Sporshohin: A Tale of Devising Visible Light Based Low-Cost Robust Touchless Input Device

Tusher Chakraborty, Md. Nasim, Sakib Md. Bin Malek, Md Taksir Hasan Majumder Sami, Mohammed Samiul Saeef, and A. B. M. Alim Al Islam
Bangladesh University of Engineering and Technology
tusherchakraborty@matholympiad.org.bd, nasim.buet.bd@gmail.com, 0905039.smbm@ugrad.cse.buet.ac.bd, mythoss1092019@gmail.com, saeef.sami@gmail.com, alim_razi@cse.buet.ac.bd

ABSTRACT

In recent times, migrating from touch-based input devices to touchless input devices has become one of the major research problems considering the health hazards exposed in public usages (e.g., information kiosk) of the touch-based devices. The problem still remains mostly open, since a solution having the properties of being low-cost, low power consuming, robust, and easy-to-use, is yet to be proposed in the literature. As a remedy to this situation, in this paper, we propose a visible light based touchless input device (named *Sporshohin*), retaining all the properties mentioned above, for ensuring ubiquitous usage. *Sporshohin* recognizes predefined gestures performed by the user, through an underlying mechanism that exploits well-known reflection model over the visible light spectrum. The underlying mechanism is intelligent enough to guarantee robustness against varying environmental lighting conditions and undefined noisy gestures. Real implementation, involving interaction with diversified users, confirms high accuracy and usability along with existence of all the above mentioned properties. We show the emulation of *Sporshohin* as an input interface for an information kiosk. The attributes of *Sporshohin* exhibit its prospect of being used in diversified applications going beyond information kiosks.

CCS Concepts

•**Human-centered computing → Gestural input;**

Keywords

Gesture recognition, Touchless device, Visible light

1. INTRODUCTION

Touchless input devices open a new door towards interactive and intelligent interaction with machines. Touchless input devices also provide a more hygienic framework of interaction than touch based input devices of interactive machines in public spheres such as information kiosk. An information kiosk is a computer terminal designed to interactively provide access to information and applications in public spheres. In today's world, many people use information kiosks for quotidian purposes: bill payment, ticketing, wayfinding, hospital registration, Internet access, etc. Following the augmentation of this worldwide technology, many lower-middle income countries, such as Bangladesh, India, Vietnam, Philippines, etc., have introduced information kiosks in various public places [19, 21, 25, 26].

Information kiosks provide a natural and interactive interface to the users. In such a machine, the input interface, for navigation purpose, can be either touch-based or touchless. Touch-based input devices, specially in public places of developing countries, suffer from hygiene problem [2, 3, 24, 32]. This hygiene problem is exacerbated by highly dense population of countries like Bangladesh, Philippines, India, etc. Consequently, increasing use of touch-based input device, in public information kiosk, will aggravate the situation. Moreover, previous research study claims that touch-based interface is not appropriate for information kiosk [16]. Nevertheless, touch-based screen of information kiosk, gigantic in size, demands colossal cost compared to normal screen. Touchless input devices can serve as alternative that has the potential to address these issues, including hygiene issue, and provide a much more interactive user experience.

Gesture recognition is one of the principal approaches used for devising touchless user interfaces. It refers to recognizing meaningful expressions of motion by a human, involving hand, arm, face, head, body, etc. Several different approaches have been proposed for detecting gestures. All these approaches can be divided into two major categories - vision-based and sensor-based. Vision-based approaches demand using cameras, while sensor-based approaches mainly utilize ultrasonic, infrared, and proximity sensors [1, 23]. Nevertheless, most of the sensor-based approaches demand using tracking devices such as wearable gloves, markers, body suit, etc., which hinders ease and naturalness of interaction [4]. Vision-based techniques, through involving the use of camera, can remove such inconveniences introduced by tracking devices. Besides, vision-based techniques are capable of recognizing a large set of gestures. However, these techniques are resource-hungry and expensive. Moreover, applications such as input interfaces for most of the information kiosks, which entail navigators or number pads to operate, require recognition of only a *small set of gestures* [14]. Here, the large gesture set recognized by vision-based techniques becomes mostly redundant. On the other hand, sensor-based approaches having a smaller set of gestures mostly remain prone to external interference and noise. From HCI perspective, interaction with invisible waves makes the gesture performance less interactive as an input device. Moreover, these approaches can easily be jammed (e.g., RF signal jamming, ultrasonic jamming), and the jamming is not readily recognized as signals such as RF and ultrasonic sounds are

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not perceivable by humans.

