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# Posture Sleeve: Using Smart Textiles for Public Display Interactions

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**Abstract**

Today, public displays are used to display general purpose information or advertisements in many public and urban spaces. In addition to that, research identified novel application scenarios for public displays. These scenarios, however, mainly include gesture- and posture-based interaction mainly relying on optical tracking. Deploying optical tracking systems in the real world is not always possible since real-world deployments have to tackle several challenges. These challenges include changing light conditions or privacy concerns. In this paper, we explore how smart fabric can detect the user's posture. We particularly focus on the user's arm posture and how this can be used for interacting with public displays. We conduct a preliminary study to record different arm postures, create a model to detect arm postures. Finally, we conduct an evaluation study using a simple game that uses the arm posture as input. We show that smart textiles are suitable to detect arm postures and feasible for this type of application scenarios.

**Author Keywords**

Smart Textiles; Public Displays; Posture Detection

**ACM Classification Keywords**

H.5.m [Information interfaces and presentation (e.g., HCI)]:  
Miscellaneous

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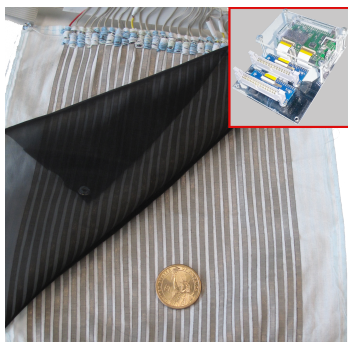
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## Introduction and Background

Public displays have become common in urban landscapes. While they are currently used to display either general information or advertisement, research has identified interesting application scenarios for such displays. Most of these application scenarios require some form of interaction which in many cases is an optical tracking system such as the Microsoft Kinect [7, 8]. Gesture and posture interactions show several advantages compared to other forms of input. While they are easily implementable in a lab setting, real-world deployments face several challenges such as bad lighting conditions or privacy concerns through the camera in public space. In contrast to optical tracking systems, wearables have been shown to be capable of providing similar information on the user's posture and body movements [4, 5]. In this work, we explore how smart textiles can be used to interact with a public display. We used a touch-sensitive sleeve that detects the angle of the user's arm. We report on a preliminary study that is used to record different arm postures and develop a model of the arm posture based on the recorded data. We also report on an evaluation using a simple game that uses the user's arm posture as input.



**Figure 1:** Used touch-sensitive fabric and used processing board (top left).

## Posture Sleeve

Resistive fabrics have been used to measure several different inputs of the user ranging from explicit gesture input [6] to implicit movement while exercising [10]. In this work, we explore how the arm posture of the user can be detected with a smart fabric and can be used as input.

### *Resistive Sleeve*

We use a resistive, touch-sensitive fabric that is similar to smart fabric developed by Zhou et al. [9]. The smart fabric itself consists of three layers. On the inner sides of both outside layers, groups of 32 parallel conductive stripes (width of the stripes: 3mm; distances between the stripes:

2mm) are attached to the fabric (see Figure 1). Both outside layers are placed perpendicular to each other. A force sensitive fabric is placed between the outside layers. This fabric changes resistance based on the applied vertical pressure. Thus, each crossing of two conductive stripes acts as a resistive sensor and can individually be accessed.

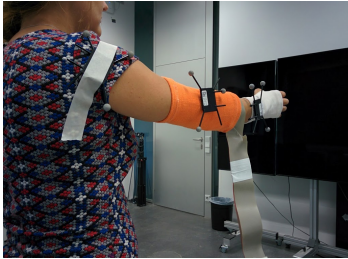
The smart fabric has a size of  $16 \times 16$  cm and contains 1024 individual pressure sensors (i.e., 32 by 32 overlaps of the conductive stripes). A small processing board is connected via cables with the smart fabric (cf. Figure 1, – top left). The processing board has a sampling rate of 50 Hz and forwards the sensed information in real time by a wired and wireless connection.

## Exploring Arm Posture

We conducted a preliminary study to record different arm postures, namely, the angle of the elbow joint. We recorded the data from the smart sleeve as well as the angle and created a model mapping different pressure values to specific angles of the elbow joint.

### *Apparatus*

For the data collection, we used the smart sleeve as well as an OptiTrack system (consisting of 14 Flex 3 cameras with a sampling rate of 100 Hz, and a desktop computer to operate the OptiTrack software). To record the arm posture, we attached in total three OptiTrack rigid bodies with three markers each onto the participant's arm. The first rigid body was placed on the shoulder, the second rigid body was placed at the outer part of the elbow joint, and the last rigid body was placed at the wrist. Therefore, we are capable of establishing a baseline of the angle of the elbow joint. Figure 2 displays the smart sleeve and the rigid bodies placed at the participant's arm.



**Figure 2:** Participant during the data collection pre-study equipped with the posture sleeve and three rigid body markers placed at the arm.

### *Participants & Procedure*

We invited ten participants (four female, six male) to the user study. Our participants were aged between 19 and 26 years ( $M = 22.30$ ,  $SD = 1.95$ ).

