Multi-Touch Steering Wheel for In-Car Tertiary Applications Using Infrared Sensors

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ABSTRACT
This paper proposes a multi-touch steering wheel for in-car tertiary applications. Existing interfaces for in-car applications such as buttons and touch displays have several operating problems. For example, drivers have to consciously move their hands to the interfaces as the interfaces are fixed on specific positions. Therefore, we developed a steering wheel where touch positions can correspond to different operating positions. This system can recognize hand gestures at any position on the steering wheel by utilizing 120 infrared (IR) sensors embedded in it. The sensors are lined up in an array surrounding the whole wheel. An Support Vector Machine (SVM) algorithm is used to learn and recognize the different gestures through the data obtained from the sensors. The gestures recognized are flick, click, tap, stroke and twist. Additionally, we implemented a navigation application and an audio application that utilizes the torus shape of the steering wheel. We conducted an experiment to observe the possibility of our proposed system to recognize flick gestures at three positions. Results show that an average of 92% of flick could be recognized.

Categories and Subject Descriptors
H.5.m [**Information Interfaces and Presentation (e.g. HCI)**]: Miscellaneous.

General Terms
Measurement, Design.

Keywords
Automobile, Multi-touch, Torus Interface, Infrared Sensor, Interaction Design, Gesture Recognition.

1. INTRODUCTION
Automobiles are installed with in-car tertiary applications such as air conditioning, audio system and navigation system in order to improve the driving experiences. In addition, recently, a majority of automobiles are starting to get connected to the network, allowing communications such as mail and social networking service to be possible. In the near future, information offered by in-car applications will increase. Currently, most of the information are controlled by interfaces such as button and touch displays. However, as these interfaces are fixed on specific positions, the drivers have to consciously move their hands to operate them. This may cause drivers to be distracted during their driving operation.

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Figure 1: Multi-touch steering wheel.

In this work, we focus on developing an interface and applications that can control the information offered by in-car applications, without interrupting the driving operation. Thus, we propose a steering wheel where touch positions can correspond to the operating positions to control the information. As drivers have different methods of holding the wheel and many tend to move their hands to different position from time to time, we developed a multi-touch steering wheel for in-car applications that can recognize hand gestures at any position on the interface. These gestures, which include flick, click, tap, stroke, and twist, are detected by 120 IR sensors that are embedded in the steering wheel. Through this, drivers do not have to be conscious about the operating position on the steering wheel.

In this paper, we will also present a navigation system and an audio application utilizing this gesture recognition method. Driving-related activities are commonly classified into 3 categories [9]: 1) Primary tasks, for maneuvering purposes (e.g., steering and operating the pedals); 2) Secondary tasks: for safety purposes (e.g., signals, windshield wipers, etc.); and 3) Tertiary tasks: for comfort, information and entertainment purposes (e.g. navigation, audio system, and air conditioner). Our main target of this system is to address the tertiary tasks. We developed a navigation system and an audio application that can be operated by the steering wheel. Through this work, we aim for drivers to feel as though their body is augmented by using this system.

2. RELATED WORKS

2.1 Automobile Interfaces

In our proposed system, we utilized the Head Up Display (HUD). HUD is a technology commonly used in automobiles to superimpose images over the driving scene, to reduce the drivers' gaze movements and the accommodation time for their eyes to see information while driving [14]. Some of the in-car applications that utilize this technology are such as speed meter and navigation system. However, most of these applications are operated using buttons or touch display and thus, these may distract drivers if the position of these displays is away from the HUD. Previous researches have shown that the driver distraction can be reduced if the interfaces are on the steering wheel [2][3]. Therefore, we retrofitted an input system by embedding IR sensors into the steering wheel interface.

There are several previous works related to automobile input systems for in-car applications on the steering wheel. Gonzalez et al. embedded a touch pad on a steering wheel where drivers can operate using their thumb on the interface [4]. Doring et al. developed a multi-touch steering wheel that applies the frustrated total internal reflection (FTIR) principle to detect the drivers' thumb activities [2][6]. As these input systems are embedded on the steering wheel, it can reduce the drivers' distraction. However, the operating positions of these interfaces are fixed on specific positions. On the other hand, for our system, drivers do not have to be conscious of their hand positions as our system detects the drivers' gesture from any position on the steering wheel.

2.2 Photo Reflective Sensor Based Sensing Methods

In this work, we utilized IR sensors to detect the different gestures. There are a wide variety of researches that uses IR based sensing methods. Sugiura et al. proposed a small, flexible and wireless module consisting of IR sensors, to be embedded into soft objects to measure the shape deformation on the objects. [13]. This module can be easily inserted into soft objects without affecting its material properties. Similarly, we embedded IR sensors into steering wheel while keeping its torus shape.

In order to detect hand gestures from any position on the interface, we placed 120 IR sensors in an array. An array configuration is said to be able to detect multiple inputs from the users. Ogata et al. proposed a method to measure the deformation on the skin surface using IR sensor array, to recognize gestures on the skin [10]. Hachisu et al. developed an architecture that can measure the approaching velocity of an object and predict its contact time with the touch screen using two optical sensing layers [5]. This shows that placing IR sensors in an array has its advantage to detect multiple inputs.

