Localization with Ambient Sensors

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***Abstract*—This paper deals with the design, implementation and evaluation of an indoor tracking system that relies solely on an infrastructure of wirelessly-connected sensors and on architectural, behavioral and contextual knowledge to locate and track a person.**

Such a system can be very useful when users do not want or cannot wear a transmitting device. This situation arises when it would be obtrusive to ask to wear a tag, e.g. in a home-automated apartment inhabited by people of all age that do not require special assistance, or in an elderly-assistive situation when the person is changing clothes, going to bed, taking a bath, etc.

The paper fully describes the techniques used and shows some performance data collected in a laboratory environment with real sensors.

***Index Terms*—situation aware tracking algorithms, context aware applications, localization in wireless sensor networks, heterogeneous sensor fusion, pedestrian navigation and tracking, hybrid technologies.**

I. Introduction

In this paper, we propose an approach to the problem of indoor position estimation that aims at extending tracking to a level of "awareness" bringing to bear ambient data and opening the possibility of "reasoning" not only on simple positioning but also on the situation at hand.

We can divide the space of tracking and location systems in three areas (see Figure 1):

i) systems that only use an infrastructure with no device on the unit being tracked or located;
ii) systems that make use only of hardware on-board of the device being tracked (with the possibility of some help from a remote system located anywhere and reached via a digital radio network);
iii) systems that use both an infrastructure and on-board hardware.

Most of the current commercial location and tracking systems are of the third kind with a rather small and cheap on-board device. Systems with only on board-hardware have been built, however they are either extremely costly and bulky or quite inaccurate; they can be viable as low-cost systems only if augmented with other devices/information, e.g. pictures of the surroundings [1]. Systems of the first kind have been studied extensively starting from the 80's in the context of recognizing the track of an unknown (and possibly unfriendly) object in the outdoors [2] [3] [4].

The system we are presenting is also of the first kind but it is not focused on a large outdoor area or an unfriendly, unknown object. Rather, it relies on a light indoor, radio-connected, infrastructure, one that might have many other useful purposes like temperature control, burglar alarm, etc.

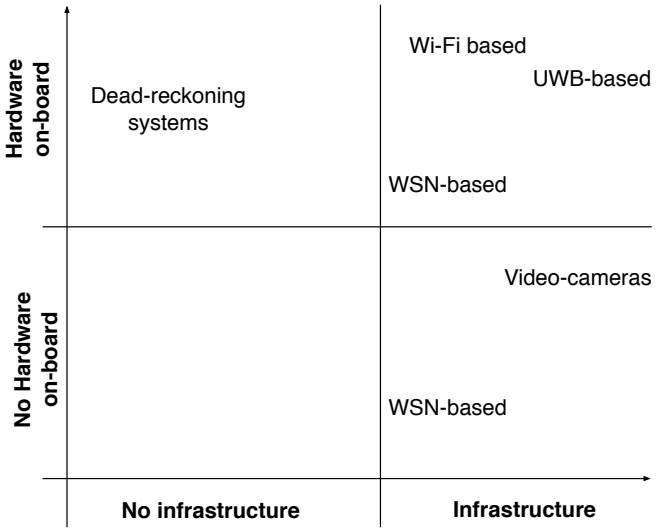

Fig. 1: Localization and Tracking Systems Taxonomy

Moreover, the system relies on knowledge of the architectural layout and of the situations that might arise when people move in their apartment to infer their position. Therefore, we call it a "situation driven" system that supports the lack of device on the moving person with ambient and behavior knowledge.

The remainder of the paper is organized as follows. Section II describes the approach giving an architectural overview. Section III details the components used for its implementation and the preliminary evaluation environment. Finally Section IV draws the conclusions.

II. System Architecture

We tested these ideas in a system called Localization with Ambient Sensors System (LASS). The context model used for this work is described in [5]. The architecture and the main components of the LASS system are shown in Figure 2. Its main components are:

- a localization infrastructure;
- a feature extraction layer;
- a persistence layer;
- a situation assessment layer;
- a presentation layer;

