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USE OF AN ENERGY HARVESTING SMART FLOOR FOR INDOOR LOCALIZATION OF PEOPLE

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ABSTRACT

The development of "intelligent" floors is a growing interest, but often the ensuing solutions involve high production costs as well as complicated installation and management. Aim of this paper is to propose a novel smart floor that makes use of an energy harvesting system in order to allow people localization and to track their movements in an indoor environment. The contribution starts from reviewing the state of the art of smart floor solutions, which are categorized according to the different applications they are addressed to. The system developed in this research is based on capacitive sensors that are mounted on a polymeric support and embedded between a bulk wooden base and floating parquet flooring. The paper outlines the detailed architecture of the proposed apparatus and reports the results of the preliminary test phase. The proposed solution is part of HDOMO, an Ambient Assisted Living (AAL) project aiming at the development of smart solutions for active aging.

Keywords: Smart floor; Intelligent home environment; Interaction technology; User identification; Energy Harvesting Indoor positioning.

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1. INTRODUCTION

The localization and tracking of users in a specific space has in recent years become a goal of computer science re-searchers. With the advent of smart environments, transparent user localization has become even more pressing purpose than before the rise of these paradigms. If a system or environment could transparently follow the movement of the user, it could customize its interface and behaviour to match the references, history, and context of that particular ambient so as to intervene in the case of necessity or danger. The greatest danger for aged people living alone is falling down. More than 33%.There has also been much work recently that has focused on more passive forms of user localization in enclosed spaces, such as people recognition and tracking using video, noise analysis using audio systems, analysis with the distance sensor such as optical or ultrasound [1].

These types of analysis are transparent user however, but these technologies have problems, too. Video recognition and distance optical sensors system are limited by occlusions, shadows, and lighting inconsistencies, and do not work at all in the dark. Audio recognition suffers from problems of background noise and ultrasound distances are limited by multiple reflections. One of the most interesting ways to localize people in an enclosed space is based on pressure sensing systems integrated into the tile or wood floors. Nowadays, the major fall detection solutions use some wearable sensors like accelerometers and gyroscopes, or help buttons. However, elders may be unwilling to wear such devices. Also, systems based on help button would be useless when the elders are immobilized or unconscious after a fall. Another way of fall detection is to use video cameras. In that case, however, the privacy of the elders is not preserved anymore. They would be uncomfortable to be observed for a long time in the home environment, even if some novel camera based systems are working in that direction. To overcome these limitations, in this study, we consider a system that has little physical or psychological disturbance to our daily life. The sensing devices are supposed to be unnoticeable, and the process of behaviour analysis and fall detection is expected to improve the extent of privacy protection of users with respect to other systems.

The smart floor pressure sensing systems have a number of characteristics that make it an obvious choice for this scope: users always walk over it, it is always there and it can sense information not only about users but also about objects. Thanks to the smart floor, the user does not need remember anything, it walks over the floor tile and the system utilizes biometric data pressure of the user for localization and tracking and fall detection. It is also possible to identify dangerous situations thanks to information on the pressure distribution on the surface of the floor and in the time. The Smart Floor also works fine when the room is noisy and dark, and it does not care if a view of the user is occluded. In addition, due to its very nature the floor gives accurate position information. However the algorithms for identification and tracking are simple and not computationally intensive [1].

The aim of this work is to propose an innovative smart floor based on an energy harvesting system able to allow the localization and analysis of the movement of the users in a specific space. The solution presented in this paper involves the use of capacitive sensors on a polymeric support to insert between solid wood and a wooden part of floating parquet. The proposed system is part of HDOMO, an Ambient Assisted Living (AAL) project developing smart solutions for active aging. A detailed architecture of the smart floor is proposed together with a preliminary test phase. In addition, systems for detecting the pressure require little energy to operate and can be powered through energy harvesting systems. In this work, the solution presented utilize an innovative energy harvesting smart floor based on capacitive sensors situated on a polymeric support insert between solid wood and the wooden part of a floating parquet. The aim of this solution is to allow the localization and analysis of the movement of the users in a specific space. Also falling situations are monitored.

Paper is organized as following described: Section II introduces the state of the art of pressure sensing system. Section presents a description of the system. A description of the planning of the experiments is explained in Section IV. Conclusions and future works are given in the last section V.