After arriving at the lab, participants first signed an informed consent form and filled out a demographic questionnaire. Afterwards, we placed the smart sleeve on the participants' arm to measure the angle of the elbow joint. Also, we placed three rigid bodies on the participants' arms. In the study, we asked the participants to execute four different activities twice. Once with the sensing fabric placed on the inside of the arm and once with the fabric placed on the outside of the arm. We counterbalanced the fabric position to avoid sequence effects. First, we asked our participants to bend and stretch their arms to measure the minimum and maximum angles of their elbow joints. Afterwards, we asked the participants to execute gestures of three everyday activities. We used the activities to get more realistic movements that might occur during everyday interactions. The first activity was to pick up a glass from a table and to drink a sip. For the second activity, we asked the participants to move their smartphone from their trouser pockets and to their ears and back to the trouser pockets to simulate answering a call. Third, we simulated the motions of executing a dumbbell training. During the execution of all gestures, we recorded data sets of the smart sleeve with a frame rate of 50 Hz as well as the positions of the OptiTrack markers with a frame rate of 100 Hz.

### *Data Analysis*

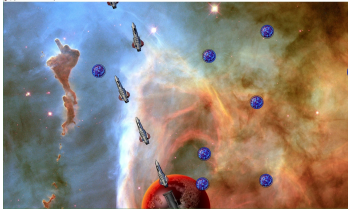
In a first preprocessing step, we mapped the recordings from the smart sleeve as well as the OptiTrack system. The sampling rates of the OptiTrack system and the smart sleeve (OptiTrack 100 Hz, Smart sleeve 50 Hz) differ. Thus,

we used two data recordings of the OptiTrack and calculated the arithmetic mean.

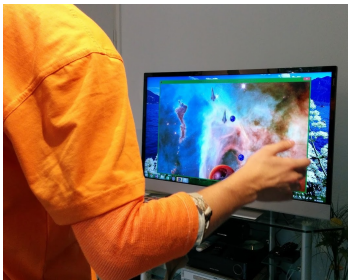
Then, we calculated the vectors between the shoulder and the elbow joint as well as the vector between the elbow joint and the wrist using the OptiTrack data. We used these vectors to calculate the angle of the participants' elbow joints. For the recorded data from the smart sleeve, we first reduced the noise in the data by including a threshold defining a minimum pressure value counting as an intended input. Additionally, we ignore all sensor values exceeding the threshold which do not have at least three neighbors that also exceed the threshold. This prevents that folds in the sleeve influence the recorded data.

For the development of a model to determine the angle of the arm, we investigated three different feature sets. As first feature set, we used a set of statistical features (average value, standard deviation, the sum of all sensor values, amount of sensors that exceed the threshold for intended touch interactions, maximum sensor value, and the minimum sensor value). As second feature set, we used the same statistical features that we used in the first set but z-transformed them. For the last feature set, we used the Haralick features of the sensors data [3]. Haralick features analyze the characteristics of textures by investigating the spatial distribution of the data.

Then, we analyzed all three feature sets for both placements of the smart sleeve (i.e., inner and outer side of the participants' arms) using a 10-fold cross-validation approach using the Random Forest algorithm as the classifier. The results of all the cross-validations are displayed in Table 1. The best classification rate with 95.54% ( $MAE = 8.28$ ) was reached using the Haralick features recorded at the inner side of the elbow joint.



**Figure 3:** In the game "Flying Saucer Attack" the user has to defend the red planet in the middle against attacking blue UFOs. The game uses the user's arm posture to control the direction of the rocket (and the missile(s)) in the middle of the red planet. When a missile hits a UFO the UFO is destroyed, and the planet is saved.



**Figure 4:** Participant playing the game in the evaluation study.

Feature set	Elbow's inner side	Elbow's outer side
Features 1 (statistical)	93.70 % (MAE: 9.84°)	90.17 % (MAE: 12.85°)
Features 2 (z-transformed)	90.90 % (MAE: 12.90°)	85.86 % (MAE: 16.93°)
Features 3 (Haralick)	95.54 % (MAE: 8.28°)	93.23 % (MAE: 10.74°)

**Table 1:** Classification rates resulting from the cross-validations according to the feature sets and the positions of the smart sleeve.

Based on the results of the classification, we decided to use the sensor data that was recorded at the inner side of the elbow joint with the Haralick feature set for the creation of our model for the arm posture detection.

### Evaluation Study

To evaluate our created model for the arm posture detection, we conducted a study in which the participants played a simple game. The game used the detected angle of the arm in real time as input.

#### Apparatus

We implemented the game "Flying Saucer Attack" that is controlled by the angle of the user's elbow joint. In the game, the user has to defend a small red planet against unidentified flying objects (UFOs) controlled by aliens. The red planet is located in the center of the bottom of the screen (cf. Figure 3). Every 1.5 seconds appears a new UFO at the top of the screen at a randomly determined angle to the planet from  $60^\circ$  to  $160^\circ$  in steps of  $5^\circ$  (in total  $N = 21$  angles). All UFOs attack the planet by moving towards the planet with a speed of 70 pixels/second. To defend the planet against the UFOs, the user controls the angle of a gun that activates a new missile every 300 ms automatically with the arm. The angle of a new activated

missile corresponds the angle of the user's elbow joint. Here, a stretched elbow joint corresponds to a gun oriented to the right. If a missile collides with a UFO, the UFO and the missile are destroyed. If a UFO reaches the planet, the game counts how many UFOs attacked the planet successfully, and logs the angle of the approaching UFO. In the game, the planet was attacked three times from all possible angles (i.e., 63 attacking UFOs). The game terminated automatically after the last UFO was destroyed or attacked the planet successfully. For the game, we used similar artwork as in the work of Alt et al. [1].

