

Indoors Multi-visitors Pervasive Installations using Mobile Sensor Networks

Ioannis Chatzigiannakis*, Alexander Kröller** and Irene Mavrommati***

* Research Academic Computer Technology Institute (CTI) and CEID, University of Patras, Greece. Email: ichatz@cti.gr

** Algorithms Group, Braunschweig University of Technology, Braunschweig, Germany. Email: kroeller@ibr.cs.tu-bs.de

*** School of Applied Art, Hellenic Open University, Greece. Email: mavrommati@eap.gr

Abstract—We present a unique location-based application of sensor networks. The “Magnetize Words” installation produces word clouds following visitors around, interacting with each other as the visitors meet in physical space. The installation can be based on either of two localization-providing platforms. The first achieves high localization accuracy while requiring visitors to carry identifying tags. The other provides low accuracy, but is fully nonintrusive.

Index Terms—Smart Floor, Location Tracking, Pervasive Installations, Interactive Installations, FinN.

I. INTRODUCTION

Today’s technological advances make it possible to create innovative interactive installations in the public space. In these, an automatic system creates an environment for passers-by that allows for a surprising, and often inspiring, experience. The technology driving the system is invisible to the user, leaving him to fully experience the installation without having to deal with systems issues.

A commercial example of such installations are the projector-based floor games to entertain kids, as found regularly in shopping malls across the US. More advanced installations combine the technological possibilities with modern forms of art, creating stunning art installations in public space. Examples for these are Project Blinkenlights¹, which turned 20-story buildings such as Toronto City Hall into interactive graphics displays, and Electroland’s Target Breezeway², which created an interactive room on top of Rockefeller Center in New York City. At best, installation can be fun and educational, as for example The Fun Theory’s Piano Stairs³ in Stockholm, which turned subways stairs into a piano, thereby making people use stairs instead of escalators.

In this paper, we present two platforms, a complete software system, and an installation in the same spirit. Both platforms provide localization services to the software, using different approaches, and with different characteristics. The “Magnetize Words” installation proves that our approach is feasible.

II. FINN SYSTEM

FinN [1] is a platform for creating, deploying and administering multi-visitor installations with pervasive and location-based features that employ mobile sensor network nodes as

the interaction devices. Using FinN, we have implemented a set of installations that fall into the discussed application category. We utilize Sun’s SPOT⁴ nodes as our prototype implementation hardware platform, which provide the basic functionalities of mobile sensor network nodes.

The FinN system uses similar devices in size and CPU capabilities with the Sifteo⁵, and share a number of concepts with the technology behind our installations, that have a more targeted educational approach. Our work differs from approaches like Microsoft’s Kinect, where the use of cameras translates into constraints in the deployment field and the number of players supported, such as obstacles and other means of blocking line-of-sight and strictly indoors operation; FinN supports up to 50 players, whereas such technologies are typically limited to just 4. Moreover there are FinN games where there is not always a need for central processing or for having a visualization screen⁶.

FinN targets scenarios where a large number of users participate using wireless handheld devices with sensing capabilities. These installations can take place in the same or different place and time and are supported by a “backbone” infrastructure that provides a number of services. The users’ devices use wireless ad hoc networking protocols to establish network connections/neighborhoods, communicating with other user devices or infrastructure ones. Embedded sensors are utilized for providing input from the physical world, translated according to the rules of each installation. E.g., high temperatures could be translated as “prohibited” areas. Accelerometers are used for recognizing gestures made by visitors; gestures are mapped to visitor interactions, e.g., “wave your hand”. Proximity estimation is also used as a means of input, as well as movement overall, apart from gestures. Such input can be used to monitor the progress of a game and also enforce the rules defined for it. By utilizing such input we essentially create installations with extended interaction features.

