A Gesture-Based Door Control Using Capacitive Sensors

Steeven Zeiß, Alexander Marinc, Andreas Braun, Tobias Große-Puppendahl, and Sebastian Beck

Fraunhofer-Institut für Graphische Datenverarbeitung IGD,
Fraunhoferstraße 5, 64283 Darmstadt
{steeven.zeiss,andreas.braun,
tobias.grosse-puppendahl}@igd.fraunhofer.de,
alexander.marinc@gmail.com, s.beck@stud.tu-darmstadt.de

Abstract. In public places sanitary conditions are always of concern, particularly of surfaces that are touched by a multitude of persons, such as door handles in rest rooms. Similar issues also arise in medical facilities. Doors that open based on presence are common in environments such as shopping malls; however they are not suited for sensitive areas, such as toilet stalls. Capacitive proximity sensors detect the presence of the human body over a distance and can be unobtrusively applied in order to enable hidden gesture-based interfaces that work without touch. In this paper we present a concept for a gesture controlled automated door based on this sensor technology. We introduce the underlying technology and present the concept and electronic components used in detail. Novel interaction patterns and data processing methods allow to open, close, lock and unlock the door using simple gestures. A prototype device has been created and evaluated in a user study.

Keywords: Ambient Assisted Living (AAL).

1 Introduction

The importance of proper sanitation is a well-understood principle to help prevent the spreading of diseases. Door handles in public spaces can be used by hundreds of people in the scope of the day and may act as a source of infection by passing bacteria or different virus between persons [1]. Ideally, these surfaces should either be cleaned or contact be avoided. Automated doors are commonplace in modern environments, e.g. in front of shops, to allow easy entrance and minimize heating cost. However, these are limited to detecting the presence of persons and usually rely on a simple timer to close again. This prevents application in scenarios where the door requires more than one mode of operation, e.g. if it has to be locked and unlocked. In this paper we present a method for a gesture-based door control relying on a set of capacitive sensors that are able to detect the human body over a distance. Using a few simple hand gestures in front of an unobtrusively applicable box it is possible to control an automated door without touching any surface, thus considerable reducing associated health risks. We consider three different potential applications. Public toilets in

N. Streitz and P. Markopoulos (Eds.): DAPI 2014, LNCS 8530, pp. 207–216, 2014.

crowded areas can be visited by a large number of persons each day and have numerous lockable stalls. There are various technologies that improve sanitation, including automated flushing and self-cleaning seats, controlled using presence sensors. However, in order to lock and unlock the stalls it is still necessary to use a handle, as mere presence sensors do not have the required expressiveness to control the locking process. This can be achieved using a set of gestures and our proposed system. The second application area is hospitals. Sanitation is a major concern here and often doors have to be controlled without the use of hands, e.g. using foot switches. The automated doors typically only allow opening and self-close after a preset amount of time. Using our system it is possible to use dedicated opening and close gestures that could be also controlled with a foot-based system. A final application would be door controls for persons with physical disabilities. When there are limitations to the fine motoric skills of the user it is possible to configure the system in a way that it can be controlled by coarse gestures that are specifically tailored to a user.

On the following pages we will briefly introduce the technological basis of capacitive proximity sensors and discuss the related works before detailing the system design and gesture sets available to control the system. We will describe the components of the prototype we created, including components used. Finally, the results of a user evaluation testing the usability of the system will be presented.

2 Related Works

Capacitive proximity sensing is a fairly old technology, first introduced by Russian physicist Leon Theremin around 1918, who created an early electronic instrument – the eponymous Theremin [2]. It allows controlling pitch and volume of a generated sine wave by moving the hands in the range of two distinct antennas.

Fig. 1. Thracker prototype attached to a display [3]

The potential applications in HCI have been a research interest at the MIT in the 1990s [4]. Additionally, the technology has been used for different interaction devices in the last years [5, 6]. A closely related application is Thracker, developed by Wimmer et al. and shown in Figure 1 [3]. Using four sensors that are placed on the corners of a monitor it is possible to track the position of a hand moving in front of it and detect grasp gestures, in order to control typical UI functions, such as scrolling and zooming.

