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Passive Monitoring Techniques for Elderly: A Review on Recent Development and Prospective

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Abstract—**Real time tracking and monitoring systems designed for observing the response of elderly population has proven its significance in recent years. The spectrum of sensing applications in tracking is on proliferation which is why it is important to review the progress of technological advancement and prospective of monitoring techniques. To implement a tracking system, a low cost, low power consumable, precise and wireless solution should be developed. The active tracking volume should be capable of facilitating a normal range of human motion. This paper highlights the review of various types of active and passive tracking system as well as the succeeding development leading to the design tasks. Moreover this paper briefs the operation and application of the ongoing monitoring approaches with their advantages and shortcomings.**

Index Terms— **tracking, capacitive sensor, sensing, passive devices**

I. INTRODUCTION

In a living environment, elderly patient's movement tracking is of paramount importance. To improve the living standard and make it secured, extracting reliable location information is a significant issue for various location-based services. A system capable of tracking the position of an elderly makes a number of potentially rich new forms of human interaction possible. Through practical monitoring system, tracking the response of the human can be expanded to real-time tracking which can be effective for observing human activities.

To implement a general-purpose tracking system practically for elderly home, a number of requirements should be accomplished. An accurate, cost effective, secured and wireless solution should be introduced. Any component of the system placed in/on the floor surface should have nominal requirements of power. The active tracking volume should be void of physical obstruction and big enough to facilitate a normal range of human motion. Researchers have been working on the development of tracking approaches worldwide. Although each approach concentrates on the requirements mentioned earlier, presently no existing solution has offered a comprehensive solution. The existing solutions are camera / video based systems, pressure based sensor system and capacitive / electric field sensing based sensor systems. Among the mentioned techniques, capacitive sensing has proven much prominent.

This paper highlights the significance of human movement tracking and reviews the operation and application of the existing tracking approaches along with their concomitant advantages and shortcomings.

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II. STATE OF THE ART TECHNOLOGY

The initial step towards identifying the daily activities is to equip activity detection systems with sensing abilities. A number of different techniques and technologies can be used to make tracking and identification possible. Two approaches have been mainly employed for this purpose: active system and passive system. The active systems require people being tracked to carry a physical device or an attached device to a person such as global positioning system (GPS) unit, radio frequency identification (RFID) tag, ultrasonic system, infrared (IR), and so on. Hence active systems are considered to be obtrusive and troublesome during continuous use. From the view point of an elderly living at home [1], these techniques are not practical or user-friendly because one must pay attention to the device and remember to carry it at all time otherwise continuous monitoring is not possible, also if they are battery powered then regular charging is required or battery needs to be replaced from time to time. An alternative method to overcome the problem of active systems is the use of automatically functioning passive device that would allow the users to perform their daily activities freely. Passive sensing means that people being tracked by the system can move freely without the need for attaching any tags or devices. Such monitoring techniques include video based localization systems that use cameras; other technique includes pressure sensing, IR passive systems, ultrasound passive system, radio frequency passive systems and electric field sensing. One advantage of using passive system is that the tracking can be done without wearable tags or badges.

The focus of the work is on the passive systems; hence the state-of-art technology will be mainly based on passive sensing devices. Some existing detection systems are discussed below.

1. Camera/video based systems

A promising identification and positioning system today is the camera/video based system [2] that has long been used for positioning purpose and identifying the human actions. This system operates well in laboratory, although it cannot achieve the same accuracy under a real time home setting because of variable lighting, clutter, and significantly varied actions which happen in usual environments. Complications of handling the changes in the scene, specifically the presence of several people, lighting, and clutter give further challenges. Furthermore, cameras and microphones are quite expensive. Multiple cameras are needed to be installed in a single room which make the tracking system more complex, takes lots of space and also requires more computing power. Ultimately, as these devices generally work as recording devices, they can also be assumed as threats to privacy for some people.

