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EMFi-based low-power occupancy sensor

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ABSTRACT

The use of bed/couch occupancy sensors is imperative for certain ubiquitous computing systems such as ambient assisted living (AAL). DIA (Dispositivo Inteligente de Alarma, in Spanish) is an AAL system that allows to infer a potential dangerous action of a dependant person living alone at home. This inference is obtained by a specific sensitization with sensor nodes and a reasoning layer embedded in a personal computer. In this kind of systems, energy is a limited resource therefore sensor devices need to be properly managed to conserve energy. A first approach to solve the bed/couch occupancy detection problem is found in pressure mats, but several environmental dependencies make them weak to be an efficient and reliable solution for large volume deployments. Solutions based on force-to-resistor transducer imply a too high power consumption to be integrated on wireless sensor nodes. In our previous paper, an occupancy sensor based on force-capacitive transducer has been proposed, implemented and tested. This sensor is based on electro-mechanical film (EMFi) transducer which is able to detect force variations in a quasi-passive way and, besides, is a capacitor with variable capacitance depending on the static force exerted on its surface. This detection of force change is used to trigger an active mechanism to measure the weight by means of the transducer capacitance. In this paper, we present a new low-power circuit to measure weight, by means of the capacitance of the EMFi transducer, which enhances accuracy and power consumption, simplifies the signal sampling procedure and can be implemented as a standalone device. A low-power wireless sensor node prototype including this new design has been assembled and tested with a wide range of weights. The occupancy detection was successful and the power consumption of the occupancy sensor accounts for only 2%, which is acceptable for implementation.

1. Introduction

Increasing health care costs and an ageing population are placing significant strains upon the health care system. Small pilot studies have shown that seniors' needs for independence and autonomy can be satisfied with expanded use of home health technologies, providing improved care outcomes. Difficulty with reimbursement policies, governmental approval processes, and absence of efficient deployment strategies has hampered adopting non-obtrusive intelligent monitoring technologies.

In this field, DIA project (Dispositivo Inteligente de Alerta, in Spanish) is an AAL (ambient assisted living) system that aims to develop devices which detect behaviour patterns from their users (elderly person living alone at home) and use them to take alert actions when significant variations happened. This project is leaded by the company Ambient Intelligence and Interaction S.L.L. (Ami2) [1] in collaboration with Universidad Politécnica de Cartagena (UPCT) in the design and implementation of the sensory layer of the system [2], and with Universidad de Murcia (UMU) in the development of the reasoning and context extraction layers [3].

The occupancy detection in bed or seat is very important in AAL systems [4]. The main aim of this kind of sensor system is to monitor the bedtime use of an old person or a patient who is living all alone in a house. In this kind of situations, the bed-monitoring sensor can act as a lifesaver. By using the historical data points from its database, the system will decide whether to trigger an alarm signal, which alerts the concerned person, who can be a close relative or a caregiver, for an immediate medical assistance. The developed DIA system incorporated an implementation of these detectors based on contact mats deployed under the mattress, in the case of bed, or under a cushion, in the case of the chair or couch [2]. These detectors have presented serious problems to solve since their functionality is dependent on various environmental factors such as the type of mattress, mattress position or weight of the user. On the other hand, in ambient intelligence systems based on wireless sensor network like DIA, one of the most precious commodities is power. Sensor nodes can only operate as long as its battery maintains power. Low-power electronic devices (mainly micro-controller and radio) are used in our node design. These electronic components allow the use of small batteries for operation. The trend in ambient intelligence

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is towards more communication-dependent activities, with sensor nodes using wireless communication. This trend makes imperative that a power-efficient occupancy sensor node need to be designed.

We propose to solve both problems (energy consumption and functionality) by using MEMS (Micro-Electro-Mechanical Systems) in bed/couch occupancy sensor nodes. In particular, electro-mechanical film [5] (EMFi) based transducers can be used to implement foil capacitors, whose capacitance is dependent on the pressure supported by the surface. In this paper, we present a qualitative enhancement to our first implementation [6,7].

The background of the paper is presented in Section 2. It includes the related works to detect occupancy in bed or seat and EMFi technology-based sensors, the EMFi transducer characterization and the application scenario. The design and implementation, on a prototype, of the new sensor for the AAL system is described in Section 3. Results obtained from the different modules and the entire device are shown in Section 4. Conclusions and possible future work lines are referenced in Section 5. Finally, acknowledgments are collected in the "Acknowledgements" section.

2. Background

2.1. Related works

Pressure mats have been appropriate as a first approach to detect the bed or seat occupancy for AAL systems [2,8]. However, their functionality is dependent on various environmental factors such as the type of mattress and bed base or weight of the user. Its operation is simple. It consists of two foils separated by a layer of foam with cylindrical holes. Both sensor foils conform a normally open (NO) contact that closes under the weight of the user. The main disadvantage of this device is that, once made, its sensitivity is determined by the diameter of the holes. The sensitivity required is dependent on the type of mattress, bed base and weight of the user. The use of mats with different sensitivity to each individual is not feasible on a large scale. For these reasons, finding adaptive systems to maintain consumption and bounded cost is desirable.

