited. Successfully locate the sensor's position and orientation is an ordeal when cart go through the door. It did well in this experiments as shown in (e) and (g). All detected pedestrians during the measurement are shown in (g). Their trajectories are colored to reflect different IDs. The circular marks denote the final positions they are observed. The computation cost is counted during this experiment. It takes about 200 milliseconds in processing each frame at a notepad of IBM ThinkPad T42. It tells that for a low sampling rate, e.g. 5Hz, realtime processing is possible. If integrated with motion sensors, such as IMU, GPS, wheel encoder and so on, or previously developed map, the process for localization might be speeded up. This will be addressed in future study.

B. Experiment 2

Pictures of the exhibitional hall is shown in Figure 8. Needs come from both managers and desigers of the exhibation: how many visiters are there at a certain moment, how do they distribute at the hall, from which direction do they come to the booth, how to evacuate them in the case of emergency, and so on. The needs can be summarized to: measure pedestrians motion trajectories at a wide area and associate them with a certain map. The process do not need to be done in a realtime mode. For example, 10 min. processing after data recording is allowable, according to an exhibation manager. We tried to answer the questions by using our system. The cart is pushed walking all over the major passages of the exhibition hall. Figure 9 shows the background map in gray, the cart's trajectory points in black circles, and the pedestrians motion trajectories in colored lines with circular marks at the end. The area "A" is enlarged at Figure 10 for a clear view of the result. The background map contains the data of all motionless objects that are observed. If a people kept motionless during the period they are measured, they will be recognized as a motionless object, and their data will be reflected to the background map. Discriminating those motionless people is going to be addressed in our future research.

V. CONCLUSIONS AND FUTURE WORKS

In this research, we proposed a system of detecting and monitoring pedestrians' motion trajectories at a populated and wide environment, such as exhibition hall, supermarket etc., using the horizontally profiling single-row laser range scanners on a mobile platform. A simplified walking model is defined to track the rhythmic swing feet at the ground level. Pedestrians are recognized by detecting the braided styles, which is a typical appearance that could discriminate the data of moving feet with other mobile and motionless objects. Two experiments are conducted. One is at the laboratory environment, the purpose of which is to examine the algorithm in details. Another is at an exhibition hall, a populated and wide environment, the purpose is to examine whether the system could be applied for practical use. It is a big challenge, while the system did well. Pedestrians in the exhibition hall at the moment of measurement are detected. Their motion trajectories are extracted, and associated to the background map, which is made of the motionless objects, and covers the whole exhibition hall.

As has been addressed previously, the motionless people are not able to be discriminated in current method. Also, in a populated environment, there are the mobile objects, such as baby car, shopping cart, suitcase, etc., which are not being recognized at the current framework. In future research, methods is going to be developed to solve the above problems. In addition, motion sensors as well as a previously generated map is going to be introduced to speed up the process in localization and reduce error accumulation.

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