2. Pressure based sensor systems

A way to construct a discreet tracking system is to carry out the measurement of the pressure under humans' feet. Pressure sensors have been known to be the most traditional existing positioning system technology available. The basic way of constructing a pressure sensing positioning system is by embedding pressure-sensitive sensors on or underneath a floor surface. If the sensors are installed beneath the floor, users cannot see it, but the installation of such set up is quite complicated. This kind of installation needs flexible flooring and adequate installation space under the floor.

This system allows user identification; as the pressure created make a correspondence to a person's distinctive weight and gait [3-5].

The concept of pressure sensor was primarily introduced by Paradison et al. [6] who named their design The Magic Carpet, it measures the pressure caused by a person that steps onto mat place on the floor surface. In [7] a pressure sensing positioning system was implemented with 2.4 x 1.8 m tile on the floor to determine a person's location on a single tile by computing the centre of pressure on the surface using the load calculated at every side of the tile. However, this system only works with one person on the tile at a time.

Some researchers implemented [3] a 3.0 x 0.5 m sensor mat system which uses a pixelated surfaces made up of many sensors. Basically the sensors are simple structured binary switches. These sensors are constructed by detaching a pair of wires using a deformable material namely foam. When a user put a sudden force to the constructed sensor, wires come into contact. The sensor mat is comprised of 96 horizontal and 16 vertical wires. Since the sensors are one kind of binary on/off switches, this system is able to sense only when a person is in standing position on the mat. For instance, it cannot compute the weight measurement of the person standing on the mat. Additionally, the prototype mat costs around €80. If a comparatively bigger area needs to be wrapped with such type of mat it would be costly.

In [8] an improved technique for measuring pressure has been discussed which uses electromechanical film (EMFi) which is a thin, and flexible polypropylene film coated with metal electrodes. EMFi is able to store huge permanent charge. If an external force affects the EMFi surface, a change in the charge becomes obvious between electrodes, detected as a voltage.

In [9] the author investigated the use of a 30 x 34 EMFi sensor stripe matrix with a cell size of 30 x 30cm under normal flooring. These authors aimed on identifying users. This kind of system operates well for locating purposes. Nevertheless, a quality footstep signal indeed cannot be achieved in this system since the footsteps show significant impact on multiple sensor stripes.

EMFi only reacts to pressure variations, it cannot be used to sense unmoved persons, to be precise, a person who is standing still or who has fallen to the floor and lies still. The ability to monitor the person incessantly for a long period is essential while noticing slow-moving elderly people. Furthermore some other problems are associated with the polypropylene films such as their price, electret films are limited in size and the ageing of the material (material loses sensitivity over time). The disadvantage of the systems stated so far is that the systems require many fixed wirings. To alter the wiring, hardware, software, reshaping and resizing them are essential.

Richardson [10] proposed an innovative system, the Z-Tile system. Z-Tile is basically a floor sensing system which eliminates the large number of wirings. The Z-Tile system makes use of modular nodes which can be connected to make positioning areas of different shapes and sizes. Each node contains 20 hexagonal force-sensitive resistors on its surface. Due to their shape, the nodes are able to interlock and act as self-holding. Furthermore, the Z-Tile system does not need any different and separate data wire for all nodes. In lieu of that, the interlocking tiles form a self-organizing network. Each node acts as a power source and a data gateway for the network. The main demerit of the system is that the data volume being produced by the Z-tiles is very high which made the data processing very challenging if larger areas would be covered with Z-tiles.

Using pressure as an assessable quantity, it has been a big step towards tracking invisible human approach. However, such systems have substantial complex structures. Accordingly the manufacturing and installation are not scalable, because pressure sensors require flexible floor and a lot of installation space under the floor level in order to keep the sensors hidden. Additionally, due to the mechanical arrangement of the pressure sensors, such sensors are not optimally cost-effective and robust. Also pressure sensor has deformable parts. These deformable parts require recurrent maintenance which enhances the cost. Consequently, more sophisticated approaches are required.

3. Capacitive / Electric Field Sensing based sensor systems

Electric field sensing (EFS) uses the concept of a measurable distortion. An object with some electrical features (namely capacitance) is able to sense within an electric field oscillating at low frequency. The other name for electric field sensing is "capacitive sensing".

