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Minimal information sensor system for indoor tracking of several persons

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***Abstract*—In this paper, we introduce an on-going experimentation in our laboratory for indoor tracking of several persons with a minimal set of informations, based on photoelectric beam barrier sensors. Incremental design, data analysis and acceptance concerns are discussed.**

I. INTRODUCTION

Population ageing becomes an important problem in our societies as it incurs both financial and social costs. Although human care and interaction for the frail and the elderly cannot be replaced by technological approaches and tools, at least for ethical reasons, these approaches may bring some relief to medical staffs and families. General objective of our laboratory is to bring technological services for the care of frail and elderly persons. A long-term focus is the design of continuous indoor monitoring devices for answering questions related to gait and activity analysis as expressed by medical staff.

In addition to the relief brought to medical staff, continuous monitoring brings several advantages compared to classical monitoring during medical examination: Continuous monitoring may help early detection of changes in the gait of a person that may show physical or mental alteration; It may also prevent the "examination" effect where a patient may be prone not to adopt his/her usual gait during the examination.

Our scenarii are residential care or nursing home where several persons, potentially belonging to several groups (staff, residents) can evolve. Hence the first step toward our objectives is to be able to track each person and determine to which group he/she belongs. We need therefore to localize him/her whenever necessary and to retrieve his/her daily trajectory.

Tracking persons with the aim to have statistical measures or indicators on gait does not require, in general, high precision or high reliability. From a medical point of view, qualitative results and evolution trends on physical activity are sufficient. Collecting information and data on daily activities may collide with feeling of privacy, which may yield a strict refusal of adopting such kind of technologies [1]. There is a tradeoff between collected data, needs as expressed by medical staff and privacy. Namely, this drove us not to use camera nor wearable devices, as low acceptability has been reported.

To reach our goal, a monitoring system has to be designed by paying careful attention to the geometry of the site under consideration as well as the use of residents. We promote an incremental design of the system. A first coarse system is designed and installed on the basis of the building geometry and then it is refined based on the analysis of the first collected datasets.

To summarize our objective is to design multi person/group indoor localization and tracking systems strictly fitted to answer identified monitoring objectives of medical staffs. They have to be flexible in order to adapt to evolving needs of medical staffs, easily installed, sufficiently robust, and of reasonable cost.

Related Work

Sensors for healthcare have been used since years ago. In [2] a survey on wireless sensor networks with application to healthcare have been dressed till 2010. Many works have been carried out on Smart Homes as well, where sensors are central, another interesting and thorough survey on this subject was done by Chan et al. in 2008 [3]. In 2013 Barath and Anithapriya present a brief survey on health care for aged people based on sensor network [4]. Health care with sensor detection for elder person is precisely our target application.

Authors of [5] demonstrate a proof-of-principle that night-time falls detection might be achieved using a low complexity and completely unobtrusive wireless sensor network in the home. Recently, researchers make a survey to know the interest of people on senior fall prevention. Eighty-one percent (over 1900 respondents) "expressed an interest in sensor technology that can anticipate and prevent falls" [6]. Our idea follows this proof-of principle, while trying to identify more than falls, but even a change on behaviour, and not only one person but multiple people.

In [7] authors used PIR sensors to count people in a office building in order to save energy. For tracking many people entering or exit the offices they installed PIR sensors on both sides of each office door. This system is useful to detect empty rooms. Our model differs from this system because we are interested in residents tracking and counting persons in each room.

In [8] an empirical study of human movement detection and identification using a set of PIR sensors is presented. The authors use an experimental design close to ours, but they uses three PIR-based modules: one module on the ceiling and two modules on opposite walls facing each other. Their results based on machine learning algorithms for classification analysis are encouraging for us. They could achieve more than 92% accuracy in classifying the direction and speed of movement, the distance interval and identifying subjects.

We describe in this paper an ongoing experiment conducted in our laboratory and a few preliminary results obtained. A similar experiment involving more persons split in distinct groups is also under development in an EHPAD (retirement home).

Our paper is organized as follows: in section II we describe our experimental platform. Section III outlines our first results and IV presents our first conclusions and our perspectives.

II. EXPERIMENT DESCRIPTION

The primary goal of our experimental platform is to determine the minimal set of data to acquire to localize multiple persons moving in our indoor environment. In a first version, a network of infra-red barriers is installed taking roughly into account the topology of the environment. Then, we will refine the hardware configuration according to our data analysis results. Such an iterative approach allows us to take into account, beside the topology of the environment itself, the use of the residents in terms of locations and trajectories. A zone intensively used will need more sensors and we want our incremental design to exhibit and quantify this need.