FinN’s architecture is based on a hierarchy of layers for scalability and easy customization. Among these layers, the World is the topmost element that manages multiple physical installations and allows interaction with social networking

¹<http://blinkenlights.net/>

²<http://electroland.net/projects/targetbreezeway/>

³<http://www.thefuntheory.com/piano-staircase>

⁴<http://www.sunspotworld.com/>

⁵<http://www.sifteo.com/>

⁶<http://www.funinnumbers.eu>



Fig. 1. The interactive hallway, and its Smart Floor, at Braunschweig.

sites, e.g., Twitter. Using a high-level perspective, the fundamental elements that are present in the lower layers, can be monitored and managed in a unified way. The templates provided with the implementation of the platform, i.e., means to instantiate players, interaction rules and places, can be customized according to each scenario. Currently, we provide a limited number of options regarding this aspect.

FinN uses Sun's SPOT platform⁷ as the players' devices. It is a small, battery-operated device, allowing programming in the Java Micro Edition (J2ME) platform. It uses an 180MHz ARM9 MCU with 512KB of RAM and 4MB Flash. An IEEE 802.15.4 transceiver is used for communication. They also provide a basic user interface (2 buttons and 8 LEDs) and a number of sensors. Localization of is achieved using the RSSI and LQI of periodic message exchanged between the devices and the infrastructure [2]. Given the implemented interactive installation (see Sec IV), the localization of the devices needs to be done only on a single axis and the mobility of the players is fairly low. Therefore the accuracy of the provided position information is on average about a meter.

III. SMART HALLWAY

At Braunschweig, we operate a "smart hallway". It can be used as a platform for FinN installations. It does not require the players to carry identifying items such as Sun SPOTs, rather it is able to detect presence of people using sensors in the floor. The sensory input is non-intrusive, unlike other approaches such as cameras. It is unable to identify individuals, it is even unable to decide whether a person entering the area has been there in the past. This sidesteps privacy issues, paving the way for permanent pervasive installations.

A. Platform

We have chosen a hallway at our institute for the installation site. It is publically accessible, and is frequently being passed

by students and visitors. The installation is permanent, and running 24/7. This enables the system to interact with passers-by at any time, there is no need to set up a visible game environment and invite people to come see it. Rather, the installation can attract people all by itself.

The hallway is approximatively 20×3 meters in size, with two main exits at the ends. Figure 1 shows the hallway. The installation can provide FinN with both input (i.e., people tracking) and output. See also our previous paper [3] for a more technical discussion.

The hallway has 29 "output boards" installed in about 2.40 meters height, at both sides. Each board has a programmable LED light that can emit the full RGB spectrum, and a speaker that can play audio samples in phone quality. Therefore, the hallway can interact with people using both visuals and audio. By playing synchronized effects on all 29 boards, one can achieve the impression of both moving "light clouds" and moving, yet invisible, audio sources. Furthermore, the hallway can talk to people to invite them to join an installation, explain rules or interpretations, and alike.

On the input side, the hallway features a so-called "Smart Floor". The regular floor consists of quadratic tiles, forming a regular grid. It rests on small metal columns, one at every grid intersection. We have enhanced the columns with simple custom-built sensors, consisting of a strain gauge on a supporting structure made from spring steel. They operate as load sensors, reporting the approximative weight of people standing on the floor. The construction is of very low price (about 10 Euros per sensor), to allow for installation of many sensors. This comes with the drawback that the sensor data is of very low quality. The sensors are massively influenced by the environment (e.g., temperature and humidity), making a proper calibration impossible. In total, the Smart Floor consists of 120 sensors.

The sensor data feeds into 30 sensor nodes (i.e., four sensors per node). These do local data preprocessing. For the nodes, we use standard iSense⁸ nodes, extended with additional custom-built A/D transformer boards. The nodes can communicate wirelessly, using the IEEE 802.15.4 standard. They are also connected using a USB-based wired backbone to a server.