The earliest artificial electric field sensing system was the Theremin, a musical instrument which could be played without touch, was invented by a Russian scientist Lev Termen (Leon Theremin) in the early 1920's. The musical instrument [11] measures the player's capacitance relative to a set of transmitter/receiver antennae. The Theremin is the initial device that can measure the location of an object (player's body parts) by making measurements of changes in an emitted electro-magnetic field.

Rekimoto in [12], presented an interactive table based on capacitive proximity sensing which reliably tracks the position of a user's hands and fingers over a table surface. In their proposed system, a grid of copper wires was used as electrodes. The transmitter electrode was excited by a 100 kHz signal. The received signal is relatively proportional to the frequency and voltage of the transmitted signal. When a user approaches the table, the user capacitively couples to the electrodes hence interfering the electric field. By measuring the effect on the strength of the electric field, the proximity of the user is detected. The pros of this system is that the system can allow multiple hand gesture tracking since each point on the transmitter-receiver electrode grid can independently measure the proximity of the user. However, the system is not suitable for human position estimation; the range of sensing will be very small since the strength of electric-field is anti-proportional to cube of distance. Due to this problem, this system is inappropriate for estimating human position. For instance, when human raises his legs for walking, the system can easily loose human position. In order to overcome such problems, high voltage and thick antennas need to be implied.

Diamond Touch [13] is a system which produces different signals at different parts of a table and distinguishes the touch location by identifying which signal is received by the user. The design of Diamond Touch is implemented by attaching a grid of metal strips (transmitters) under a table and a separate set of grid (receivers) located in the chair of each user. The strips of the grid attached to the table emits an electric field when a user touches the table, a capacitive coupled circuit is complete. The receiver can then determine which parts of the table surface the user is touching. However, the Diamond Touch table only senses when the user has a direct skin contact to the table.

Aud, et al. [14] states the development of ''smart carpet'', a scalable system has been designed to detect a fall and track people walking over it. Capacitive sensors are embedded in the textiles and woven into a carpet. The smart carpet is built on a network of 180 capacitive sensors using one sensor connected to a PC. Each sensor has its own sensing wire placed on a 15 x 15cm size squares with a 5cm gap between the sensors. Loading mode is implemented in this device. When a person walks on the carpet, the sensor will be activated behaving like a transmitter and increasing the current flow to the other tiles which providing the return path to the ground. Using this carpet, a number of categorization techniques were analyzed to identify person's footsteps and thereby assess walking trajectories. The aim of the system was to detect issues such as whether a person is walking on the carpet, or the person is lying flat on the floor. Advantages of this system include that the shape and the size of the carpet can be modified by cutting it between the sensors. Furthermore, in the smart carpet system, the user does not need to remember to maintain the batteries as it uses ''energy scavenging sensors'', which allows the sensors to harvest energy (that is light, thermoelectric and vibrational energy) from the environment. Moreover, Aud et al. revealed that participants found no significant dissimilarities between walking on a standard carpet and walking on the smart carpet and proposes that this feature would increase the suitability of the fall detector.

The Tile Track system of Valtonen et al. [15-16] is based on determining the capacitance between multiple floor tiles. The sensors are placed on the wall and the floor surface. An accuracy of 15 cm was achieved for the persons in standing position and 41 cm for persons in walking state. The system was capable of identifying many persons, when those persons remained one tile far from another tile. Advantage of this tracking system is that it can function well even with a thick layer of insulating material such as thick furnishing carpets or thick shoe soles, between the person and the electrode.

The construction cost of this system is quite little: roughly €16 per m^2 for cabling and electronics and €4 per m^2 for electrodes [17]. Nevertheless, the installation itself is quite difficult when the transmitter electrodes are mounted and installed beneath the floor surface.

