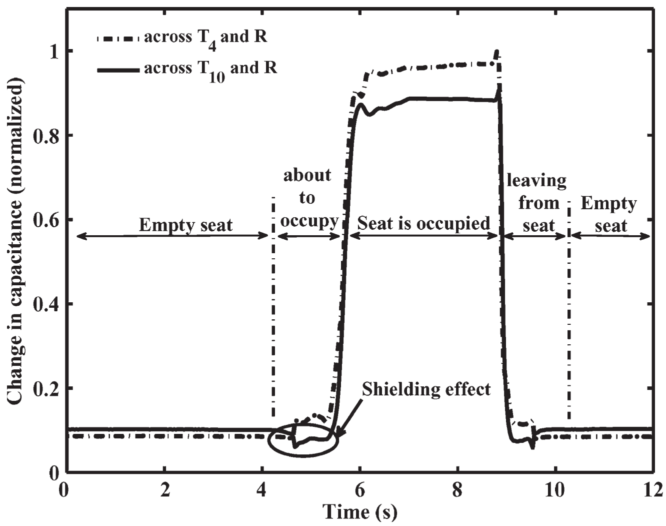

Fig. 10. Typical change in capacitance values observed with the prototype. Capacitance values were recorded between each transmitter and receiver for conditions such as when the seat is empty, when it is about to be occupied by an adult passenger, when it is occupied, and when the occupant is leaving the seat. Capacitances recorded between T_4 and R, as well as T_{10} and R, are shown here. As expected, capacitance values increase, due to coupling, when occupied by an adult. Shielding effect is also visible in the data from electrode T_{10} when the passenger is near and about to occupy the seat.

run in parallel to the data acquisition. Hence, the measurement time of the overall system can be equal to the measurement time of the sensor IC. Thus, the system takes up to 200 μs to complete a full set of measurements. Fig. 9 shows a photograph of the automobile seat equipped with sensor electrodes along with required sensor electronics. Shielded cables were used for the electrical connections from the receiver and transmitter to the sensor IC board. A virtual instrument has been developed in the LabVIEW environment to read the capacitance values, process the data, and give a display about the position and type of the seat occupant.

The developed system has been tested for different conditions of occupancy. Readings were recorded for the capacitance between each transmitter electrode and the receiver. The typical changes in capacitances recorded between T_4 and R, as well as T_{10} and R, when the seat is empty, when it is about to be occupied by an adult passenger, when it is occupied, when the passenger is leaving the seat, and when it is empty again are shown in Fig. 10. Electrode T_4 is situated in the backrest area while T_{10} is placed in the sitting area of the seat. As expected, capacitance values were increased, due to the coupling effect, when the seat was occupied by an adult. Shielding effect was observed in the data from electrode T_{10} when the passenger was near and about to occupy the seat. The measured values of capacitances for ES, AO, FB, Turned Right (TR), Turned Left (TL), and Legs Up (LU) conditions were tabulated and given in Table I. Readings are normalized using the maximum value observed for the condition AO. A large amount of change in capacitance was observed between ES and AO conditions. As expected, the capacitances measured across T_1, T_4, T_{11}, and R were decreased when the occupant was in an FB position. T_1 and T_4 are in the top row of the backrest area, and T_{11} is in the head position of the seat. When the occupant was in position TR, the coupling with electrodes in the left column of the backrest area of the seat got reduced. Hence, the capacitances between T_4, T_5, T_6, and R were much lower than those for the condition AO. Similarly, the coupling with electrodes in the right column increased, and a corresponding increase in measured values from T_2 and T_3 were observed. In position TR, the shoulder and head portions of the occupant were moved forward. This was observed as a corresponding reduction in capacitance from the reading of T_1. Similar effects were observed when the occupant was in condition TL. The characteristics were similar, except for the fact that the right and left columns of electrodes have an opposite effect as compared with the case TR. It is an out-of-position condition if the occupant keeps the legs in upward direction while sitting. In such a condition, coupling with the outermost electrodes from the sitting area of the seat alone will be reduced. As expected, readings from T_8 and T_{10} were low while all other readings were less affected. Tests were also carried out, placing a portable computer, textbooks (3.5 kg), plastic boxes, water bottles, leather bags, etc., in the seat. The capacitance change observed for each case were recorded, and the important situations along with the readings for an AO are shown in Fig. 11. It can be seen from Fig. 11 that the changes in capacitance values observed in the presence of a portable computer, textbooks, water bottles, etc., in the seat are not significant compared to the corresponding values during an AO. This indicates that, in most practical cases, the system can successfully distinguish an AO from the presence of other materials as previously seen and avoids the misuse of air bags.

Tests were also carried out to validate the performance of the developed system for various practical situations. Important test results are tabulated and given in Table II. For all the mentioned test cases in Table II, capacitance readings between T_3 and R are used. The reading obtained for a normal AO is taken as unity. The first test was to study the effect of the passenger wearing a wet cloth, for example, due to sweat. In order to test this condition, the sitting and backrest areas of the seat were covered with a wet cotton blanket of nearly 2-mm thickness, and then, an adult passenger occupied the seat. The capacitance values observed in this condition were 1.07 times more than its corresponding values for a normal AO. Thus, a passenger wearing thick wet clothes will be seen by the system as a human with a slightly enlarged size (1.07 times in this test case). However, the system can still successfully perform occupancy detection and classification as this condition is equivalent to a person with a bigger body size occupying the seat. The effect of wearing a thick pullover garment (as a sweater) was also tested. Two layers of pullovers, each with a thickness of 4 mm, were used. As expected, the capacitance readings decreased because of the presence of the pullover material with low relative permittivity between the electrodes and the human body. The use of special seat covers made of wooden or cotton material is common to improve the sitting comfort. The capacitance measured with the presence of such a cover was nearly 0.04 per unit higher than an ES condition. The aforementioned test cases, namely, wearing a wet cloth and a pullover garment and placing a seat cover, nearly equally alter the capacitances between every transmitter and receiver and hence effectively allows the correction for such environmental effects. The capacitance reading was 0.16 per unit higher than an empty condition when a