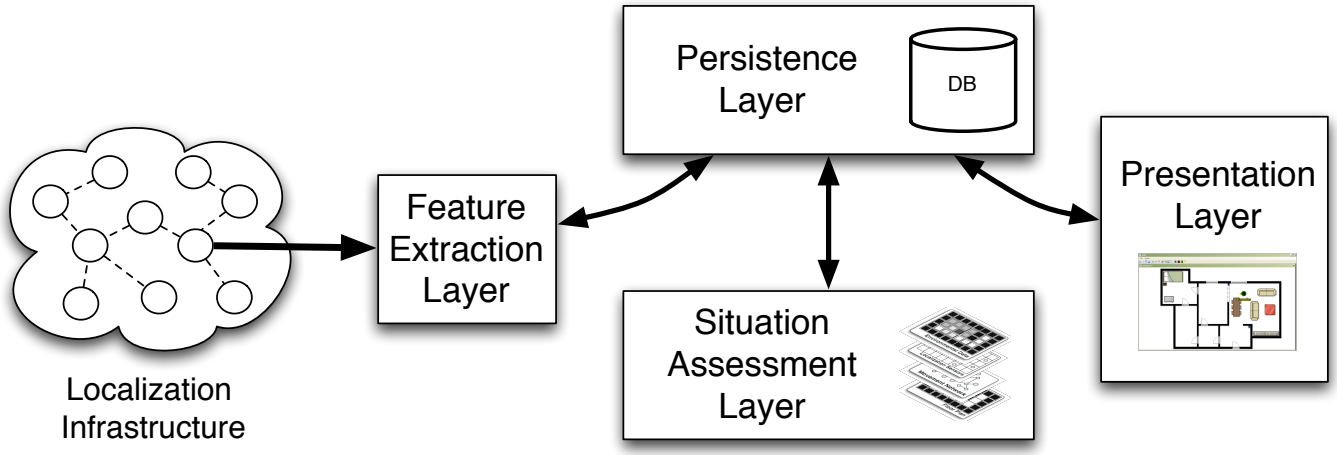

Fig. 2: System Architecture

A. Low-cost, Low-Consumption Localization Infrastructure

The localization infrastructure of LASS is based on a Wireless Sensor Network (WSN) [6].

The sensor nodes are custom-built based on the Jennic JN5148 transceiver. They are typically battery-operated with the exception of a few network coordinators that might need a 5V, telephone-charger type, power supply. Each node has four sensors that measure: temperature, humidity, light and movement. The movement sensor is based on the very common infrared devices (PIR) typically used to automatically open doors. Nodes can be built at very low cost if in large quantities. The nodes are installed in the environment on the walls at a height of 2.5 meters. The PIR is mounted in the node so that it is pointing downwards and covers a cone of about 2 meter radius at pavement level.

Nodes have precise crystal oscillators that are active even when the node is off. In this way the network software can easily schedule the battery operated nodes to turn on at precise times and never interfere with each other (the whole system is based on the MAC protocol IEEE 802.15.4 and would work even without tight synchronization, albeit at the cost of longer transmission times and more current consumption because of medium-access collisions).

The infrastructure is very energy-thrifty because most of the nodes are normally off and turn-on only if the PIR is activated or, periodically with a very low duty cycle, to communicate the value measured by the other sensors. The turn-on time is also very short (~10ms).

The network is organized as a tree hierarchy whose leaves are zones (typically rooms) with many slave nodes and one coordinator. In some cases it is necessary to operate the coordinator with a power supply but this is not strictly necessary. Coordinators report to a single "gateway" node that interfaces the WSN with the rest of the world. This is the only node that has to be always on.

Our network structure and software organization also allow for "roaming" nodes that are useful for applications that are out of the scope of this paper, e.g. monitoring the vital parameters of a patient.

B. Feature Extraction Layer

This layer filters the sensor data to extract features that are less noisy and easier to manipulate than raw data. For example, the PIR on-off signal is translated into:

- crossing of doors,
- arrival or depart from a given area;
- movement in a given area.

The other sensor data are filtered to compute average values and rate-of-change in a given area over a given time (typically one minute).

C. Persistence Layer

This is a standard database layer that saves all the raw data and the results from the situation assessment layer (see later) indexed over time. It makes it possible to show and reason on trends and events over a long span of (past) time. A low-cost disk can currently hold a few years worth of data.

D. Situation Assessment Layer

This layer critically differentiates this system from a simple data collection and storage device. The layer attempts to interpret the sensor data, current and past, in order to compute "situations" that can occur in the monitored environment, e.g. being in bed for a long time, compulsive wandering in the apartment, odd use of light and extreme temperature variations, etc. Moreover, this layer handles all the interpretations of basic movement information in order to yield the time spend in a zone and the likelihood of changing zone.