2.3 Multi-touch Interfaces

Multi-touch interfaces have also been widely investigated. Matsushita et al. proposed a multi-touch wall called HoloWall [8], where an infrared camera is placed behind the wall to detect users gestures, to allow users to interact with the wall with their fingers, hands and body. Dietz et al. proposed a multi-user touch tabletop front-projected display [1]. It works by transmitting signals through the antennas in the table. Rekimoto also developed a new sensing architecture, known as SmartSkin, which is based on capacitive sensing [11]. This sensor recognizes multiple hand positions and shapes and calculates the distance between the hand and the surface. In this paper, we describe a gesture based multi-touch steering wheel by utilizing the limited operating space on a steering wheel. A previous research shows that gestural input on the steering wheel advantages over console interfaces in regards to the visual demand, as the drivers do not require to change their gaze position [2].

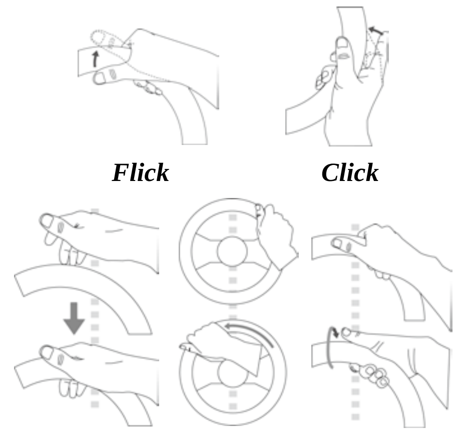

Figure 2: Gestures.

The existing multi-touch interfaces that are stated above are two-dimensional (2D) interfaces. Not limiting to 2D, there are methods to detect in 3D as well. Shizuki et al. proposed an interaction technique to browse 3D media by using a cylindrical multi-touch interface [12]. This system uses a cylinder wall as its controlling surface, to allow interaction in 3D space. In addition, a cylindrical interface for robot manipulation is also proposed [7]. Similarly, our multi-touch steering wheel can recognize three-dimensional inputs. Our system can detect gestures by utilizing the torus shape feature of the steering wheel. It will detect in two axes; stroking on the circumference interface and twisting the hands around the handle.

3. SYSTEM DESIGN

3.1 Gesture Design

As illustrated in Figure 2, the system can identify flick, click, tap, stroke, and twist gestures. In our proposed application, drivers can browse objects using the flick gesture and select them by clicking with the index finger. The advantage of these gesture is that drivers can apply them while remaining their grip on the steering wheel. Drivers can tap with their palm to select different tasks as well. For the stroke and twist gesture, we utilized the torus shape feature of the steering wheel. The stroke gesture is


Figure 3: Inner circuit (left), Embedded sensors (middle), Sensors in the steering wheel(right).

Figure 4:Detecting hand positions on steering wheel.

initiated when drivers move their hands along the edge of the steering wheel, while the twist will be initiated by rotating their wrist on the same position. Drivers can use both of these gestures to control volume or to zoom in and out a digital map.

3.2 Sensing Method

We utilize IR sensors to detect the gestures. This has several advantages such as; 1) it can detect hands that are covered with gloves, 2) it can be easily embedded in custom arrays and 3) as IR sensors can sense at a wide angle, the number of sensors can be reduced.

In order to recognize hand gestures at any position on the interface, the interface has to recognize the hand positions and its activities. Therefore, we embedded 120 IR sensors in an array into the steering wheel. Figure 3 illustrates the circuits and prototype of our system.

In the steering wheel, there are 30 small inner circuits around the entire circumference of the steering wheel. Each inner circuit (Figure 3 left) consists of 4 IR sensors, arranged at a short distance (less than the size of the thumb) apart, and an onboard local microcontroller. This microcontroller will convert the analog data to digital and will carry out all the noise cancellation and stabilization functions. All the processed data will then be communicated via an I^2C to the central microcontroller, which is located in the center of the steering wheel.

In our implementation, our system can detect fingers when the distance between the finger and the wheel is up to a maximum of 2cm. Our system updates at a rate of 10Hz, making it possible to identify fast gestures. With this system, drivers can operate the in-car applications without moving their hands to other positions. In addition, the torus shape of the steering wheel is maintained.

3.3 Gesture Recognition

In order to recognize gestures, the position of the hand has to be detected. It was found that 4 x 6 IR sensors would be enough to cover the domain of a hand. The system will obtains and averages the sensor data from the 30 different domains. Using these data, the system will be able to recognize hand positions as shown in

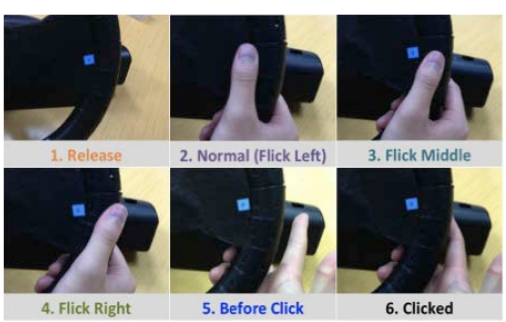

Figure 5: Hand shape patterns.

