Seat Occupancy Detection Based on Capacitive Sensing

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***Abstract*—This paper presents a simple yet efficient seat occupancy detection scheme based on a capacitive sensing principle. Parameters such as the presence, position, and type of the occupant of the seat are essential for successful air-bag control in vehicles. Without this information, during a collision, the air bag may be inflated to an empty seat (ES), wasting it and, hence, leading to allied repair and reinstallation. Also, if deployed, it can cause fatal injuries to infants in rear-facing infant seats. The proposed capacitive sensor system detects the presence of an occupant and provides information about the occupant's position. A prototype occupancy detection system has been developed, and the feasibility of the new method has been validated through practical tests. The developed system takes 200 μs to complete a measurement and, hence, promises real-time operation of the air-bag system. The presented method employs a carrier-frequency method and lock-in-amplifier technique to measure the capacitances. Thus, the influence of external electromagnetic fields on the final result is kept low.**

***Index Terms*—Capacitive sensor, carrier-frequency-based measurement, electric field sensing, seat occupancy detection.**

I. Introduction

AIR-BAG systems in vehicles play a crucial role in passenger safety. Air bags save thousands of lives each year, according to the National Highway Traffic Safety Administration, Washington, DC [1]. A typical airbag safety system consists of a set of crash sensors, a control unit, igniters, and air bags. The air-bag control unit, for its efficient operation, requires information about the presence, position, and type of the occupant of the seat. In the absence of this information, during an accident, the air bag may be inflated to an unoccupied seat, wasting it and, hence, leading to associated costly repairs. If the air bag is deployed to a seat that is occupied by an infant in a rear-facing infant seat, it can cause fatal injuries [1]. Automobile manufacturers are currently developing smart air-bag systems [2] that may be able to optimize deployment force based on parameters such as severity of crash and occupant type, size, and position. It is important for a sensing system to provide data on the aforementioned parameters at a sufficiently high rate to enable the air-bag control unit to take decisions dynamically.

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Efforts for sensing the presence of an occupant using pressure sensors [3]–[5] and occupant classification using stereovision [6] and optical sensors [7], [8] have been reported. The optical and weight-based systems are ill suited for dynamic observations. Forces during an incident can hardly be used to obtain information about occupancy. Optical sensors provide rather low sampling rates and require complex signal processing to cope with rapidly changing illumination levels, large data sets, etc. Capacitive sensors offer advantages in such situations. The relationship between the capacitances between the human body and nearby electrical wirings in a building has been studied in [9]. Detailed theoretical and practical aspects of electric field imaging have been reported in [10]. Seat occupancy detection based on electric field sensing has been presented in [10]–[12], which provides a comparatively low measurement rate. A capacitive sensing system with a low electric field radiation has been proposed [13]. An electric field sensor for human proximity sensing to be attached on the air bag inflator cover has been developed [14].

We propose a new seat-occupant sensing system based on a capacitive principle. It uses a single receiving electrode and multiple transmitting electrodes [15]. The proposed system provides information about the presence, type (distinguishes between adult and child occupants), and position of an occupant. The developed system typically takes 200 μs to complete a full set of measurements and, hence, enables the air-bag control unit to react in real time during an accident. The measurement principle employed is based on a carrier-frequency method [16] and uses a lock-in-amplifier technique. This technique promises a precise measurement of capacitance even in the presence of external electromagnetic interferences. As the system uses a single receiving electrode, the calibration of the system is much simpler in comparison to systems with multiple receiving electrodes. The principle behind human proximity sensing, the technique employed for capacitance measurement, details of the prototype occupancy sensing system developed, and test results are described in the following sections.

II. Capacitive Sensing for Seat Occupancy Detection

The sensor electrode arrangement of the proposed seat occupancy detection scheme is shown in Fig. 1. There are 11 transmitting electrodes $T_1, T_2, \ldots, T_{11}$ and a common receiving electrode R. The system makes use of the change in capacitance between the receiver R and each transmitting electrode to obtain parameters related to the occupant. The receiver

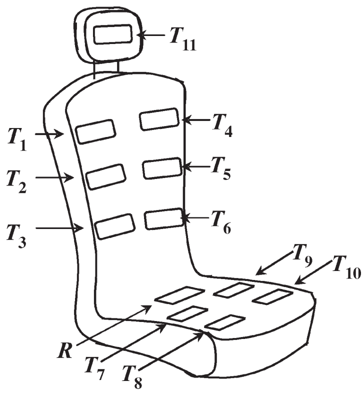

Fig. 1. Automobile seat equipped with the proposed structure of capacitive sensing electrodes. Electrode R in the sitting area is the common receiver, while electrodes $T_1, T_2, \ldots, T_{11}$ are transmitters.