3 Capacitive Proximity Sensing

Capacitive sensors measure the capacitance of an electric system. Both the sensor and the human body act as a part of an electric field that is generated with regard to a common ground. Using a simple plate condenser model this relationship can be described using the following equations for capacitance C, charge Q, electrode area A, distance between plates d, vacuum permittivity ε_0, dielectric constant ε_r and electric field strength E [7].

$$C = \frac{Q}{U} = \epsilon_0 \epsilon_r \frac{A}{D} \quad , \quad E = \frac{Q}{\epsilon_0 \epsilon_r A}$$

Smith et al. distinguish three different measurement modes of capacitive proximity sensing of the human body [8, 9]. Transmit mode uses a dedicated sender and receiver electrode, whereas the sender is placed close to body creating a capacitive coupling, resulting the body to act as sending electrode. This allows the sender and receiver to be placed further apart. The second mode is shunt mode using a field created between a dedicated sender electrode and a dedicated receiver electrode. The human body entering this field causes a displacement current, reducing the overall capacitance that can be associated to a distance from the center point between the two electrodes. The final method is loading mode that uses a single electrode creating an oscillating electric field with regards to the environmental ground. If the human body enters this area, the capacitance of the system increases with regards to the proximity between electrode and body. The latter is used as method of choice for our proposed system. Loading mode allows for a simpler technical setup and increased detection distances on a planar and dense electrode layout.

4 System Design

As described in the previous sections, capacitive proximity sensors are employed when hand gestures close to the door have to be recognized. For a simple-to-build and low-cost setup, four sensors are sufficient and provide basic gesture recognition. These sensors allow for recognition of circular gestures and horizontal or vertical movements, also known as swipe gestures. The four sensor electrodes are arranged in a diamond shape, as depicted in Figure 2. For swipe gesture detection, only two sensors will be active: either the horizontal, or the vertical ones. The door lock is installed as a stand-alone, as it can be opened manually from one side only.

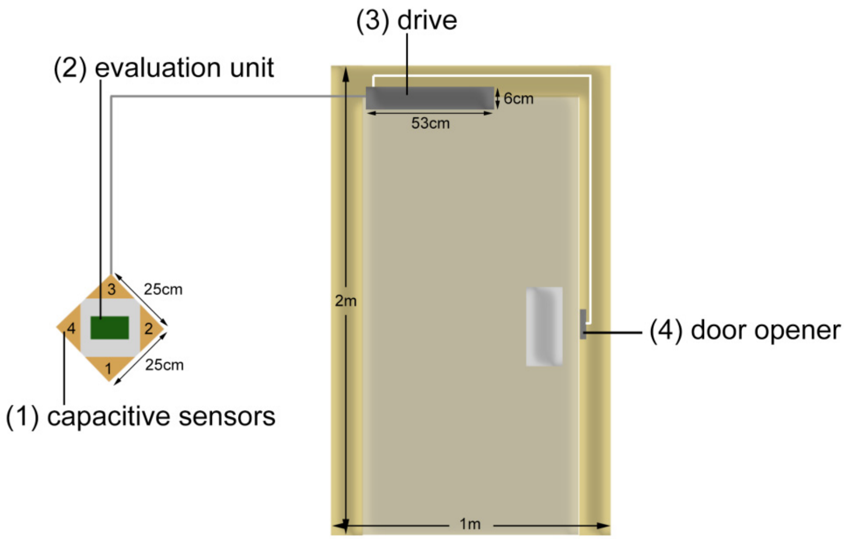

Fig. 2. Simple schematic of the installation

4.1 Gesture Control

The general process of recognizing gestures is depicted in a state diagram, shown in Figure 3. The microcontroller stays idle until one of the sensors' measurements exceeds a threshold value. Once that has occurred, the sensor's current ID is written into a buffer. Depending on the start- and endpoints of a gesture, e.g. when leaving and entering the interaction area, the buffer's values are matched to pre-defined sequences, similar to Dynamic Time Warping. In case no pattern was recognized, the microcontroller is turned back into idle mode and waits for the next gesture trigger. When a pattern has been recognized successfully, succeeding actions can be executed – for example opening of the door.

In order to recognize gestures, sets of predefined patterns are defined *a priori*. These patterns contain the sequential activation orders of the four sensors. As a simple example, pattern 12341 would represent a circular gesture, whereas pattern 1111444 would represent a vertical swipe gesture.

