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A METHOD FOR SEAT OCCUPANCY DETECTION FOR AUTOMOBILE SEATS WITH INTEGRATED HEATING ELEMENTS

Boby George, Hubert Zangl, Thomas Bretterklieber and Georg Brasseur

Graz University of Technology, Graz, Austria, bgeorge@tugraz.at

Abstract − Seat occupancy detection systems based on a capacitive or an electric field principle, developed for an automobile seat, may not work well for seats with integrated electric heating systems. A new detection method, suitable for this type of automobile seats, is presented in this paper. In the proposed scheme, the heating element is a part of the sensor system while its operation as a heating element is kept unaffected. Results obtained from a prototype system demonstrate the practical validity of the method.

Keywords: Seat occupancy detection, capacitance measurement, synchronous detection.

1. INTRODUCTION

Passenger safety has considerably improved with the introduction of airbag systems [1], [2]. Seat occupancy systems provide information about the presence of a passenger to the airbag control system. The airbag system uses this data for making a decision to trigger the airbag in case of an accident, if the seat is occupied by a passenger and deactivate the firing of the airbags to vacant seats. This prevents the wastage of air bags and related costly repair. Fatal injuries have been reported when an airbag is executed with full power into a seat occupied by an infant [1].

Seat occupancy systems based on optical, vision, change in pressure or force, capacitive or electric field principles have been reported. Optical and vision based methods may not perform well for changing illumination intensity in the car [3]. They also have to process huge amount of data in order to obtain a final decision. Systems based on pressure or force sensing are directly based on the weight applied in the seat [4]. A belt-tightened empty baby seat or a basket of beer bottles may also be sensed as a human.

Capacitive seat occupancy systems mostly provide a simple and cost-effective solution [5], [6]. However, in most of the existing systems, the electrodes need to be placed in the surface or near the surface of the seat [6], [7]. Consequently, the overall seat manufacturing process is tedious and costly. Thus, the optimal location of the sensor electrodes is below the seat foam, fixed to the seat frame. It is found from our investigations that such systems may fail to function well for seats with integrated electric heating elements.

This paper proposes a method for seat occupancy detection suitable for automobile seats with electric heating elements. In the new method, the heating element is advantageously used as a part of the sensing system. A synchronous detection method [8] is employed to detect changes in capacitances owing to the presence of a passenger. The principle of seat occupancy sensing, the method of measurement and experimental set-up with results and conclusions are elucidated in the following sections.

2. METHOD OF SEAT OCCUPANCY DETECTION

Fig. 1 illustrates the basic principle of a capacitance based seat occupancy detection using the shielding effect [6] of electric field due to the presence of a human or part of human body within the sensing volume. The transmitter (*T*) is excited by a sinusoidal source v_1. The receiver (*R*) is connected to a low impedance shunt (A) to ground and its potential is kept nearly equal to ground. There are electric field lines, originating from the transmitter and ending at the receiver as well as near by surfaces at ground potential. An illustration of the useful electric field lines for human proximity sensing is shown in Fig. 1. When a human body approaches the sensing volume, some of the electric field lines get shielded. This generates a current flow I_{HG} through

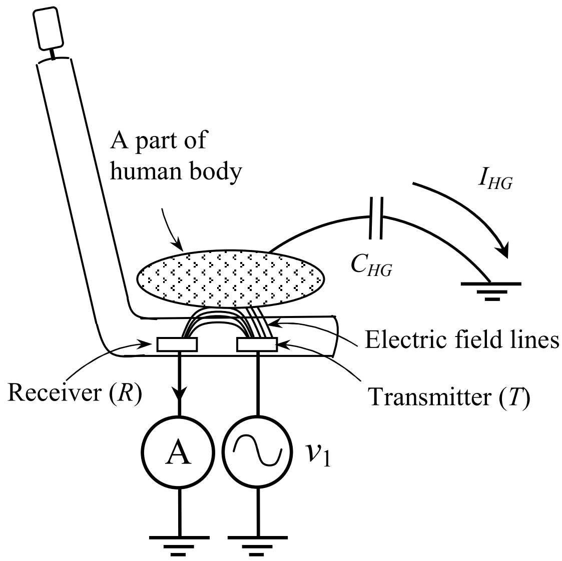

Fig. 1. Principle of seat occupancy detection based on electric field shielding. Parts of the electric field lines from the transmitter to the receiver are shielded by the human body. C_{HG} is the equivalent value of distributed capacitances between the human body and ground. ‘A’ indicates a low impedance shunt.