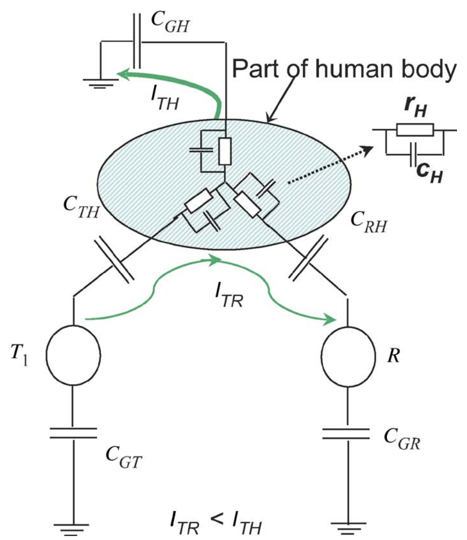

Fig. 2. Equivalent circuit showing the shielding effect by a human body. In shielding mode, current $I_{\rm TH}$ increases as the human body enters the vicinity of the sensor. Hence, the signal received by R is reduced.

electrode R is placed in the sitting area of the seat, as shown in Fig. 1. A conducting sheet is placed below the receiver and kept at circuit ground potential. An insulating layer is provided between the conductive sheet and the receiver electrode R. The conducting sheet shields the electric field lines that will otherwise reach R mainly through the seat material and structure, thus resulting in a large offset capacitance. An electrical equivalent circuit of the sensor system with a human body in the vicinity of the sensor electrodes is shown in Fig. 2. For simplicity, only one transmitter T_1 and the receiver R are used to explain the principle of operation. There are capacitances $C_{\rm TH}$ between the transmitter T_1 and the human body, $C_{\rm RH}$ between the receiver and the human body, and $C_{\rm GH}$ between the human body and ground. There are also capacitances $C_{\rm GT}$ and $C_{\rm GR}$ from the transmitter and receiver to ground, respectively. The part of the human body that is in the sensor vicinity is represented in the equivalent circuit with a parallel combination of a resistance r_H and a capacitance c_H [11], as shown in Fig. 2.

Let us consider that the transmitter is kept at an electric potential and the receiver is at circuit ground potential. Then,

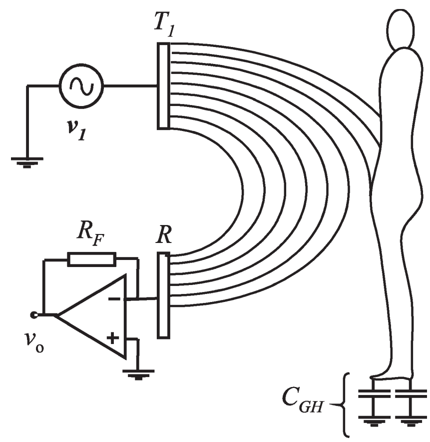

Fig. 3. Pictorial representation of the shielding of electric field lines due to the presence of a human in the far sensor vicinity. For clarity, the electric field lines from transmitter to ground are not shown. Similarly, the distributed capacitances between the human body and ground are represented by a lumped capacitance $C_{\rm GH}$.

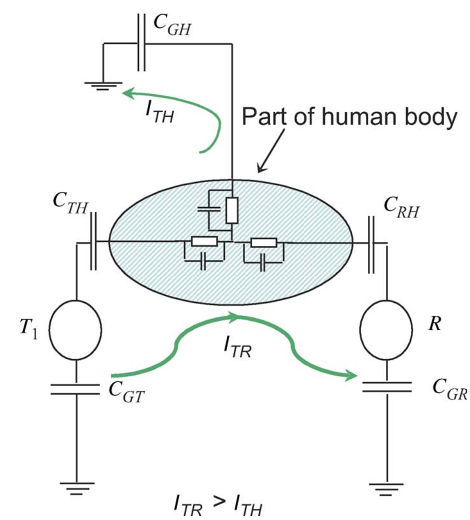

Fig. 4. Capacitances $C_{\rm TH}$ and $C_{\rm RH}$ are larger than $C_{\rm GH}$ when the human body is very close to the sensor vicinity. Under this condition, the coupling effect is more dominant than the shielding effect.

there will be electric field lines emanating from the transmitter to the receiver. Consider, as shown in Fig. 3, that only a small portion of the sensing volume is now occupied by the human body. In such a case, the human body shields some of the electric field lines as shown in Fig. 3. Consequently, the signal received by R and, hence, the output signal v_0 will be reduced compared to a vacant condition. In this mode, the capacitances $C_{\rm TH}$ and $C_{\rm RH}$ will be low in value as compared with $C_{\rm GH}$. Thus, as in Fig. 2, a significant part of the transmitted current $I_{\rm TH}$ will flow to the ground through the human body. Consequently, the displacement current $I_{\rm TR}$ that flows between the transmitter and receiver will be reduced. The receiver signal will gradually be reduced as the human body enters more into sensor vicinity. This continues as long as $C_{\rm TH}$ and $C_{\rm RH}$ are lower in value than $C_{\rm GH}$. This is called the shielding mode of operation. On the other hand, when the human body comes very close or is between the transmitter and receiver (refer to Fig. 4), $C_{\rm TH}$ and $C_{\rm RH}$ become much larger than $C_{\rm GH}$, and hence, $I_{\rm TH}$ will be much lower compared with $I_{\rm TR}$. Thus, the $I_{\rm TR}$ from