2. STATE OF ART

The realization of a floor able to localize and analyse the movement of the users in space applications presents many and varied approaches. In the literature, there are different solutions to implement a smart floor all based on the pressure sensing system. The MIT Magic Carpet [2], [3], [4] created by MIT Media Lab and the University of Limerick Ireland uses piezoelectric wires and optical proximity sensors. This system is characterized by a large sensing area and frame rate but presents poor sensor densities. This interactive environment uses a pair of Doppler radars to measure upper-body kinematics, i.e. velocity, direction of motion, amount of motion and a grid of a PVDF piezoelectric wire hidden under a foot carpet to monitor dynamic foot position and pressure. The aim of this system is an application for an audio installation, for that user modifies and transforms complex musical sounds and sequences while they are moving on the carpet. The system is illustrated in figure 1.

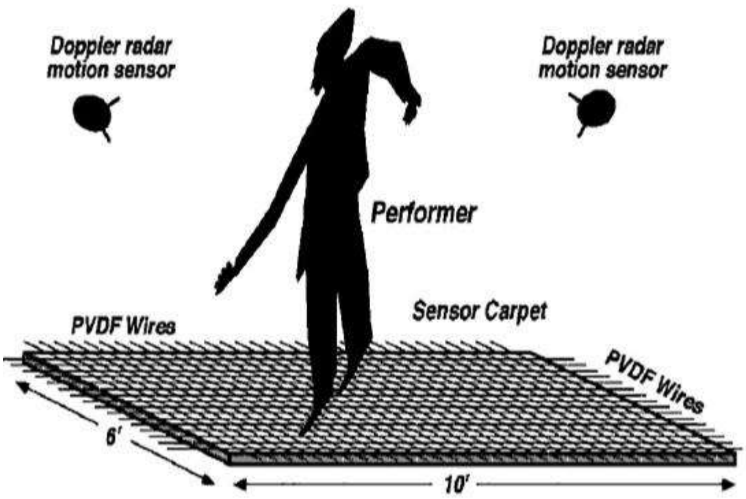

Figure 1 Representation of the Magic carpet system [2]

The ORL Active Floor [5] designed by Oracle Research Lab uses load cells that provide little detail, and it cannot be used for high sensor densities. Arrays of sensors provide information on the distribution of vertical ground reaction force over the area of the floor. When only an object is in contact with the floor, its centre of pressure. There is a problem when two or more objects are in contact with the floor since it is not possible to determine univocally the centres of pressure for the objects, departing from the sensor array readings. This aspect was a subject of research at ORL. The University of Tokyo, Japan, created height resolution pressure sensor distributed floor [6] can simultaneously detect both human and robots. This distinction is possible thanks to the high resolution of the floor and its modular structure allowed easy application to a real room. The authors retain that the sensor floor system can be used to understand the behaviour of humans in a room, and that it will also play an essential role in the future human-robot symbiosis environment by detecting the position and direction of humans and robots in the room. Figure 2 represents the sensor floor unit consisted of three parts. The sensor floor has a number of sensor units: for example 16 sensor floor units arranged in 4x4 array.

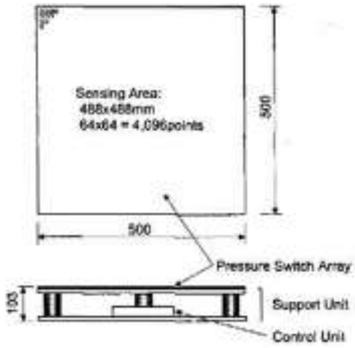

Figure 2 The structure of the sensor floor unit [6].

Another system sensor is Z-Tiles [7], [8] designed by University of Limerick Ireland and MIT Media Lab. It uses a force sensitive resistor technology. This system has the advantage of having a modular design, a series of prototype Z-tiles nodes join together to form a flexible, pixelated, pressure sensing surface, a high frame rate, but a low sensor density. This surface provides full time-varying, force-distribution information, since the Z-tile nodes form a self-organising network to allow for easy data extraction from the floor, without restricting the size or shape of the floorspace. The applications of this structure concern generating music from the movements of dancers, as an input device for the control of computer games, and so for virtual reality application. The Floor Sensor System [9], a solution of The University of Southampton in UK, has binary switch technology. The advantage is the low cost of the design, but because of the binary floor, it allows to have poor data useful for tracking and localization user. In this work a prototype system for acquisition of footfall data has been presented designed to help study the gait by applying an alternate modality. The system consists of three main components: a large sensor mat, showed in figure 3, hardware interfacing, and analysis software. The sensor system is a promising prototype.