To the best of our knowledge, a low-cost, low power consuming, robust, and easy-to-use gesture recognition approach for developing a touchless input device worth of using in an information kiosk, is yet to be explored in the literature. In this paper, we attempt to address this problem and come up with a real solution exploiting visible light spectrum. We name our developed device as *Sporshohin*.

Sporshohin manipulates visible light spectrum to detect hand gestures performed by users. In our solution, we use light-sensitive versatile devices (e.g., photodiodes, phototransistors) such that they can easily be used in public places at *lower cost* ($<$ \$1) compared to existing sensor-based and vision-based approaches. *Sporshohin* exploits reflection characteristic of visible light in road to devising a methodology for taking input from users through detecting their easy-to-make gestures. We also show how to eliminate noise despite the presence of additional and varying light sources, and thus confirm robustness of *Sporshohin*.

We summarize our contributions made in this paper as follows:

- We investigate a novel model for hand gesture recognition based on the reflection model of visible light spectrum. We confirm effectiveness of the mechanism through rigorous experiment.
- We design and build a *low-cost* input device, having *low power requirement*, which is worth of using in information kiosks which require a *small set of gestures* to operate. To interact with the device, we design a set of *simple* and *intuitive* gestures that are harmonious to *diversified applications* from HCI perspectives.
- We develop an algorithm for making the input device *robust against environmental changes.* Here, by environmental changes, we refer to different lighting conditions along with abrupt variations in these lighting conditions. Additionally, we consider undefined noisy gestures to be detected and eliminated through our algorithm.
- We perform user evaluation to confirm efficacy and usability of the device along with robustness of the algorithm in recognizing hand gestures under different environmental changes.
- Finally, we point out more *diversified applications* of *Sporshohin* along with its future enhancements.

To the best of our knowledge, *Sporshohin* is the first touchless input device based on reflection of visible light spectrum, which addresses the issues of cost, power consumption, noise, and environmental changes. The device is able to detect hand gestures with an accuracy of 98.6% in dynamic environments, which is confirmed through real experiments.

2. MOTIVATION AND RELATED WORK

Information kiosk in public spheres is a worldwide burgeoning technology and also popular in many lower-middle income countries [19, 21, 25, 26]. Use of touch-based input interface in information kiosks may become viable sources of microbial infection [3, 8, 24, 32], specially in countries like Bangladesh, India, Philippines, etc., having highly dense population. Additionally, the touch-based technologies are not always convenient specially for very large-screen information kiosk [16].

An obvious solution to this problem is to make input the interfaces of the kiosks touchless. Hand gestures are inherently contactless and thus have the potential to serve more hygienic means in place of the touch-based input interfaces. Consequently, design and development of hand gesture based touchless input interfaces present an ongoing trend among recent research works. Different approaches have already been proposed for recognizing hand gestures. Most of the examples of such approaches cover use of ultrasonic sensors [7, 9, 11], proximity sensors [5, 33], infrared sensors [6, 29], and video cameras [12, 18, 36]. The other examples cover capturing noise in transmission channels of radio waves [34], Microsoft Kinect [14], etc.

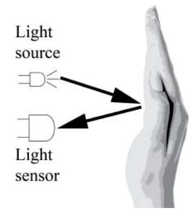
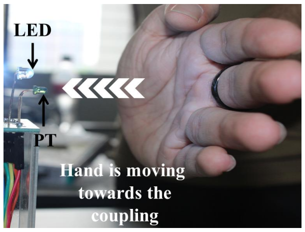