Using the sensors, the Smart Floor can get an understanding of where in the hallway people are. This does require a global picture of the sensor values, which is not always available. If fast response times are required, the sensor nodes have to solve the tracking problem by themselves, communicating with each other to complete the view of spatial weight distribution in the hallway. In such a distributed setting, the nodes can process sensor values with a stream rate of up to 1 kHz, allowing for a very accurate tracking. A simpler approach is to simply collect all data at the central server, but this comes with a drastic reduction in speed due to the USB-based communication. In such a setting, we can process the sensors with a stream rate of about 10 Hz.

⁷<http://www.sunspotworld.com/>

⁸<http://www.coalesenses.com/>

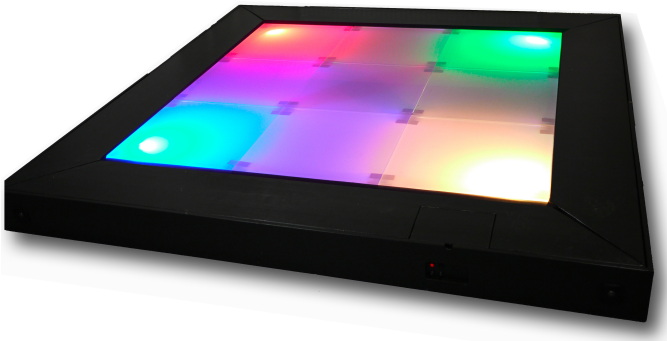


Fig. 2. A portable version of the Smart Floor.

For teaching and demonstration purposes, we have built a portable variant [4] of the hallway, see Figure 2. It consists of 3×3 tiles, covering a monitored area of 1.8×1.8 meters. It uses 16 sensors, four sensor nodes, and four output boards. In all technical aspects, it is equivalent to the large hallway installation.

B. Localization Scheme

As said before, the hallway provides 120 data streams describing a weight distribution on the Smart Floor, of very low data quality. Therefore, the localization algorithm needs to deal with very poor input.

We have devised a localization scheme with the following components, which will be discussed next:

- 1) Binary presence sensors
- 2) Virtual presence sensors
- 3) Event generation
- 4) Event matching

The first, *binary presence sensors*, deals with turning an individual input signal into a stable 0/1 state telling whether there is a person on the sensor or not. For that matter, we do not rely on any pre-calibration, as experiments showed that the sensor behaviour is not stable over time. Instead, we use a sliding window to decide whether the current load is substantially different to the average. This is based on computing the signal's variance over the sliding window. Anything differing from the average by more than k times the standard deviation is considered a substantial change, where k is a constant parameter. Setting k too low results in false positives, i.e., misinterpreting sensor noise as people, whereas a too high k might suppress detection of an actual person. In prestudies, we have found values of about 3 to work well, and consequently we use $k = 3$.

In the second step, *virtual presence sensors*, we address the issues that the sensors form a very coarse grid. We wish to detect people on a smaller scale, using the fact that somebody standing in the middle of a floor tile will influence up to four sensors at the same time. We construct virtual sensors on different positions within each tile, that operate on a weighted convex combination of some of the 0/1 streams produced by the binary sensors. The basic principle of detecting change patterns over a sliding window remains the same.

In *event generation*, we analyze what sensors (both binary and virtual sensors) are currently firing and extract a map of potential positions. This map is then filtered using heuristics to weed out erratic signals, and to unify clouds possibly describing the same person to a single point.

Finally, we create trackings of individual people in *event matching*. Here, we maintain a list of persons currently being tracked. Periodically, we update this list with the current active events. Every person has some properties (speed and direction) that are maintained as well. We use these to heuristically create likelihoods of people encountering each other and thus the generation of new interaction events. This exploits observations we did with passers-by in the hallway, for example

- A person either walks at constant speed, stands still, or switches between these two. He seldom changes speed.
- Some exits are used more often (the main exits) than others (doors to storage rooms).
- People make turns within $\pm 90^\circ$, seldom at acute angles.
- There are upper bounds on speed.

The resulting likelihoods describe how well a person in the hallway may generate a new interaction event. This feeds into a combinatorial matching algorithm that attempts to find the most probable mapping between persons, and events. Here, we also allow new people entering the hallway, and removal of people when they leave it.