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the distributed capacitance C_{HG} that exists between the human body and ground. The shielding effect essentially reduces the number of field lines that are terminating on the receiver electrode. Hence, when a human occupies a seat, a reduction in the displacement current received by the receiver R is noticed. This feature can be employed for seat occupancy detection.

A class of seats that incorporates heating elements to provide better comfort to the passenger is already available in the market. A cross-sectional view of the sitting area of such a seat is described in Fig. 2(a). The transmitter and receiver electrodes of the capacitive sensor are also shown in Fig. 2(a). A top view of the same, with a typical structure of the placement of the heating element is illustrated in Fig. 2(b). The nodes p and q are the electrical input terminals of the heating element. The heating element is nearly at ground potential, hence a major part of the electric field lines emanating from the transmitter are shielded by the heating element itself. Thus, when a human comes close to the seat, very low additional shielding is observed and ultimately a reliable detection becomes extremely difficult with the basic method illustrated in Fig. 1.

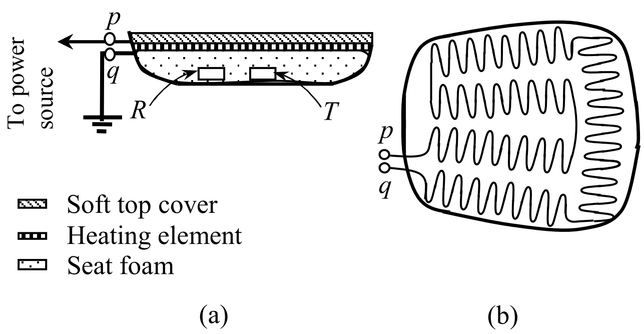

Fig. 2. A cross-sectional view (a) and top view (b) of the sitting area of the seat with integrated heating elements.

The method described above (Fig. 1) works well only when an electric field exists above the seat surface and a human body shields it. For seats with integrated heating elements as in Fig. 2, this condition can be achieved only when the heating element is in a floating condition. In such a condition, the heating element will have an electrical potential, due to capacitive coupling with the transmitter electrode, and therefore an electric field will be established around it. An ideal floating condition is difficult as the heating element is connected to a dc power supply (or a modulated voltage from a dc power supply). Nearly floating conditions can be reached by inserting inductors in both the input terminals p and q (refer to Fig. 2) of the heating element and performing the measurements at very high frequency.

A nearly floating condition can also be reached at a suitable measurement frequency if a parallel resonance condition can be achieved, with the help of the additional inductors, in the heating element circuit. In such a condition, the heating element reaches its maximum potential due to its capacitive coupling with the transmitter electrode. A method for achieving such a condition is explained next.

2.1. Introducing a resonance in the heating circuit

Fig. 3 shows the heating element with two inductors L_a and L_b connected to its terminals p and q respectively. C_T denotes the capacitance between the transmitter and the heating element. A pictorial representation of the electric field distribution is illustrated in Fig. 3. This is equivalent to the presence of a distributed capacitance between the heating element and ground.

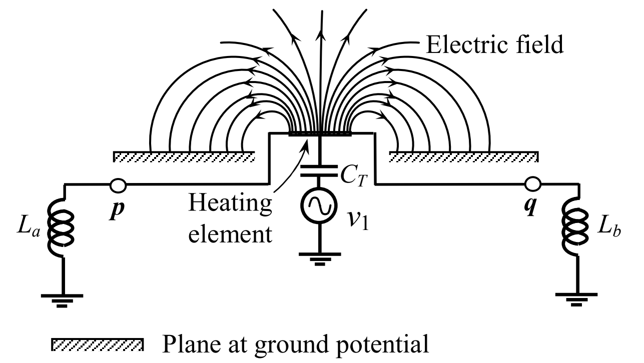

Fig. 3. Heating element of the seat connected to ground through inductors L_a and L_b. The heating element will be at a certain potential, due to the sinusoidal source v_1, and the coupling capacitance C_T. A pictorial view of the electric field is also shown