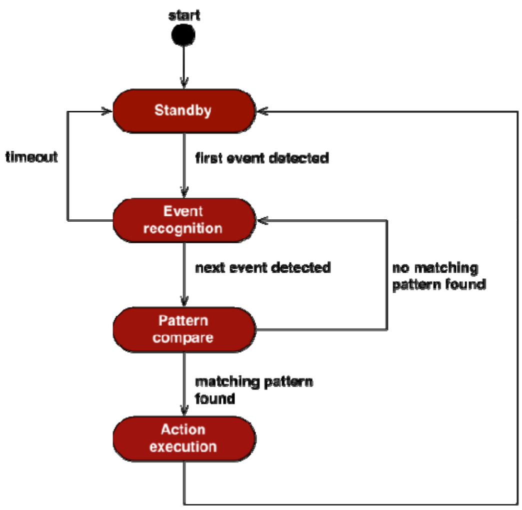

Fig. 3. State diagram of the event detection

4.2 Gesture Set and Triggerable Actions

A door can be reduced to four basic functions: Opening, closing, locking and unlocking. We diagramed these function as six different gestures: swiping horizontally, from left to right, and vice versa; swiping vertically up or down; and a circular gesture from left to right, and vice versa. In the following, we describe four different ways of matching these gestures to the actions the door can executed.

Method 1. Circular gestures are used to open and close the door, while vertical and horizontal swipe gestures lock and unlock the door. Method 1 bears the advantage that it is hard to open and close the door on accident. The necessity of this can easily be determined when considering application in a public restroom. For example, the gesture could accidentally be triggered when a person turns her back to the gesture recognizing surface. Circular gestures may happen less frequently by accident. In order to avoid unintended unlocking of the door, vertical swipe gestures are applicable.

Method 2. In this approach, circular gestures are mapped to locking and unlocking the door. This approach was developed in analogy to ordinary doors, as keys or door knobs are also turned around to lock and unlock the door. Moreover, the direction of locking and unlocking is also given by a natural mapping and habits. Thus, we argue that this is the most intuitive approach, and will prove this assumption in our evaluation. On the other hand, opening and closing the door is initiated by a horizontal or vertical movement. As explained in method 1, this bears the danger of opening or closing the door by accident when there is limited space around the gesture recognition. However, when the door is locked, an open gesture can be restricted: The door must then be unlocked prior to opening it. Figure 4 depicts the two different methods which are evaluated in our user study.

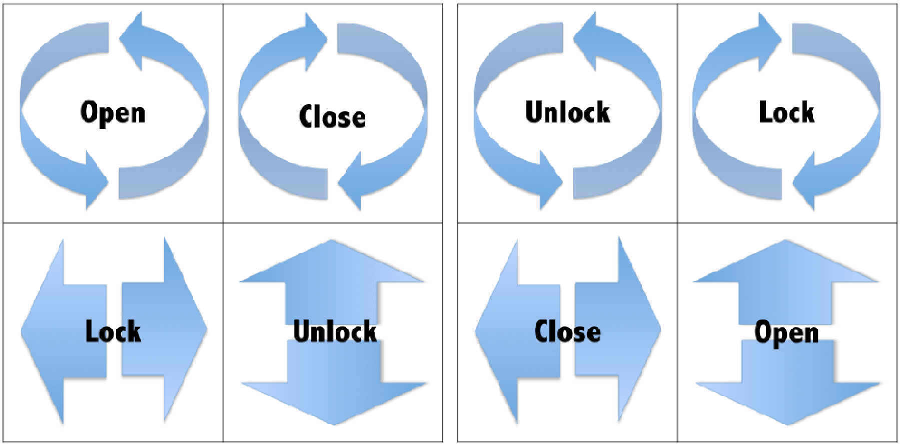

Fig. 4. Possibility 1 (left), possibility 2 (right)

4.3 Functionality and Implementation

Locking and Unlocking the Door. As described in the previous section, the setup does not depend on a dedicated door lock. When the door is closed, it may only be opened by manually turning the door knob on the inside of the restroom, or by gestures. To keep the option of manually opening the door is very important in case people find it hard to cope with gesture recognition systems, or in the event of electricity blackouts and evacuations within a building. Locking and unlocking the door is realized in software with the possibility of indicating the current state by a status LED attached to the gesture recognition device. Even though locking and unlocking is not really necessary, we argue that the psychological effect cannot be neglected with the intention of people feeling more secure when the door is locked. It is also imaginable to extend the setup by an additional capacitive sensor on the outer part of the door. This would allow for additional security when the door is opened after unlocking it.