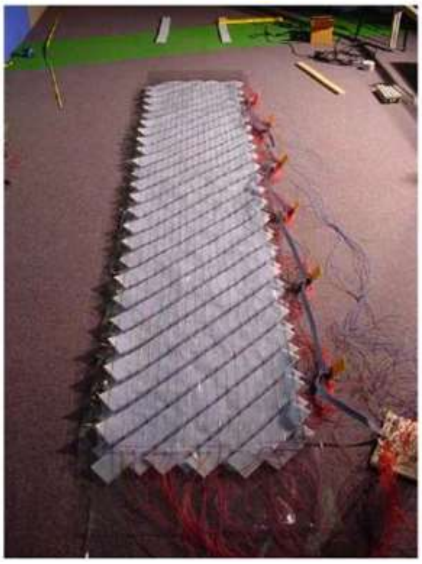

Figure 3 The prototype sensor mat with 4 grids and 2 layers [9].

The projects AME floor I, AME floor II and AME floor III [10] developed by Arizona State University are based on force sensitive resistor technology. They have a temporal domain, but not spatial domain. The pressure sensing floor system has a higher frame rate, less latency, high sensor resolution, large sensing area useful with real time data to know the location and amount of pressure exerted on the floor. The floor has been integrated and synchronized with the marker based motion capture system to create a smart environment for movement based human computer interaction. The sensing system has been used to drive a gesture recognition system that uses both kinematics and pressure distribution to recognize gestures. These gestures could have similar body shapes but different weight distribution, so pressure sensing is fundamental to distinguish between such gestures. The ability to read and analyse both body kinematics and pressure distributions suggests users to communicate with computers. A problem of AME Floor-III is that now is not portable, and so interfacing is one of the problems must be solved.

3. DESCRIPTION OF THE SYSTEM

The smart floor system is part of the HDOMO project, founded by INRCA and Marche Region in 2013. The goal of the project is an effective provision of care and assistance services in ambient assisted living with the collaboration of multiple stakeholders. To support such collaboration, the development of an ecosystem of products and services for active ageing plays an important role in HDOMO. This project, involving 17 companies and 2 research institutes, introduces a conceptual architecture that supports such AAL ecosystem. In order to facilitate understanding and better interrelate concepts, a 3-layered model is adopted: Infrastructure layer, Care and assistance services layer and Ambient Assisted Living ecosystem layer.

A holistic perspective of ambient assisted living, namely considering four important life settings is adopted: (1) in-dependent living; (2) health and care in life; (3) occupation in life and (4) recreation in life. The proposed architecture is designed in the context of a national Italian project and in accordance with the findings of a large European road mapping initiative on ICT and ageing. The smart floor goes in that direction inside HDOMO in the independent living target. To better serve its function, the smart floor should have the following features. It must have a low cost of installation and operation, it must be invisible, easy to install, implementable on existing structures, it should have quickly and accurately identify the location of the user in order to report in time of danger situations such as the fall of the user. Indeed the reduction of the waiting time after a fall is a priority goal. Therefore is prevalent the need to immediacy of local processing of the signal by transmitting only the result. The minimum frequency of sampling for efficient processing of data is 7 Hz, the distance of the positioning of sensors on the floor (or mesh grid) is 180 mm. Moreover, the maximum limit for recovery of energy is 5.8 J by step otherwise the “walking on sand” problem will occur. For these reasons, the designed solution uses capacitive sensors on polymeric support to be inserted between solid wood and wooden part of a floating floor as shown in figure 4.

The system is also able to detect a falling using a simple multiple sensor activations. This enables to activate two differ-ent information sources: the indoor localization and the falling detection. Inside the HDOMO project the system is providing data to the classification layer. For practical use of the system, we propose a new approach to personalize the system instead of training an activity model for new users. In the modelling phase, we build a pool of activity models from a group of people. Localization and falls data are classified, together with other data coming from HDOMO smart sensors are classified for HBA purposes by an activity model composed of Bayesian networks and support vector machines are constructed through the process of pre-processing and model training. The pre-processing module filters out noise, segments the data every half second, and extracts statistical features (minimum, maximum, average, median, standard deviation) from the smart floor data. Instead of conventional approaches that construct a population model or train an individual model for a new user, we apply a most matching activity model in the pool of activity models already constructed from the other people.

The system thus created does not need to power the control unit except the task of collecting data from the various sensors and process all the information. The main criticism is that represented by the capacitive measurement is very sensitive species in the transport phase of the signal. The cable is usually insulated with Teflon to address this problem.

Figure 4 Capacitive sensors on polymeric support inserted between solid wood and wooden part of a floating floor.