The value of this distributed capacitance depends on the area occupied by the heating element and its distance to the ground plane. For this seat system (according to Fig. 2), the ground plane is in a comparatively far location from the heating element. Therefore the distributed capacitance between heating element and ground is mainly depended on the surface area of the wire used for heating element [9] and the medium between the heating element and near by surfaces at ground potential. Thus, for such a given composition, the value of the distributed capacitance remains constant for a vacant seat condition. Let L_{EQ} be the equivalent inductance of the parallel combination of L_a and L_b and C_{EQ} be the equivalent capacitance of the heating element to ground. The resonance frequency f_r is given by

$$f_r = \frac{1}{2\pi\sqrt{L_{EQ}C_{EQ}}}. \tag{1}$$

The presence of L_a and L_b helps to achieve a resonance condition but introduces an additional impedance in the heating element circuit. This impedance can be minimised by replacing L_a and L_b with a Common mode Inductor (CI) as shown in Fig. 4. The CI connected in this manner provides a low impedance for a differential signal [10] and hence to the power supply of the heating element. This is, in particular, useful for a heating element connected to a modulated power supply. In contrast, the CI provides a large impedance to common mode signals, i.e., the measurement signal.

2.2. Equivalent electrical circuit

An equivalent electrical circuit of the entire system is depicted in Fig. 4. The capacitances C_{H1} and C_{H2} represent the equivalent distributed capacitance between the heating element and the ground plane. C_R is the capacitance between the heating element and the receiver electrode. R_{HE} denotes the resistance of the heating element. V_S is the dc power supply for the heating system. The switch S is used to regulate the heating system. The control voltage v_c from a temperature regulator controls the switch S.

Fig. 5 illustrates a simplified circuit of Fig. 4 at resonance condition (measurement condition) as explained in section 2.1. The coupled circuit is replaced by an equivalent common mode inductance L_E, provided by CI. The capacitance C_E represents the equivalent capacitance between the heating element and near by surfaces at ground potential. This includes a parallel combination of capacitances C_{H1}, C_{H2} and C_R. According to the equivalent circuit in Fig. 5, the equation for resonance frequency (1) modifies to

$$f_r = \frac{1}{2\pi\sqrt{L_E\left(C_{H1} + C_{H2} + C_R + C_T\right)}} . \tag{2}$$

A sinusoidal excitation v_1 at frequency f_r gives a parallel resonance condition for the circuit shown in Fig. 5. In this condition, the potential of the heating element attains maximum value as the current flow from v_1 to ground through L_E and C_E reaches its minimum. Thus, as can be seen in Fig. 4, the receiver (R) receives the maximum displacement current.

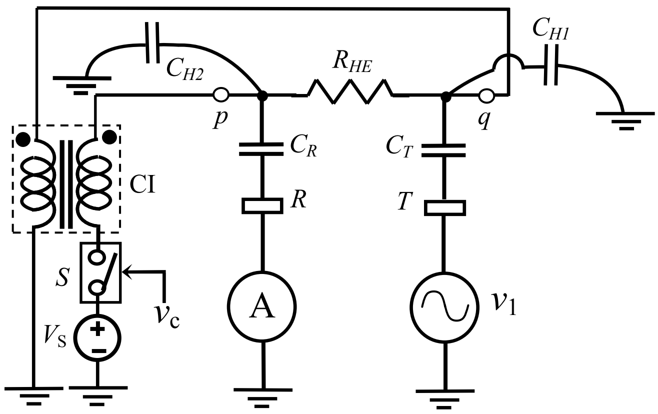

Fig. 4. Equivalent electrical circuit of the system. R_{HE} is the resistance of the heating element. C_{H1} and C_{H2} represent the distributed capacitances between the heating element and ground.

When a passenger (adult) occupies the seat, the capacitances C_{H1} and C_{H2} change. An adult human has good capacitive coupling [11] (above 100 pF) to ground. Thus, the presence of a passenger acts as a capacitive load for the heating element at resonance. Hence, the potential of the heating element reduces as the human body comes closer. This effect reduces the displacement current received by the receiver.

Another implication of the change of C_{H1} and C_{H2} is the shift in the resonance frequency f_r. For an adult occupied condition, the capacitances C_{H1} and C_{H2} increase. Consequently, the resonance frequency gets shifted to say f_{r1}. According to (2), $f_{r1} < f_r$, consequently the heating element circuit is no longer in resonance at f_r and thus it will not develop a useful electric field as described in Fig. 3. The change in output due to such a condition is significant especially for a heating element circuit with high quality factor. Ultimately, for a system with excitation frequency at f_r, considerably lower displacement current is received by the receiver, when the seat is occupied by an adult passenger.