Opening and Closing the Door. In the previous sections, we described the door motor-control with two input lines for mechanical buttons. Therefore, the enable signal is pulled to 3.3V. In order to trigger the motor control, two succeeding impulses must follow during the next second. Unfortunately, there is no way to distinguish between the actual door, as it is not communicated to the peripheral components (either open or closed). Therefore, an internal marker is used that saves the current state and may trigger a different system behavior.

5 Prototype

We have created a prototype of the system, as shown in Figure 5. It is a portable system with the door applied on a stand. Sensor and evaluation electronics are integrated into a single unit that only requires a power supply and a single connection to the motor control of the door. We are using a set of motor and locking mechanism provided by DORMA PORTEO.

Fig. 5. Overview of the prototype system. Left - door full view. Middle - door close-up of locking mechanism. Right - control unit open and closed view.

5.1 Sensor Electronics

The basic sensor is based on an oscillating circuit that changes frequency based on the capacitance of the system. The layout of the board is shown in on the left and is based on the IC TLC555 provided by Texas Instruments [10]. The system is grounded upon the OpenCapSense rapid prototyping toolkit for capacitive proximity sensing developed by Grosse-Puppendahl et al. [11].

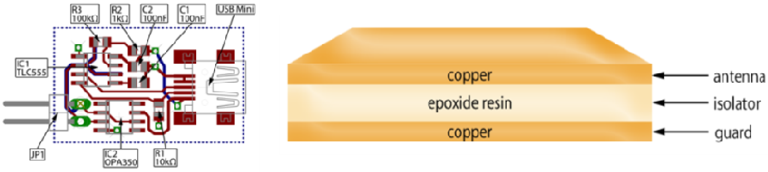

Fig. 6. Left: board layout of sensor module. Right: layer model of sensor electrode

Some features of this toolkit include different filtering algorithms, such as moving average or median filtering with a variable sample count. In this project we use a combination of arithmetic mean and moving average to generate a smooth signal for further processing. Additionally, we employ a guard electrode to prevent external electric fields from disturbing the measurements.

5.2 Motor Control

In order to control the different functions of the door, an interface between the control unit and an input channel of the motor control is used. As we are only in need of four of the eight provided sensor channels of OpenCapSense it is possible to use one of the free channels to control a relay attached to the door switches, as shown in Figure. 7. We employ a FTR-B4 provided by Fujitsu-Takamisawa that has low power consumption and can be controlled using the board supply of 5 V.

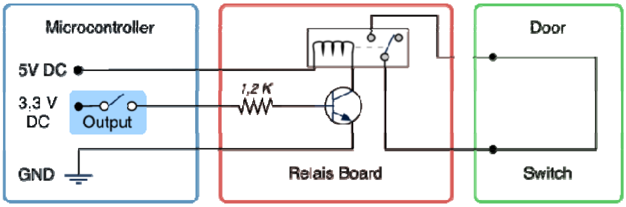

Fig. 7. Circuit diagram of the simulated switch

6 Evaluation

We have evaluated the usability of the system using our prototype. The control unit was placed at a height of about 1.20 m on the left part of the door frame. We wanted to compare both of the presented gesture sets and get a general feedback on the system concept. There were 16 users participating in the study (2 female) between the ages 21 and 35 (mean 27). They were randomly assigned an order of the two sets to avoid learning bias. Afterwards the users had to fill out a small questionnaire with various Likert-scale questions (scale 1-10). The error results are shown in Fig. x. There is a visible and fast learning effect from first to last gesture regardless of set, as the users were trying out the system at this point. The error rate on the second set was generally lower, implying a significant learning effect. There is no obvious preference for any set, however, circular gestures were considered more intuitive.

Related to questionnaire results, the perceived speed was ranked with an average of 7.13, which was somewhat below expectations as the system was designed to be usable swiftly. This can be attributed to the higher error rate when performing gestures. Many users tried to access the system from further away than possible. We also asked some questions regarding the use case of public toilets. The users considered hygiene to be very important in those areas, with a rating of 8.88. Finally the users would like a system such as this to be available in public toilets with a score of 9.25, indicating that the current hygienic standards may be insufficient.