The system is also not applicable for wide area rooms, the use of separate transmitter and receivers electrodes can result in the possibility that some object in the measurement space many affect the accuracy in the whole of space, thus, it may be difficult to track multiple persons. However it can be concluded that the design is suitable for narrow rooms or when only movement close to walls has to be detected. In those cases they accomplished a good precision in their evaluation. Another proposed extension to their work includes placing receiving electrodes in furniture to provide better resolution in living environments.

A recent work in [18] demonstrated a system based on Electric Sensors with Intelligence (ELSI) which makes use of near field imaging (NFI) to track people. When a conductive object is present (a person) near to the actuated electrode, the displacement current passing from the object towards the adjacent grounded sensors is increased. The system carries out the measurement of the displacement current from every single sensor, makes use of the current and the physical location of the sensors to identify the person's position.

In the ELSI system the sensing electrodes are quite cost effective. However the installation is complicated and costly, particularly if mounted on an existing home [19]. The disadvantage of this system include its' incapability to recognize the located person or object. This system measures only electrical parameters from the human body, therefore it cannot identify people.

A study by Rimminen et al. [20-22] explored the use of electric field for human tracking system by positioning people over a segmented floor electrode. This system design utilizes a matrix of planar electrodes which is placed under the floor surface in sequence. When a person stands over a tile that tile functions as a transmitter which transmits a low frequency signal at a time, while all the other tiles becomes grounded. An electric field coupling is formed between the person and the floor thus affecting the impedance and the current flow. Hence the system measures the variation in impedance (capacitance between the transmit electrode and ground) at a point frequency. To track people effectively, the element of the sensor matrix is then scanned in sequence by multiplexing the transmitted signal.

The system showed inaccuracy when people fell to their knees. Only 20 per cent of such falls were detected. Moreover, the measuring method by this system cannot neglect the influence of stray capacitances and environmental noises.

From the state of the current art, it is apparent that electric field sensing based approaches offer numerous advantages.

The electric field is capable of penetrating less conductive materials namely furniture or walls and thus hiding the capacitive sensing electrodes into building structures and making the system invisible to the users. The required hardware is quite simple in structure and cost effective as well. The sensing electrodes can be made from very thin, inexpensive, scalable, and durable materials. For instance, the electrodes can be constructed of simple aluminium foil, purchasable at any grocery store, and the foil can be cut in to proper pieces at the installation site. The method is scalable and has better resolution. An active tracking volume can be achieved by enhancing the number of transceivers.

This scalability can be considered appealing as it makes it plausible to gather as many or as small amount of information as required in a specific application" [18]. By using the ground planes in electric field sensing active volume can possibly be protected from noise.

A major disadvantage of electric field sensing is the mathematical complexity of inferring accurate information about an object's position and orientation from indirect measurement of electrical properties. The couplings between transmitter and receiver are nonlinear. Since there are more unknown parameters than measurements, position and orientation must be found in terms of ambiguity classes and probability distributions. Another disadvantage of electric field sensing (as it has been explored thus far) is that it presumes the type of object being sensed. Thus, tracking different types of objects requires the use of different modeling assumption sets. Most of the work that has been done in electric field sensing concentrates on modeling the human hand and body. According to Smith, real time position tracking appears to be tractable, while the tractability of real time orientation tracking remains unknown [18]. The mathematical complexity of electric field sensing is daunting; however the modality has great "potential".

III. Conclusion

In order for precise monitoring and tracking of elderly population, extracting location information is a crucial issue. The positioning system must be passive, tag-free, and unobtrusive particularly when monitoring needs to be carried out at homes. This paper has presented an overview on the existing techniques along with its advantages and disadvantages. In my view it is apparent that the electrical field sensing is advantageous over other techniques. The sensing electrodes are quite cost effective and simple structured. Also the electric field is capable of penetrating less conductive materials namely furniture or walls and thus hiding the capacitive sensing electrodes into building structures and making the system invisible to the users. However the installation is complicated and costly, particularly if mounted on an existing home. Also the mathematical complexity lies in extracting accurate information about an object's position and orientation. Therefore, the overview of existing complexities leads toward developing a novel tracking technique which should be cost effective, simple structured, easily installable and maintenance-free.

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