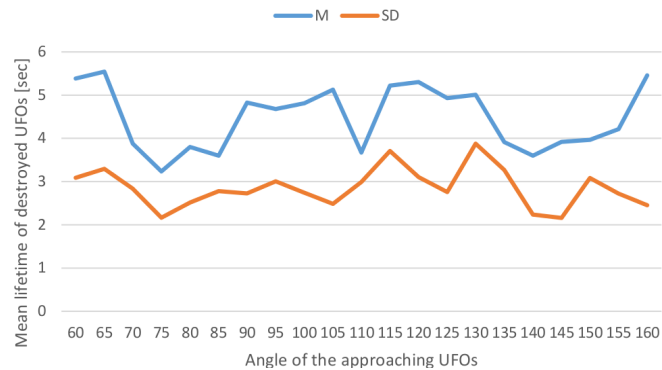
#### Participants & Procedure

In total, ten participants (two female, eight male) took part in our study. The participants were aged between 14 and 42 years ( $M = 24.40$ ,  $SD = 7.81$ ). All participants except one participant had not participated in the preliminary study. Further, all participants had no physical constraints on the movements of their elbow joints.

After the participants arrived in our lab, they signed a consent form and answered our demographic questionnaire. Then, we placed the fabric on the inner side of the participant's elbow joint. To avoid carry-over effects while playing the game, our participants played a trial round with the game, to get familiar with the interaction modality. Afterwards, the participants played a second round where we recorded the interactions.

#### Results

In total, 99.98 % of UFOs ( $SD = 0.02$  %) were destroyed by the participants before they could attack the planet successfully. The lifetime of a destroyed UFO was between 0.01 sec and 14.19 sec ( $M = 4.47$  sec,  $SD = 2.94$  sec). The mean lifetimes of the UFOs according to their approaching angles are displayed in Figure 5. Also, from zero to five UFOs ( $M = 1.10$ ,  $SD = 1.52$ ) attacked the planet suc-



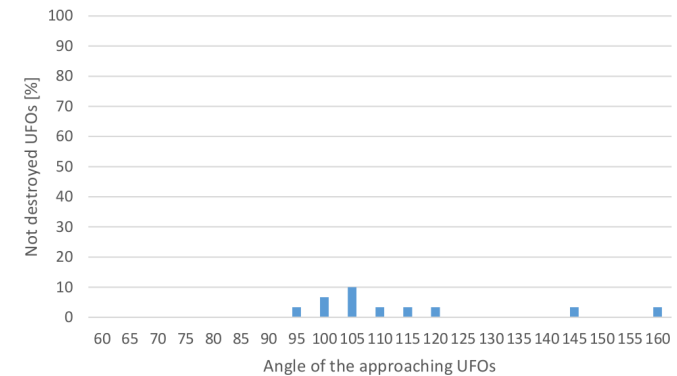
**Figure 5:** Mean lifetime of UFOs according to their angles.

cessfully per participant. The approaching angles of the not destroyed UFOs are displayed in Figure 6.

### Discussion and Limitations

The results of our evaluation study show that smart textiles integrated into a sleeve are suitable to detect the user's arm postures. In the conducted evaluation study we used the arm posture to interact with a simple game that could be displayed on public displays in the future.

However, if a smart sleeve is deliberately developed to support one purpose, e.g., to detect the arm postures for interactions with public displays, most users might not be convinced to buy such a textile. To provide real value to the end-user, a smart sleeve has to support several applications. Therefore, the hardware and software of a smart sleeve need to be decoupled to allow several applications using the textile for their own purposes [2]. For example, the smart sleeve could support activity recognition, e.g., for tracking sports activities. Thus, an end-user who is interested in tracking sports activities could customize the smart sleeve to track his dumbbell training to count repetitions or to avoid overstretching the muscles.



**Figure 6:** Surviving UFOs according to their angles.

In both conducted studies, we placed the smart sleeve using an elbow brace tight to the user's arm. In a real-world scenario, the users will wear the smart sleeve without an elbow brace. Thus, the textile might get wrinkled which could reduce the detection accuracy.

### Conclusion

In this paper, we explored the use of smart textiles for the interaction with public displays. We used a resistive smart textile to detect the user's arm posture by the angle of the elbow joint. We conducted a preliminary study to record different arm postures and a baseline using a motion capturing system. Furthermore, we developed a model of the arm posture based on the recorded data. We implemented a simple game that uses the user's arm posture as input. Finally, we showed that smart textiles are suitable to detect arm postures and feasible for this type of application scenarios that use the user's arm posture as input.

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