The questionnaire also included open questions where users could state potential improvements of the system. Drawing from this, users would prefer a more concise visual feedback of the current system status. Our system used a single LED, which was not considered sufficient. The error rate was considered too high. It has to be determined whether an angled setup or optical feedback once the hand enters the detection area is more reasonable. Additionally, there should also be an acoustic or visual warning for people standing in the swing area of the door when it is moving automatically.

7 Conclusion and Future Work

In this paper we presented a gesture-based door control system based on capacitive proximity sensors that allows controlling doors in public spaces without touching any surface. We have provided the system concept and two sets of gestures that can be used to control the door. The system was implemented in prototypical form and evaluated in a study with 16 participants. The results show that the system is intuitive to use and that the subjects would strongly prefer this system to touching door handles in public toilets, indicating that this system is a viable alternative to current solutions. However, our system signifies only a first step in this direction and there are numerous improvements that can be applied to future iterations.

The door system we use does not provide its current state to our control unit, thus it has to be tracked with software. In the future, we plan on switching to a system providing this functionality, or integrate additional sensors that measure the state.

Another addition to the system, suggested by study participants, is providing a better visual feedback. It is particularly interesting to display whether a door is closed or open. We are considering using a LCD display that could provide an iconic representation of the system state if an error has occurred or if the hand is obstructing the gesture area. This feedback should ideally be available on both sides of the door. Finally, we would like to investigate other interaction systems that provide an even higher expressiveness. The Leap Motion allows for a fine detection of finger and hand locations [12]. This enables detecting actual gestures associated with doors, such as grabbing a virtual door handle or moving an imaginary key. Particularly for user groups that are often using these gestures, this might increase the intuitiveness and acceptance.

References

1. Barker, J., Vipond, I.B., Bloomfield, S.F.: Effects of cleaning and disinfection in reducing the spread of Norovirus contamination via environmental surfaces. J. Hosp. Infect. 58, 42–49 (2004)
2. Glinsky, A.: Theremin: Ether music and espionage. University of Illinois Press (2000)
3. Wimmer, R., Holleis, P., Kranz, M., Schmidt, A.: Thracker - Using Capacitive Sensing for Gesture Recognition. In: 26th IEEE International Conference on Distributed Computing Systems Workshops (ICDCSW 2006), pp. 64–64. IEEE (2006)
4. Zimmerman, T.G., Smith, J.R., Paradiso, J.A., Allport, D., Gershenfeld, N.: Applying electric field sensing to human-computer interfaces. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI 1995, pp. 280–287. ACM Press, New York (1995)

5. Braun, A., Hamisu, P.: Using the human body field as a medium for natural interaction. In: Proceedings of the 2nd International Conference on PErvsive Technologies Related to Assistive Environments - PETRA 2009, pp. 1–7. ACM Press, New York (2009)
6. Grosse-Puppendahl, T., Braun, A.: Honeyfish - A high resolution gesture recognition system based on capacitive proximity sensing. In: Embedded World Conference 2012, p. 10. WEKA Fachmedien, Haar (Design & Elektronik) (2012)
7. Baxter, L.K.: Capacitive Sensors. Sensors Peterbrgh, 1–17 (1996)
8. Smith, J.R.: Electric field imaging (1999)
9. Smith, J., White, T., Dodge, C., Paradiso, J., Gershenfeld, N., Allport, D.: Electric field sensing for graphical interfaces. IEEE Comput. Graph. Appl. 18, 54–60 (1998)
10. Schnabel, P.: Elektronik-Fibel. Elektron. Bauelemente, Schaltungstechnik, Digit 4 (2007)
11. Grosse-Puppendahl, T., Berghoefer, Y., Braun, A., Wimmer, R., Kuijper, A.: OpenCapSense: A Rapid Prototyping Toolkit for Pervasive Interaction Using Capacitive Sensing. In: IEEE Int. Conf. Pervasive Comput. Commun., vol. 18, p. 22 (2013)
12. SparkFun: Leap Motion Teardown, https://learn.sparkfun.com/tutorials/leap-motion-teardown