A. Experiment Area

The sensor network has been installed to completely monitor a part of our lab, the first floor of the KAHN building of the INRIA Research Centre Sophia-Antipolis Méditerranée. The experimental location (Fig. 1) consists of a hallway, offices, facilities and common spaces. This topology is more or less similar to a typical floor configuration of a retirement home which consists of a hallway, rooms and shared areas such as reading hall or dining room.

Fig. 1. The Experiment location

Localization of persons can be defined in terms of precise location (2-D or 3-D coordinates), position on a trajectory (one coordinates), or appartenance to a geometric zone (discrete information). For our purpose of monitoring the third one is sufficient. We divided the experiment area into seven zones and hence equipped with 8 infra-red barrier sensors discriminating the offices area and the common spaces, as depicted in Fig. 2. In this figure, the bold red lines refer to infrared barriers delimiting a zone. It is our choice not to have any barrier at the entries of the offices, as it has been reported as an intrusive set-up by our medical partner.

During the data records of this experiment, our staff was composed of 8 persons. The group is homogeneous in terms of gait ability. Occasional visitors have also been present during that period.

Another experimentation will take place in the retirement home of Valrose in Nice (France), where the monitoring area consists of a corridor with 6 rooms, 4 staff offices, an external stairs and an elevator. Six residents, their relatives and a tenth of staff members are subject to be in this area as well as visitors. The different groups (staff, residents, visitors) are not homogeneous in terms of gait ability. Therefore, the interest will be focused on residents tracking characterized by a slow gait speed, or the use of rollator or a wheel chair.

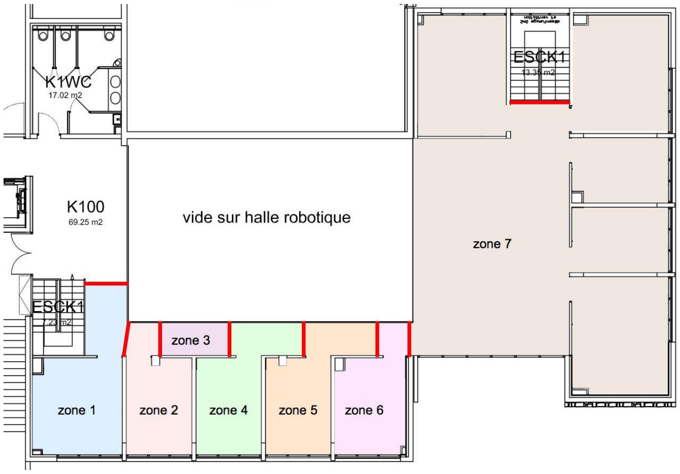

Fig. 2. The zoning area

B. Hardware configuration

Hardware configuration of our initial experimental platform is quite simple and inexpensive. It consists of commercially available ready-to-use photoelectric beam detectors - an infra-red light transmitter and a photoelectric receiver, Fig. 3 - interfaced with a Phidget micro-controller card, Fig. 4.

Photoelectric beam detectors provide an accurate information and offer a long sensing range ensuring a reliable data, quite robust to inaccuracy of alignment during installation. On the other hand, these devices do not provide the direction of motion of a people crossing the beam, and they suffer a 1 second latency, that prevents us to detect when several people are crossing or moving very closely.

Fig. 3. Photoelectric beam detector

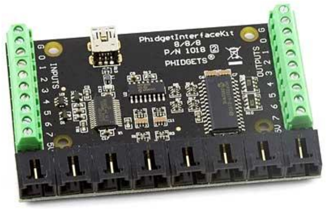

Fig. 4. The Phidget microcontroller kit

The Phidget microcontroller provides us a synchronized and timestamped sequence of event data from the inputs connected to the sensors. It is connected to a tiny fanless PC under Linux, which is programmed using shell scripts and C-code in order to store the occurence time of event data and the ID of the given sensors triggered into a data files.

These data files follow a very basic XML dialect specification recording a rough description of the hardware configuration and the sequence of events.

III. ONGOING EXPERIMENT IN OUR LAB AND FIRST RESULTS

The system described above is on use in the lab since mid-January 2016. Between January 14th and April 29th, 166 data files have been stored, one for day-time, one for night-time each day. Histograms on Fig. 5 displayed the number of files for a given range of sensor events.

