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Fall Detection and Intervention based on Wireless Sensor Network Technologies

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ABSTRACT

The present paper details the development of a cost-effective Fall-Detection and -Intervention System (FaDIS) based on Wireless Sensor Network technologies. The system is designed to integrate into existing low-tech homes, to enable Ambient Assisted Living environments, where software and hardware devices attempt to facilitate a safe and proactive independent living. FaDIS is designed to operate both as an add-on component to existing centralized solutions (complete or otherwise) and as an integral yet independent component of decentralized, scalable, and expandable solutions. Accordingly, FaDIS was implemented in two parts. Part 1 was developed as a scaled proof-of-concept that served as the foundation for Part 2, which is the principal focus of the paper. In Part 2, FaDIS is developed as a fully operational, real-scale system that uses a self-healing mesh network protocol, where its own BeagleBone Black development platform serves as the sink node, and where two Class 2M 10° line lasers are used in conjunction with light dependent resistors to gauge the probabilities of an emergency event based on the estimated dimensions of the collapsed object. In both parts, if FaDIS construes the probabilities of an emergency event as high, the same series of corresponding robotic response-actions intervene locally while automated notifications are sent to emergency-personnel, care-takers, and/or family members via both wireless and cellular technologies. A series of sample runs are detailed and described in the present work in order to demonstrate and to argue for the feasibility and functionality of FaDIS as both a Fall-Detection and -Intervention System in particular and as a WSN-based system in general.

1. Introduction

The independent exercise of activities of daily living (ADLs) becomes increasingly difficult to sustain as people enter a stage of physical and cognitive decline typically associated with the natural aging process [1]. If no intervention and/or mitigation solutions are proposed, this decline may progress prematurely and unnecessarily to the extent where those affected lose the ability to care for themselves and to live independently at home. From a practical and logistical standpoint, this represents an unexpected burden to family members and/or an additional load to institutionalized nursing-care systems. These considerations are particularly important since every emerging industrial nation is experiencing a debilitating age-related demographic change [2]. There exist Ambient Assisted Living (AAL) solutions imbued with ambient intelligence (AmI) that attempt to address this problem. However, such solutions tend to be based on centralized models that are costly (see Section 2) and therefore inaccessible to the general public. Intelligent, resilient, and—above all—decentralized solutions with respect to AmI and AAL are therefore necessary to promote and to sustain a consistently affordable and continuously evolving independent living. In the present paper, a Fall-Detection and -Intervention System (FaDIS) that is built on such solutions via Wireless Sensor Network (WSN) technologies is proposed as part of a larger unified yet distributed AAL solution.

The detection aspect of FaDIS is based on Pyo's and Hasegawa's laser reflectivity method [3], which consists of a laser-emitting component in conjunction with a light-sensing component used to generate a grid of theoretical intersections against which blocking objects may be detected via instantiated intersections. The form of this grid is not predetermined, as the user is free to distribute (uniformly or otherwise) the light dependent resistors (LDRs) conforming the light-sensing component across an adjacent wall and an opposite wall of the deployment space with respect to the position of the laser-emitting component, as long as these are within the laser's projection range. The principal innovation with respect to the *detection* aspect of the system lies in that it does not need *a priori* knowledge about the position of these LDRs with respect to neither the comprehensive spatial dimensions of the deployment area nor the laser-emitting component in order to generate its operational intersection grid. From four givens discussed in Section 4.4, the system's self-configuration and -calibration mechanisms extrapolate the position of the deployed LDRs after every scan

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iteration, thereby potentially but not necessarily generating an updated operational grid each time. Two core innovative consequences follow from this feature. The first entails that the distribution of LDRs may be automatically updated between scans without service interruption or the need for manual system reconfiguration/restart. The second entails that the system may be deployed in a variety of architectures across areas of emphasis and diversity of programs. That is to say, as depending on the proximity and distance between each LDR, the generated grid will be higher resolution in particular areas and lower in others, the user may choose to identify areas for closer observation by increasing the intersection resolution.

In the event of an identified fall-related emergency instance, and as part of the intervention aspect, a series of interrelated yet independent low-cost and low energy-consuming intervention mechanisms are executed. The principal innovation with respect to this aspect lies in the technologically heterogeneous interoperability involved within and across said mechanisms. A unifying framework brings together proprietary services and technologies with open-source and accessible technologies to provide the user with free (in the case of Internet-based intervention notifications/actuations) or low-cost (in the case of 3G-based notifications/actuations) yet reliable solutions. Between the detection and the intervention aspects, three innovative consequences may be identified. The first removes the user from constant operational responsibility. After having provided the four givens discussed in Section 4.4, the system's operation is independent of user intervention. The second allows the user to personalize the system by enabling the creation of custom theoretical intersection grids with varying resolutions depending on preference or need. Finally, the third one brings together a variety of technological services at no additional cost (with respect to Internet-based notifications/actuations) or at very low cost (with respect to 3G notifications/actuations).