In live experiments in our hallway, we have found the first three steps to work exceptionally well—a person in the hallway always has between 3 and 10 events firing around him. So the system works perfectly for single-user applications, where we simply pick a spot in the middle of these “event clouds”. Given that the sensors are placed on a 60×60 cm grid, this provides localization with an error of up to 40cm.

For the installation shown in the next section, single-user localization is not sufficient, so we need the fourth step for tracking of individual people. The matching-based procedure works reasonably well within the limits of its input, including many heuristic ingredients that we cannot present within the limited space of this paper. Experiments revealed that people are successfully tracked while they walk through the hallway, but the system gets confused easily when somebody walks close to an exit, or if two people meet. These issues will be addressed in future work.

IV. INSTALLATION

We develop a location-based installation implemented using the FinN software platform and the Smart Hallway. Visitors can interact with the installation either by physical movement (as sensed by the Smart Hallway) or by performing gestures, using a Sun SPOT that is given to them (see Fig. 3). The interactive installation “Magnetize Words” reacts on intentional or random multi-visitor movement along a pathway. Visitors move within a physical space, parallel to multiple projections. As they walk they are followed by a fluid word-cloud. Words originate from familiar poems which appear initially in their original form once a visitor enters the space, and are representative of the certain verbal choices and style



Fig. 3. Visitors interact with the cloud of words as they move within a physical space of multiple projections changing or by performing gestures.

of their authors. The initial poems are then deconstructed into words that are ever-reconstructing into new formations that and can be perceived as generative impromptu poetry.

As soon as a visitor is detected, a “poem” is formed and then decomposed into a cloud of words, following the visitor’s movements across a 10 meters long wall. The word clouds of more visitors exchange words and mix together fluidly. Words are attracted to each other (“magnetized”). At the same time certain words are highlighted or enlarged and accentuated, while some others may diminish. Words are exchanged between the clusters of different visitors according to their direction or grouping, and are being continuously rearranged. At intervals they fluidly shift to form word constructions (organized according to grammatical rules) and then remain still for a little while, in generative formations that can be interpreted by viewers as automated poetry improvisations. The resulting game of perception is based on interpretations and improvisations that are semi-randomly and collaboratively performed. A hermeneutic process occurs via the semantic interpretation of the word formations that are then read. In its more simplified viewing the “Magnetize Words” enhances the linguistic understanding of children with a playful semi-conscious manipulation of nouns, adjectives, etc.

A collaborative play within a space, occurs between users who carry their word-cluster to group together and thus alter, enlarge and enrich their word collection (or shorten it), and subsequently collectively creating a visual impact on poetry-resembling word formations. From one up to 30 people can simultaneously interact within the installation, making it gradually richer and achieving an increasingly prominent visual effect. The word cloud is constantly constructed (into a poet-resembling form) and deconstructed, playfully generating new readings all the time. Viewers play an active role either consciously (by intentional gestures or movement, or approaching other viewers) or unconsciously (by accidentally

walking around) but also by giving their own interpretation and reading to the word-formations and coloring emotively their experience (as certain words they direct their attention to have certain semantics and correlations). The interaction state of visitors can range from passive (those who are inactive at the background watching activity of others and reading he results), to active (those who move around, in proximity with each other, unintentionally, randomly or intentionally). The interaction happened in many levels, kinetic (location-based), aesthetic (experiencing fluid animations, projector based), linguistic (reading words and their formations) and perceptual (subconscious interpretations).

V. CONCLUSION

We have presented FinN, a software/hardware platform allowing to create interactive installation in public space. FinN provides high accuracy in detecting and localizing people, with the drawback of requiring players to carry an identifying tag offering more possibilities for richer gesture interaction (such as shaking or sweeping gestures, facilitated by the sensor-bouquet of the SUNSPOT devices). We also describe the Smart Hallway, a permanent installation that localizes people using a completely different, and fully non-intrusive approach. Finally, we discuss an actual installation, where visitors can interact with word clouds following them.

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