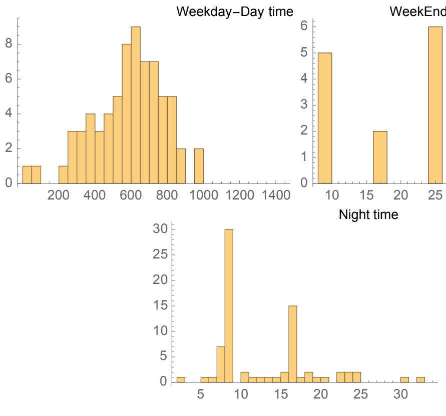

Fig. 5. Numbers of sensor events

As already noticed our sensor system constitutes the first step toward a full system. The aim of this first analysis is to get insight of the quality of results we can obtain from this coarse installation and to explore directions to follows for improving our system.

We analyzed the data with two perspectives: In the first one the objective is to study the occupancy of each zone. In the second one the aim is to trace each person and to reconstruct her/his trajectory.

In the first perspective the main difficulty ensues from the fact that our sensors do not give information on the direction of the barrier crossing. In the second perspective, the challenge is the multi-person context, because an ambiguity arises whenever more than one person are in the same zone.

A. *Occupancy analysis*

We implemented a simple finite automata. Each sensor event triggers the change of occupation of the adjacent zones. Results are given in terms of occupancy configuration, we provide the minimal number of person and the maximal number of person per zone compatible with the list of events. The difference between this maximum and this minimum is interpreted as the accuracy of the method.

For some cases, the algorithm detected inconsistencies in the sequence of events. An analyze of these inconsistencies allowed us to identify and find a workaround for two types of inconsistencies. The first one is related with the initial condition of the system. Each day, the data recording starts at some time were the building is supposed to be empty, it is our initial condition. Nevertheless, for some cases this assumption turns out to not to be true. We modified our algorithm in order to set up automatically a new initial condition compatible with the few first sensor events of the sequence.

The second inconsistency is related with a latency of the sensor. Our sensors have a one second latency after it triggers. During this latency they are unable to detect a new event. It may hence result inconsistent sequence of events if a person brushes past a barrier : only one sensor event is detected instead of two. The algorithm has been modified accordingly.

1) Night and weekend experiment: As expected the system worked fine for the night and weekend data, provided that we control the global number of people in the system - this may be an *a priori* information or may comes from additional information from extreme sensors, as discussed further. Fig. 6 show the ratio of experiments producing a given uncertainty in terms of number of possible occupancy configuration.

This results mainly covers the case of single occupancy of the building, even in the case where the motion of that person is non standard as is the case of the cleaning person in the morning whom have backwards and forwards motion.

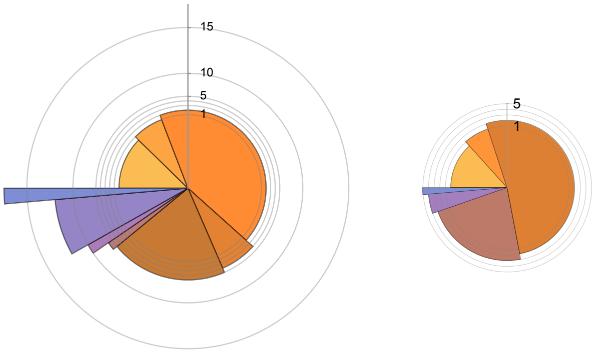

Fig. 6. Uncertainties without and with control of global occupancy

2) Weekday experiment: Our algorithm presents some problems when handling the full week day data. The results show high uncertainty (large range of compatible occupancy per zone). If the sensor between two non empty adjacent zone triggers, there are two compatible possibilities, yielding, in the worst case, a 2^n complexity, n being the number of sensor events. In the experimental case, number of possibilities generally exceed 1000 after less than 150 sensor events.

B. *Trajectories reconstruction*

In this perspective the aim is to trace each person and to be able to reproduce its trajectory (in terms of successive zone occupied by the person). This will enable us to adapt the monitoring individually.

We implemented an algorithm that built the tree of possible states. At each step (i.e. each sensor event time), a list of compatible states with prior sensor event is provided. Each compatible states keep in memory its parent.

Each time one of the entrance sensors triggers a potential new comer is introduced and his/her trajectory initiated. For each sensor event, the algorithm determines the compatible states and remove the incompatible ones. The compatible states at the new step are determined by browsing all the compatible moving of the persons in the monitored area.