FaDIS is demonstrative of the potential of *Wireless Sensor Network* (WSN) technologies as facilitators of affordable and decentralized solutions. In order to demonstrate this, FaDIS was developed in two parts. In Part 1, it was developed to validate the feasibility of low-cost components as well as to demonstrate compatibility with existing centralized AAL solutions, thereby rendering it as at least a viable add-on if not a stand-alone solution. In Part 2, it was developed to confirm the reliable functionality of high-quality yet cost-effective components in real-scale environments as well as to demonstrate decentralized scalability and resilience with respect to evolving functional requirements (see Section 3). Part 1 was implemented within the context of the *PassAGE* project [4], where AmI systems were mediated via a central terminal; and Part 2 within that of the LISA Habitec project [5], where stand-alone terminals created a decentralized-yet-unified AAL environment. In both parts, FaDIS extended the systems initially deployed in their respective foundation projects. However, the true character of FaDIS as a cost-effective WSN-based solution that provides automated fall-detection and -intervention services is showcased in Part 2, which is the focus of the present paper.

In order to detail FaDIS, the paper is organized as follows. In Section 2, a brief overview of existing related solutions is provided. In Section 3, FaDIS's concept and approach are outlined in order to explain underlying design motivations. In Section 4, the methodology and implementation are described and justified in detail. In Section 5, the results of actual sample runs are extensively described and the corresponding limitations detailed, and the conclusions are provided in Section 5.

2. Related work

In this paper, FaDIS is discussed in two qualifications, i.e., as an intelligent service with the function of detecting unexpected collapsed objects, and as an example of WSN-based solutions. Since the WSN character of FaDIS is illustrative of a variety of other possible intelligent services, the promise of the second qualification takes precedence over the first. As a result, this section will juxtapose the advantages of WSN technologies over existing centralized AAL and AmI complete solutions. However, taken in its first qualification, FaDIS may be considered against similar promising intelligent services such as the fall-detection system based on Kinect's infrared sensors by Mastorakis and Makris [6]; the system based on smartphone devices by Wu [7] as well as Abbate, Avvenuti, Bonatesta, Cola, Corsini, and Vecchio [8]; and the fall-detection and intervention system based on wearable sensors by Wu, Zhao, Zhao, and Zhongs [9] just to name a few.[1] The salient difference between FaDIS and other solutions that offer similar services is that FaDIS is representative of an emerging type of decentralized solution whose core technologies may be used to spawn a variety of other services and functions that integrate seamlessly into one system architecture, which yields a more robust performance across the entire system.

The prevailing type of AAL solution is conceived as a highly integrated and personalized complete solution based on a centralized architecture. Based on this type of architecture there exist robotized and intelligent solutions—e.g., *RoboticRoom* [11], *Wabot-House* [12], *The Aware Home* [13]—as well as ambitious AmI and AAL implementation proposals that make use of sensor networks for intelligent robots [14]. But however promising these solutions may be, their cost still makes them available to only a minority of the aging population. One reason why these and other present solutions are costly is because the research and industry sectors tend to view them as "complete solutions," "often including overlapping of almost equal or homogeneous sensors." [15]. Another reason is because the computation of self-learning methods requires considerable infrastructure to produce a useful dataset from which to draw substantial conclusions. In more recent research projects—as mentioned by Chiriac and Rosales [16]—such as SAMDY [17] and eHome [18], these system costs alone "are estimated [to be] between 3,500 EUR and 5,000 EUR" [16]. Yet another reason is that AmI/AAL solutions require customized planning and installation by experts, which in part cause the "enormous costs of today's single solutions… which are too expensive for private buyers as well as health and care insurance providers." [19]. Moreover, activity-monitoring in AAL requires the implementation of a system that is able to track the movement and positions of the user. On the whole, indoor tracking solutions, based on triangulation methods etc., provide strong and reliable performance. But "these architectures require structured environments and consequently high installation costs" [20].

WSN solutions, however, provide a viable alternative. These WSNs do away with the notion that AAL solutions must be "complete solutions" where sensors and actuators are deeply embedded and integrated into the very architecture. WSNs are decentralized solutions that avoid the high costs generally associated with highly integrated systems. Georgoulas, Linner, Kasatkin, and Bock [21] showed that a solution that seeks to reduce complexity of functions—and therefore cost—should be one that does not have all services and functions centralized in a service robot or in a static location, but rather one that strategically distributes services along a decentralized controlled environment. Furthermore, WSNs are more energy efficient, and sensor nodes can be configured to shut down at particular intervals depending on particular needs and/or the desired sense-data resolution. This is a significant advantage over sensor nodes running on a wired or WiFi system, since these latter cannot be intermittently turned off without sacrificing performance and functionality. Over the last decade, and particularly in the last 5 years (see for example, [22–26]), work on Wireless Sensors and WSNs demonstrates excellent performance—in terms of

[1] For a comprehensive overview of current trends involving Android OS in fall-detection systems, refer to the discussion and comparisons provided by Luque, Casilari, Morón, and Redondo [10].

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