Once an adult passenger occupies a seat, the seat foam gets compressed and the entire or part of the heating element, depending on the weight and position of the passenger, moves downwards by a few centimetres. These factors increase the values of the capacitances C_T and C_R. Hence, the receiver R receives more displacement current compared to a vacant condition. But this effect is low compared to the effect due to changes in capacitances C_{H1} and C_{H2}.

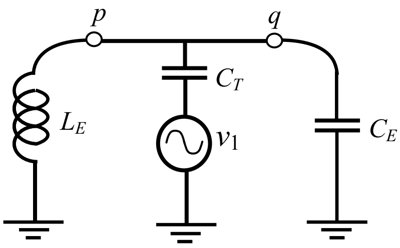

Fig. 5. Simplified electrical equivalent circuit showing the resonance condition. Capacitance C_E is the parallel combination of C_{H1}, C_{H2} and C_R. L_E is the effective inductance offered by the coupled inductor (CI) to a common mode signal.

2.3. Measurement Principle

A synchronous detection method [8] is used for the measurement of the displacement current received by the receiver R. Fig. 6 indicates a block diagram representation of the measurement system. The source v_1 provides a sinusoidal signal with variable frequency. During the

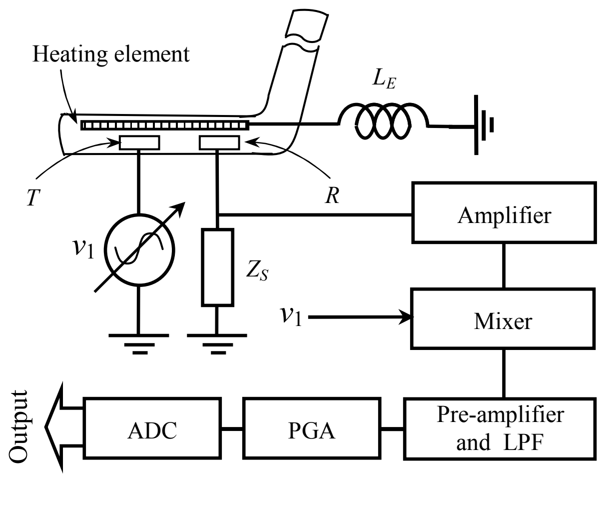

Fig. 6. Block diagram representation of the measurement set-up. During the investigations, the heating element was powered from a dc source V_S = 12 V.

measurement, the frequency of v_I is set to the resonant frequency f_r of the heating element circuit. The displacement current received by receiver R flows to ground through a low impedance shunt Z_S. The drop across Z_S is amplified before the mixer and Low-Pass Filter (LPF) stages. Offset voltages that appear at the output of LPF are removed [8] before giving the output of LPF to a Programmable Gain Amplifier (PGA). The PGA amplifies this offset compensated signal to an optimum voltage for the Analog-to-Digital Converter (ADC). The ADC provides the final output proportional to the displacement current received by the receiver.

3. EXPERIMENTAL SET-UP AND RESULTS

A prototype seat occupancy system has been developed and tested on an automobile seat. The transmitter and receiver electrodes were fabricated using copper sheets with 100 µm thickness. The transmitter and receiver electrodes have identical dimensions with a length of 12 cm and a width of 2 cm. These electrodes were fixed on an insulating medium with a thickness of 1.5 cm which was firmly fixed to the seat frame. Inductors were inserted between the dc power supply V_S and each of the nodes p and q of the heating element. The switch S was shunted with a 200 nF capacitor. This makes the switch to be a low impedance path for high frequencies even if it is in open condition, while this will not affect its low frequency operation as a switch. A measurement system, according to section 2.3, developed for capacitance measurement was used for measuring the voltage proportional to the displacement current (I_D). The details of this rapid prototyping system have been reported in [12]. In the beginning of the measurement, the frequency of the measurement source v_I was varied from 500 kHz to 5 MHz and occurrence of a resonance was noticed at 1.5 MHz. The resonance frequency was verified with a Network Analyzer, model 8712ET from Agilent Technologies. An excitation at this frequency was used for the investigations.