4. DESCRIPTION OF THE EXPERIMENTS

The simulation test of floor functional prototype must then be conducted with a load equal to about body weight (sinusoidal load weight equal to +30%) and with a frequency from 30 to 120 (maximum) distances to minute (0.5-2 Hz). The simulation must reproduce the different phases: Heel Strike-contact phase; Midfoot strike, stance phase; forefoot strike, or flaking; the initial one can last up to 60% of the entire cycle, this can be achieved by varying the height of the springs of the recliner plan. Figure 5 shows different phases of the step. The top of the figure represents the foot highlighting the curvature angle. The bottom of the figure puts in evidence the correlations between the force forces exerted by the body weight and the instants of the step.

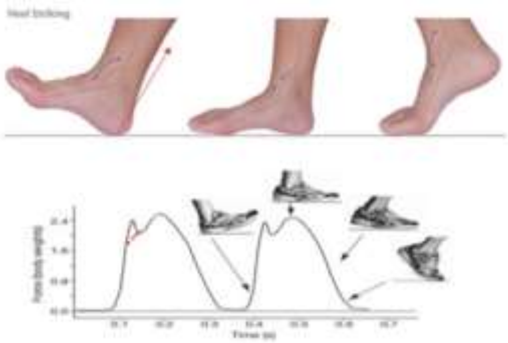

Figure 5 On the top, the movement of the foot. On the bottom, the forces exerted by different states of support

Rejected the hypothesis consisted of letting a person walk back and forth for days, we have assumed an original test. The prototype designed for the testing phase on the floor is showed in figure 6, and below the design choices have been introduced.

The contact angle between the plane of the school and the soil is about 20 and the contact force has an initial peak increasing from a normal deambulation (stance phase 60% of cycle time) to the running (stance phase 40% of cycle time). A medium person usually runs 120 steps per minute, the period per cycle is 1 second, while speed of 20 km/h the cycle time drops to 0.6 s, the contact phase changes from 0.62 to 0.2 s. The contact force increases until it reaches multiple of body weight with increasing speed of the race. So the simulation test must be conducted with a load equal to approximately body weight (sinusoidal load equal to to +30% body weight) and with a frequency from 30 to 120 (maximum) steps per minute (0.5-2 Hz).

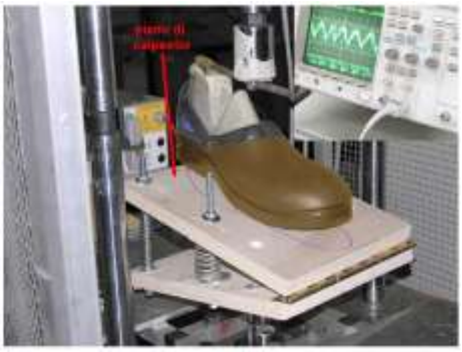

Figure 6 Prototype for the testing on the floor.

It was decided to operate with sinusoidal load, with frequency 1 Hz avoiding the original peak since shoe's proposals are suitable for normal walking and not for running. The shoe was mounted on a form with a joint that allows a rotation between the front and rear of the "Foot". The contact angle between the abutment surface and the floor of the sole was 20; proceeding with the application of the load the contact plane ("ground"), held in position by two springs in parallel by 60 kgf/cm and by further two springs (20kgf/cm) that intervened after the first centimetre of race to ensure the rigidity of the land, is lowered rotating around a pivot axis coinciding with intersection between the ground plane and that of the sole.

In this way, after heel strikes phase, due to the effect of rotation of the articulation of the foot and the lowering of the plane of contact, you have the support of the entire sole (midfoot strike) and, for the load mode, the separations phase in which the forefoot allows to ultimate contact. The cycle was conducted with a load between 60 and 80 kgf.

Results, even if preliminary, proved the feasibility of the proposed architecture. Further investigations on that direction are on-going.

5. CONCLUSION AND FUTURE WORKS

In this paper a novel smart floor based on a pressure sensing system was presented. The aim of this work is to propose an innovative smart floor based on an energy harvesting system able to allow the localization and analysis of the movement of the users in a specific space. The solution designed using capacitive sensors on polymeric support to be inserted between solid wood and wooden part of a floating floor.

The system thus created does not need to power the control unit except have the task of collecting data from the various sensors and process all the information. The solution presented in this paper involves the use of capacitive sensors on a polymeric support to insert between solid wood and a wooden part of floating parquet. The proposed system is part of HDOMO, an Ambient Assisted Living (AAL) project developing smart solutions for active aging. A detailed architecture of the smart floor is proposed together with a preliminary test phase.

Future works go in the direction of integration in the AAL environment and in an extensive cost reduction approach to cope with industrial requirements of low cost AAL smart devices. Further work will go on the direction of falls detection without hardware improvements, based only on data classification.

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