Other recent works in the same field have opted for the use of sensors based on resistive transducers [9,10]. An example of this type of sensor is based on the FlexiForce® transducer from the manufacturer Tekscan [11]. This consists of two layers of substrate composed of layers of polyester. The transducer is modeled by a variable resistance depending on pressure on the sheet. Gaddam et al. from Massey University in New Zealand have developed a bed occupancy sensor that generates a digital signal indicative of such presence by implementing a configurable threshold [9,10]. Another device developed by the researchers is a smart occupancy/weight sensor which lets you know the weight distribution on the surface of the bed [10]. This type of sensor uses a FlexiForce in each of the legs of the bed and generates a weight vector which is subsequently processed.

These devices may be suitable for supporting AAL systems, except for their high energy consumption. In this sense, the previous authors do not address the energy consumption of the sensor. A quick inspection of their proposed circuit indicates that the consumption will always be greater than 12.5 mW (2.5 mA at 5 V). In ambient assisted living systems based on wireless sensor networks such as DIA, the energy consumption is a key to success or failure. This sensor is unsuitable for a network of wireless sensors powered by batteries, with average consumption of about 1 mW. The device proposed in the above publication incorporates a power supply for connection household power grid. This feature increases the cost of product and involves difficulties in the installation, operation and acceptance of the device. These difficulties are not present in battery powered devices.

Table 1
EMFIT transducer properties.

Property	Symbol	Value	Unit	Tolerance
Storage temp.	Ts	−40 to 50	°C	
Operation temp.	Tr	−20 to 50	°C	
Thickness	*D*	70	μm	
Sensitivity	Ks	25–250	pC/N	± 5%
Young's modulus	TD	0.5	MPa	± 50%
Operational pressure range	*P*	>100	N/cm^2	

In this paper a third alternative is proposed: the use of occupancy/weight sensor based on MEMS. Specifically, transducers based on EMFi [5] (*electro-mechanical film*) can be used to implement flat capacitors whose capacitance is dependent of the force applied to the surface. For some time, this type of piezoelectric film sensors has been used in various sensing tasks. EMFi sensor has been used to detect heart rate and breathing by Technical Research Centre of Finland (VTT) [12,13], the Tampere University of Technology [14,15] and some commercial companies. Tazawa et al. from Muroran Institute of Technology, Japan, researched avian embryos, and used various technologies to measure the Ballistocardiograms (BDG). They also used piezoelectric film in one of their publications [16]. Recently, Choi and Jiang, from Yamaguchi University describe a new wearable sensor probe with a couple of conductive fabric sheets material and a PVDF film material is developed [17].

A previous approach proposed that EMFi-based devices, properly covered, may be placed under one leg of the bed to allow to obtain an approximate measure of the applied force [6,7]. Periodic signals provided by the sensor node can be filtered by a specific circuit tuned by the EMFi transducer. Thus the capacitance of the transducer can be measured and hence the applied force. The sensor node can be calibrated on place, before their operation. This solves the problem of lack of adaptability. The calibration routines can be done using information extracted from the context. The measure of weight can be an active process and therefore involve a certain consumption. However, a circuit proposed by the EMFi manufacturers [18,19] can be implemented using a passive detector of weight change. The output of the detector can be used as an interrupt to the micro-controller of the sensor node and active measurements can be made only after detection of a variation. The authors pointed out that the occupancy detection was successful and the power consumption of the occupancy sensor accounts for 15%.

In this paper, we present a new low-power circuit to measure weight, by means of the capacitance of the EMFi transducer, which enhances accuracy and power consumption, simplifies the signal sampling procedure and can be implemented as a standalone device.

2.2. EMFi transducer: properties and features

Electromechanical film (EMFi) is a thin, cellular, biaxially oriented polypropylene film [20,21]. High sensitivity, light weight and relatively low cost are the main advantages on EMFi. The film has a permanent charge that changes when pressure is applied to the film. The applied pressure compresses the air voids of the thicker middle layer, which causes the charge change picked up by the surface electrode layers. This transducer can be modelled as a charge source which is dependent of dynamical forces applied on its surface as follows [22,5]: $\Delta Q = k_s \, \Delta F$, where k_s is the transducer sensibility. Main properties of the commercial model from manufacturer EMFIT, Ltd. [18] are shown at Table 1.

On the other hand, the transducer is a capacitor with variable capacitance depending on the force exerted on its surface. It has been characterized in this way in [7]. Tests have been performed for weights from 5 to 40 kg. We assume that the weight is distributed