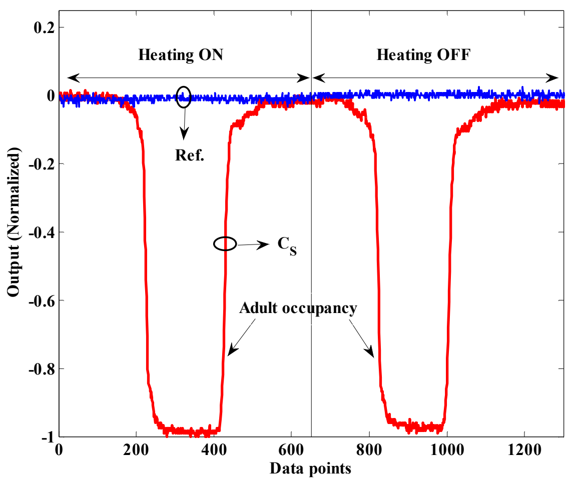

Fig. 7. Output signals recorded for an adult occupancy, when the heating element was turned ON (left side) and turned OFF (right side) conditions. C_S indicates the output from the sensor at resonance frequency. The reading corresponding to a vacant condition is shown by a reference (Ref.) signal.

A noticeable change in output (C_S) was observed for adult occupancy in comparison with the reading obtained for a vacant seat condition (Ref.). A typical change in output noticed for such a condition was recorded and shown in Fig. 7. Fig. 7 shows the output for adult occupancy when the heating element was switched ON and switched OFF respectively. The difference in readings between the ON and OFF conditions of the heating element was found to be less than 2 % of the output noted for an adult occupancy. Change in output was also noted for conditions such as presence of water bottles, mobile phones, vacant infant seats, and battery powered laptops. The changes noted in the output for the various test cases mentioned above were very low compared to an adult occupancy condition. The results are tabulated and given in Table 1. The change in output is comparable with an adult occupancy condition when a laptop connected to power supply was placed on the seat. This problem has been tackled by taking another simultaneous measurement, with the same sensor, at a frequency far below f_r. This has been successfully verified in the prototype.

Table 1. Capacitance change noted for different conditions.

Test conditions	Output (Normalized)
Adult occupancy	1.00
Water bottle (5 litres)	0.19
Mobile phone (dialling)	0.01
Infant seat (vacant)	0.06
Infant seat with a dummy infant	0.29
Laptop floating	0.06
Vacant seat	0.00

Fig. 8 depicts the output (C_S) of the sensor at resonance frequency and output (C_P) at 0.5 MHz for adult occupancy, electrically floating laptop and laptop (grounded position as far as the sensor is concerned) powered from main supply respectively. It can be seen that C_S shows similar output for adult occupancy and laptop in grounded condition but C_P gives large change for adult occupancy and very low change for laptop in grounded position. Thus, adult occupancy can be distinguished from a laptop in grounded condition. The change in C_P during adult occupancy is mainly due to the additional shielding of the electric field owing to the movement of the heating element in down-ward direction. This does not happen for a laptop, as its weight is very low compared to a human. Output C_P alone is not sufficient for reliable occupancy detection because it is also sensitive to weight of other objects such as water/beer bottles. Thus, C_S in combination with C_P, i.e. measurement with an excitation frequency equal to f_r and another frequency lower than f_r provides sufficient information for reliable seat occupancy detection.

4. CONCLUSIONS

A simple and efficient seat occupancy sensing system suitable for automobile seats with an integrated electric heating system is presented. In the presented sensing system, the presence of the seat heating element is advantageously used for occupancy detection. The sensor system introduces a few passive components in the heating system and does not affect the standard operation of it. A prototype detection system has been developed and tested. Test results from the prototype indicate the usefulness of the proposed method.

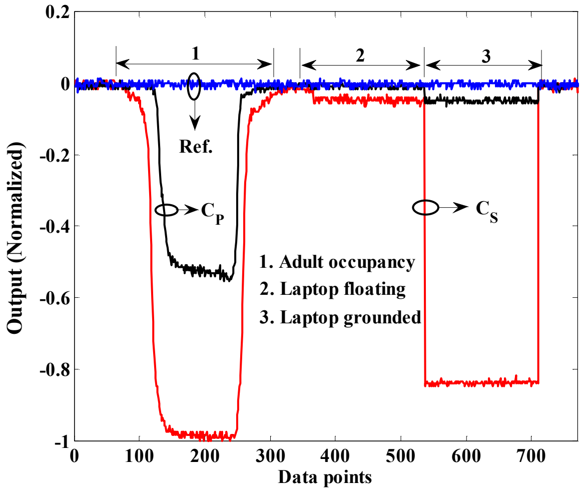

Fig. 8. Output signal obtained for conditions such as an adult occupancy, laptop floating and laptop grounded conditions respectively. The measurement result at f_r (1.5 MHz) is indicated by C_S and that at 0.5 MHz is marked by C_P.

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