The complexity is worst than the complexity of the occupancy problem since we have to consider in addition the identity of the person. Furthermore, we faced memory problems since we have to store all the intermediate compatible states. We manage to handle the night and weekend datasets but we were unable to handle weekday data sets.

IV. CONCLUSION AND PERSPECTIVES

As shown in the previous section, in the current state of the system it is not possible to solve neither the counting problem or the tracking problem.

Several directions can be followed to improve these preliminary results. We split these directions on three types : hardware improvement, use of *a priori* knowledge, software improvement.

A. Hardware improvements

1) Best coverage of the monitoring area: A closer observation of the data shows us that one of the extreme barrier (between zone 1 and zone K100) was too often crossed. Each time this barrier was crossed, provided that zone 1 is not empty, two possibilities had to be considered : either a person initially in zone 1 is leaving the observed area, either a new person is entering in the observed area. Note that this behavior is not observed with the other extreme barriere (between zone 7 and stairs).

The fact that the first extreme barrier is often triggered suggest that the observed area is not sufficiently well defined and bounded. Whenever possible, one has to define the monitored area so as to avoid areas with too much traffic of people.

Our sensor system has to be extended in that direction. This could have been anticipated in that case since zone K100 is often used as a meeting room and is part of a frequent path to go to the lavatories. This raises the question of *a priori* knowledge that we will briefly discuss latter on.

2) Improving the barrier: The barriers we are using undergo two main drawbacks : they cannot detect the direction in which they are crossed, they suffer from a big latency delay (1 second).

We are currently testing a multi-sensor barrier made up of two distance sensors and two PIR sensors, as shown on Figure 7. In addition to detect the passage, this barrier is able to detect the direction. The latency of the sensors used in this composed barrier are smaller. Having both distance sensor and PIR introduces some redundancy that may be useful.

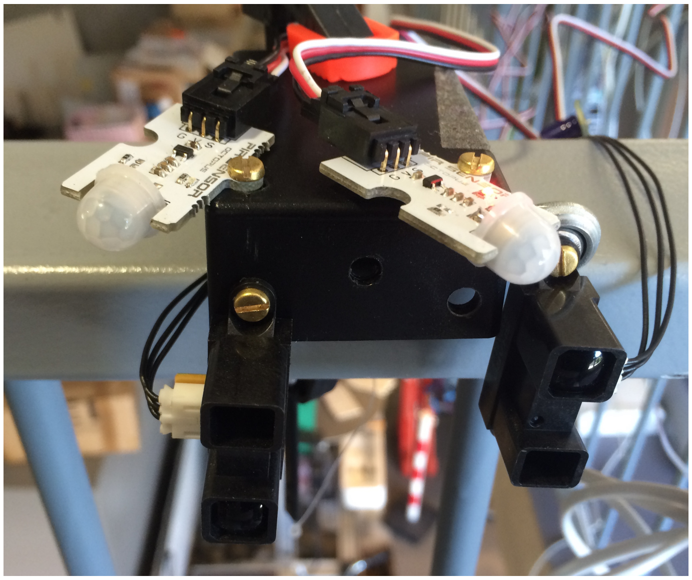

Fig. 7. New multi-sensor barrier

B. Use of a priori knowledge

As mentioned above the use of *a priori* information about the system is useful for the analysis of the data.

A priori information may covers several aspects. We have mentioned earlier the *a priori* knowledge of the use of some area that may give bounds on the number of person that may use that room, and on the identity of these persons.

For the occupancy problem, we have added a constraint on the maximal number of persons into some zone. Zone 1 to 6, excepted zone 3, are made up with a single use office plus a portion of hallway, zone 3 is a short portion of hallway. We introduced in our algorithm the constraint that zone 1 to 6 cannot support more than a certain number of person. This allowed us to run the full weekday datasets.

The drawback of incorporating *a priori* information on the algorithm is that it cannot be easily generalised to other places. A phase of analysis and adaptation of the new place would be needed.

C. Software improvement

For the tracking problem, our algorithm suffers from the combinatorial curse. It is hence essential to strictly contain the number of possible new state after a barrier triggers. In addition to software improvement and consideration of *a priori* knowledge already mentioned, we plan to optimize our software using new coding techniques and more adapted data structures. For example, up to now each person entering or reentering the monitored area is individually taken into account. One way we are exploring is to use group instead of individuals. Whenever there is unsolved ambiguity on several people we do not track them individually but instead the group they form as long as the ambiguity cannot be solved.

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