The information computed by this layer is also fed back to the sensor network in order to optimize its energy consumption by keeping awake only the nodes that are close to where the user is moving.

See Section III for more on this layer.

E. Presentation Layer

This layer can take many shapes and have different capabilities depending on the specific application. In its most complex form it can show on a map of the apartment the current and past behavior of the user by "playing back" in real time or accelerated time the collected data and their interpretation. In its simplest form it can simply output a sequence of strings indicating relevant changes of state, e.g. movement from room to room, time in a room, etc.

III. Implementation and Evaluation

This section details the implementation and the evaluation of the Situation Assessment Layer, the main layer of the LASS system.

As previously hinted, this layer computes two kinds of information:

- movements in a given zone and proximity, e.g. entering and exiting zones:
- situation information that merge position and context, e.g. the user is in bed, the user is in a dark room.

If we only use movement information the layer can only generate a proximity information. If the context model is added [5], LASS can compute information on what might have happened and therefore give a more precise tracking of the user. This layer is driven by a number of rules that infer the occurrence of specific events and movements.

We have implemented this layer with the rule management system Drools [7]. Drools is a business rule management system (BRMS) with a forward-chaining inference-based rules engine, more correctly known as a production rule system, using an enhanced implementation of the Rete [8] algorithm.

The situation-recognition rules we have implemented belong to three categories:

- Rules that use only movement features;
- Rules that use only environmental features;
- Rules that use both kinds of information.

A. Rules that use only movement features

1) Movement: These rules are used to identify the zone or area where the user is. Starting from the last information feature, if no other movement features are triggered the user is labeled as "STILL", otherwise the user is labeled as "MOVING". These rules also compute the zone and area where something is happening. For example, the rule result "STILL, $AREA_1$" shows that the user is standing in the $AREA_1$, moreover the text "MOVING, $AREA_1$, $AREA_2$" identifies a movement from $AREA_1$ to $AREA_2$.

2) Bed Localization: These rules are triggered when the last movement is in an area close to the bed. If no movements are sensed in other areas the user is labeled "IN_BED". This rule can also be supported by a sensor mounted close to the bed that can give positive evidence of the user presence. Similar rules are used to label the user as "NOT_IN_BED, POSSIBLY_IN_BED.

3) Sleeping: If the user is labeled IN_BED for a given time the system infers that the user might be asleep. If a sensor close to the bed is available there is enough information to compute other labels like "SLEEPING", "TOSSING", POSSIBLY_AWAKE or AWAKE.

4) Not_at_Home_Localization: If the last movement registered by the system is the crossing of the entrance door and no other movements are noticed inside the home the user is labeled as "NOT_AT_HOME". Please note that although this situation might sound very simple it still needs a number of rules to cover all the possible cases that might arise, e.g. the user just peeks out of the door and then remains still in an area not covered by a sensor.

B. Rules that use environmental features

1) ActivityInference: The rules implemented in this category are used to infer specific activities in certain areas of the environment. In a home, rules that deal with temperature and humidity in specific rooms, e.g. kitchen and bathroom, can infer certain user activities or the lack of such activities. This, in turn, is a way to validate the location computation.

C. Rules that use both kinds of information

1) Night Wandering: The rules in this category are used to infer the (possibly dangerous) situation caused by the user moving around the home without the necessary ambient light. This is no more simply a localization activity but also a useful monitoring activity that can either send an alarm to a caregiver (in an elderly-support system) or turn the lights on (in a home-automation environment).

2) Forgotten Lights: A symmetrical situation is when lights are unnecessarily left on in rooms where the user is not present. Again, as before, the consequence of recognizing this situation depends on the particular application: elderly monitoring, home-automation or energy-saving. Localization is a necessary component of this reasoning process and, in turn, the situation recognition process validates the localization.

The Evaluation of the LASS system

For the preliminary evaluation of the LASS system we deployed a network of ten data-gathering nodes in two zones (two rooms), as shown in Figure 3. As you can also see in the Figure, every zone contains several areas and every node covers a certain area in the zone. Specific areas have been labeled in a proper way to simulate particular areas (e.g. "Bed Area" or "Cooking Area", etc.) The nodes gather environmental and movement information for the corresponding area.

