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Smart-surface: Large scale textile pressure sensors arrays for activity recognition

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ABSTRACT

In this paper we present textile-based surface pressure mapping as a novel, unobtrusive information source for activity recognition. The concept is motivated by the observation that the vast majority of human activities are associated with certain types of surface contact (walking, running, etc. on the floor; sitting on a chair/sofa; eating, writing, etc. at a table; exercising on a fitness mat, and many others). A key hypothesis which we validate in this paper is: by analysing subtle features of such interaction, various complex activities, often ones that are difficult to distinguish using other unobtrusive sensors, can be well recognised. A core contribution of our work is a sensing and recognition system based on cheap, easy-to-produce textile components. These components can be integrated into matrices with tens of thousands of elements, a spatial pitch as fine as 1 cm^2, temporal granularity of up to 40 Hz and pressure dynamic range from 0.25×10^5 to 5×10^5 Pa. We present the evaluation of the concept and the technology in five scenarios, through matrix monitoring driver motions at a car seat (32×32 sensors on 32×32 cm^2), a Smart-YogaMat (80×80 sensors on 80×80 cm^2) detecting and counting exercises, to a Smart-Tablecloth (30×42 sensors on 30×42 cm^2) recognising various types of food being eaten.

1. Introduction

Virtually all human activities involve interaction with surfaces. At the very least, due to gravity, some parts of the body need to be in contact with a supporting surface (ground, chair, bed, etc.). In addition, many actions involve hand interactions on surfaces such as tablets, tables or work benches. The work described in this paper is motivated by the hypothesis that most of such activities can be associated with characteristic spatio-temporal pressure patterns on the respective surface. A key insight is that such patterns are not limited to activities directly related to the respective surface (e.g. steps on the ground or hands operating something located on the table). Instead, vibrations, changes in centre of gravity and balance shifts propagate throughout the entire body, causing for example hand actions to influence the pressure distribution of the bottom of the feet on the ground. Thus, as will be shown later on, when a person is standing in front of a cupboard the pressure distribution on the bottom of the feet is different when reaching for the top shelves, for a middle or the bottom shelves (see Fig. 8). Similarly, when a person is lifting weights while standing, the rhythm and balance of the lifting motion is reflected in the pressure distribution on the ground. On a more direct level, cutting, poking on a plate or scooping food from it each produces a distinct pressure pattern on the table (Fig. 9).

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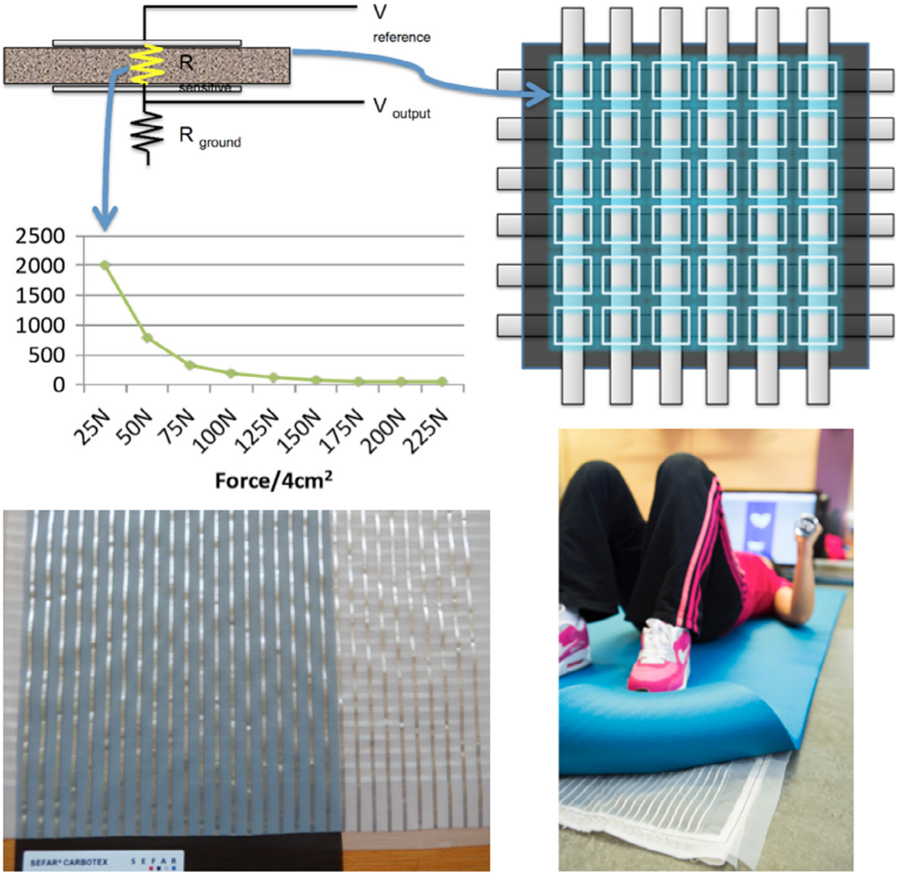

Fig. 1. The pressure sensing matrix—physical model, implementation and usage in sport.

Table 1
Overview of applications with Smart-Surface for activity recognition. Results are given in person-dependent/person-independent recognition rate. Details of each application are given in Section 4. (p = participants).

Application	Sensor position	Sensor type	Collected data	Recognition rate
Pervasive control interface	on sofa	30 × 30 sensor matrix	6 p/60 × 15 gestures	96.0/90.0%
Posture recognition	on car seat	32 × 32 sensor matrix	8 p/180 × 9 postures	85.6/71.1%.
Tracking of sport exercises	in sport mat	80 × 80 sensor matrix	7 p/140 × 10 exercises	88.7/86.4%
Activity recognition	on floor	32 × 32 sensor matrix	11 p/220 × 7 actions	81.0/78.7%
Nutrition monitoring	on dining tablet	30 × 42 sensor matrix + 4 FSR	5 p/40 meals (15–40 min each)	87.1/71.4%

From the above considerations the contribution of this paper is threefold:

1. We present **Smart-Surface**, a cheap, unobtrusive textile pressure sensing matrix (see Fig. 1) that allows the acquisition of surface pressure distribution patterns with large temporal and spatial resolution and high dynamic range (1 cm^2 pitch, 40 Hz, from 0.25×10^5 to 5×10^5 Pa, details in Section 2).
2. We present a general processing chain (see Fig. 3) suitable for extracting activity related information from the signals of our sensing system.
3. We evaluate our system in 5 experiments (see Table 1): gesture recognition as a pervasive user interface on a sofa surface, posture/activity recognition on a pressure sensor matrix augmented car seat, sports exercise monitoring using a pressure sensitive yoga mat, upper body activity recognition using floor/carpet mounted pressure sensor matrix, and nutrition monitoring using a pressure sensitive table cloth.

The focus of our work is on demonstrating the diversity of activities that can be recognised with a relatively simple sensor. This includes activities that are (1) not obviously associated with surface pressure and/or (2) contain information that is difficult to recognise using other common unobtrusive sensing modalities such as inertial measurement units (e.g. balance of weight). Thus the detailed data mining techniques for each application are not the focus. Instead we present the general processing chain and the overall recognition accuracies. We have presented 4 out of the 5 applications as conference papers, in which the data mining details can be found [1–4].