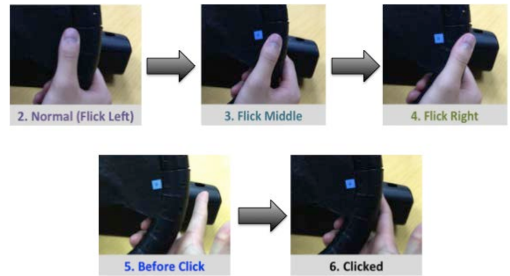

Figure 6: Flick flow (top), Click flow (bottom).

Figure 4. In the same figure, the brightness of the circles illustrates the intensity of sensors.

As mentioned, the system is capable of detecting 5 different gestures; flick, click, tap, stroke and twist. Here, both the flick and click gestures are based on finger activities. Movements of these gestures are smaller as compare to other gestures. These gestures are recognized by the hand postures and the movement of the gestures. In order for the system to recognize these gestures, we utilized a Support Vector Machine (SVM), a pattern recognition algorithm that has high generalization performance, to machine learn the gestures. There are 6 hand patterns to recognize hand postures (Figure 5) and these patterns are collected from 15 drivers to be trained by the system. The machine will also learn and recognize the different hand sizes of the participants. Flick and click gestures are recognized by the transitions of the hand patterns (Figure 6). The conditions of the transitions are not restricted in order to increase the gesture recognition rate.

On the other hand, the tap, stroke and twist gestures are influenced by the movement of the hand position. In order to detect these gestures, the movement of the hand position and the center of gravity are taken into account.

4. APPLICATIONS

Our main goal is to develop a steering wheel where touch positions can correspond to the operation to control the information offered by in-car applications. In this work, we utilize the head up display to preview the applications. In this display,

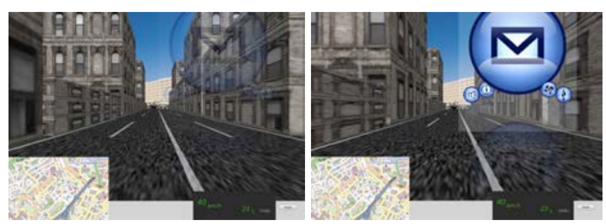

Figure 7: Menu off (left), Menu on (right).

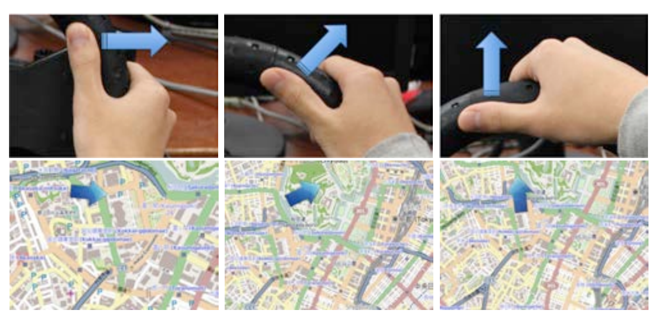

Figure 8: Operation to the right side (left), Diagonally upward side (middle), Upward side (right).

there is a menu function as shown in Figure 7. When driver grips on to the steering wheel, the menu function becomes effective. Drivers can browse the menu function by flicking on the wheel and select the function by clicking or tapping on the wheel. This menu function consists of two applications: a navigation application and an audio application. For the navigation application, drivers can move the map by flicking and zoom the map in and out by stroking or twisting. For the audio application, drivers can browse the menu by flicking and select the music by clicking. At the same time, they can also control the volume by stroking and twisting.

In order to investigate the operability of our method, we did a user study to recognize the flick gesture at three positions on the steering wheel. The positions investigated are the right side, the diagonally upward side and the upward side of the steering wheel. The participants for this study were 7 student volunteers (age range from 23 to 25, average 24). Participants were asked to flick 10 times at each position and to repeat each task about 5 times. Before the test, participants will undergo a short practice time to get used to the system and to learn the flick gesture. When the participants flick, a cursor will appear on the GUI to indicate whether the flick was successful or not and to show the direction of the flick. From the results obtained, the system was able to recognize about an average of 92% of the flick gestures (right: 95.4%, diagonally upward: 90.3%, upward: 89.1%). Although the recognition rates were different at different positions, the high percentage rate at each position shows that drivers will be able to operate the applications at any position on the steering wheel with a high flick recognition rate. For future works, we will investigate the influence of this recognition rate on the operating positions.

5. CONCLUSION

In this paper, we proposed a multi-touch steering wheel for in-car tertiary applications. The main goal of this work was to develop a steering wheel where touch positions can correspond to the operating positions, to control the information offered by in-car applications. Thereby, drivers could operate applications at any position on the steering wheel. We embedded 120 IR sensors in the steering wheel. The system was trained to recognize different hand gestures (flick, click, tap, stroke and twist) by using SVM. Additionally, we developed a navigation application and an audio application by using the proposed interface. We did a user study for the navigation application and investigated an average flick recognition rate of about 92%.

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