We made several tests by asking a person to walk freely back and forth between the two zones. In addition to the verification of the system in general, the focus of the tests if to stress the behavior of the LASS system in respect to boundary positions between different areas. The walking test has been repeated several times in different environmental situations (e.g. low ambient light and cold/hot environment).

The preliminary evaluation of the LASS system shows a promising behavior, showing that exploiting movement and

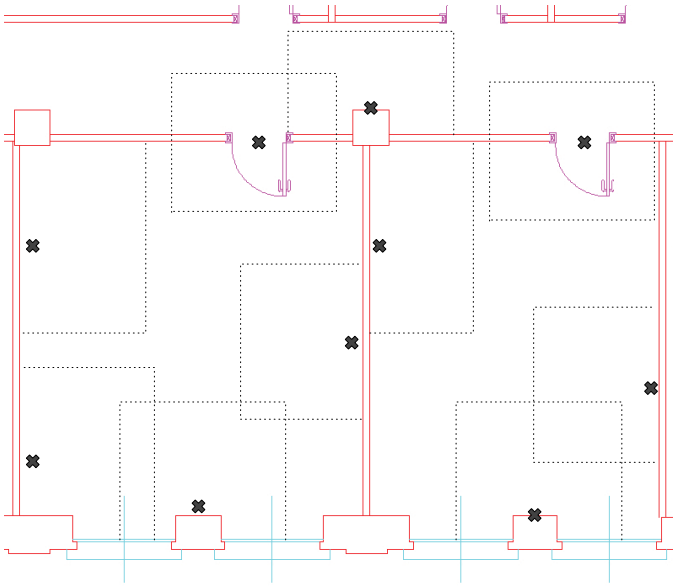

Fig. 3: Preliminary test environment, showing the position of data-gathering nodes and the movement sensors coverage areas.

ambient sensor data can lead to a sufficient precision and accuracy of localization.

A complete description of evaluation results will be given in the full paper.

IV. Conclusions

This paper described an approach to the indoor position estimation problem that is minimally invasive and also potentially inexpensive. The main contribution of the paper is that it goes beyond standard location techniques, e.g. those based on lateration over point-to-point distances) and therefore it can work without any device on the person (or object) being traced.

The main drawback of this approach is that it does not work if more than one person is present. Although we have not yet performed the necessary experiments and updates to the system it is possible, though, that this approach might remain viable if confronted with the behavior of a few people in the confined space of an apartment. Of course the accuracy and precision will be lower but the system might still be useful for applications that are not too concerned with the identity of the people involved.

References

[1] D. Merico and R. Bisiani, "Indoor navigation with minimal infrastructure," in *4th Workshop on Positioning, Navigation and Communication, 2007. WPNC '07*, Hannover, Germany, March 2007, pp. 141–144.

[2] V. R. Lesser and D. D. Corkill, "The distributed vehicle monitoring testbed: a tool for investigating distributed problem solving networks," in *Readings from the AI magazine*, R. Engelmore, Ed. Menlo Park, CA, USA: American Association for Artificial Intelligence, 1988, pp. 69–85.

[3] A. Arora, P. Dutta, S. Bapat, V. Kulathumani, H. Zhang, V. Naik, V. Mittal, H. Cao, M. Gouda, Y. Choi, T. Herman, S. Kulkarni, U. Arumugam, M. Nesterenko, A. Vora, and M. Miyashita, "A line in the sand: A wireless sensor betwork for target detection, classification, and tracking," *Computer Networks (Elsevier)*, vol. 46, pp. 605–634, 2004.

[4] D. Reid, "An algorithm for tracking multiple targets," *IEEE Transactions on Automatic Control*, vol. 24, no. 6, pp. 843–854, dec 1979.

[5] A. Mileo, D. Merico, and R. Bisiani, "Support for context-aware monitoring in home healthcare," *Journal of Ambient Intelligence and Smart Environments*, vol. 2, no. 1, pp. 49–66, 01 2010/01/01/. [Online]. Available: http://dx.doi.org/10.3233/AIS-2010-0052

[6] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," *IEEE Communications Magazine*, vol. 40, no. 8, pp. 102–114, 2002.

[7] P. Browne, *JBoss Drools Business Rules*. Packt Publishing, 2009.

[8] C. L. Forgy, "Rete: A fast algorithm for the many pattern/many object pattern match problem," *Artificial Intelligence*, vol. 19, no. 1, pp. 17–37, 1982.