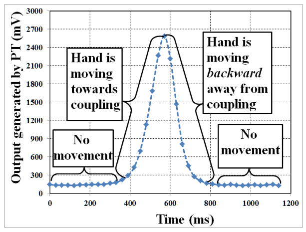
Figure 1: Working principle model

From the user perspective, interaction with invisible waves such as ultrasonic and infrared waves makes the gesture performance more error-prone, since the user has no idea if the gesture is being successfully performed within the range of the sensors. This happens owing to the invisible nature of the waves, as such invisible waves are unable to provide any perceivable feedback to the users after a gesture is successfully performed. On the other hand, vision-based approaches for gesture detection through image processing offer an alternative having the capability of detecting a larger set of gestures. However, these approaches need to be robust against transformations and cluttered backgrounds limiting their pervasive use [12, 36]. Alongside to make such approaches efficient, use of colored markers and data gloves has been proposed [15]. However, such usage causes inconvenience for users and also fails to deliver a completely touchless interface. Even without the use of markers and data gloves, gesture recognition based touchless input devices [17, 20] require at least one video camera and a high-end image processing unit. These sophisticated hardware requirements exhibit a major obstacle in ensuring cost-effectiveness of devices performing gesture recognition. Moreover, video cameras and image processing units, because of their complex operations, demand high power for their operation. Even though researchers [13, 27] have addressed this problem of consuming high power, it still remains an issue in visual sensor based gesture detection. As a result of having all these issues, a less sophisticated solution, having low-cost and low power requirement is yet to be proposed in the literature even though such a solution can perfectly serve applications requiring recognition of a *small set of gestures*. An information kiosk is a pervasive example of such applications.

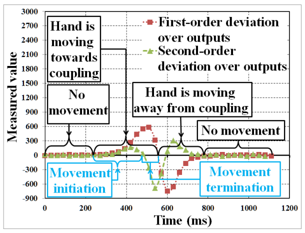
To some extent, gesture recognition exploiting visible light spectrum still remains little explored. We attempt to investigate the potency of exploiting the visible light spectrum for the purpose of gesture recognition. From the HCI perspective, owing to the widely perceivable nature of the visible spectrum, gesture recognition exploiting the visible spectrum can offer a more interactive solution compared to other invisible spectrums. In addition to this, use of the visible spectrum also provides explicit guidance to the user to perform the gestures within the range of the gesture recognition interface. Moreover, use of visible spectrum requires low-cost ($\ll$ \$1) equipments (LED and phototransistor) compared to that required for invisible spectrum. Therefore, we attempt to utilize the visible light spectrum for developing a more interactive and low-cost solution for touchless input interfaces worth of using in public information kiosks. We start presenting outcomes of our study with the basic working principle, which we extend onward throughout.



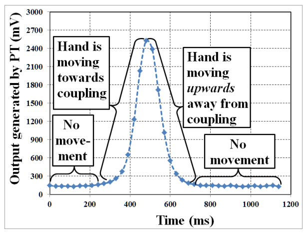
(a) Experimental setup



(b) Hand movement in front of coupling



(c) First-order and Second-order deviations



(d) When hand is moving upwards away from coupling

Figure 2: Experimental evaluation of background physics

3. WORKING PRINCIPLE

In this section, we present the working principle of hand gesture based design of *Sporshohin*. The basic working principle relies on reflection of light from hand. Here, we present the background physics followed by the experimental evaluation, of the background using custom-off-the-shelf hardware.

3.1 Background Physics of Sporshohin

All real reflector objects reflect light towards different angles, and thus can be modeled as lambertian reflectors [30]. A lambertian reflector object provides uniform diffusion of the incident radiation such that its radiance or luminance remains same in all directions from which it can be measured. Accordingly, we assume hand as a lambertian reflector object.

Figure 1 pictorially presents the basic working principle. Here, we show operation of a coupling consisting a light source and a light sensor oriented towards the same direction. The figure shows what will happen if a hand is moved towards the coupling. Here, light emitting from the light source gets reflected from the hand and the reflected light is received by the sensor.

Inverse square law [30] of light propagation states that the illuminance at any point varies with an inverse proportion of square of the distance between that point and corresponding light source. Consequently, the illuminance of reflected light incident upon the light sensor gets increased with the movement of hand towards the coupling as shown in Figure 1. Hence, the light sensor should experience a real-time deviation in its values of captured light illuminance, which arrives after being reflected from the hand, with respect to time. Note that, as hand behaves like a lambertian reflector, the illuminance of reflected light incident upon the light sensor should remain same in all directions for a certain distance. However, the illuminance of reflected light should vary with the area of reflection, i.e., the area of hand that is illuminated by the light source [30].

3.2 Experimental Evaluation

To confirm effectiveness of the background physics with custom-off-the-shelf hardware, we conduct a real experiment in a well-lit room environment. The experimental setup consists of a coupling of LED and phototransistor [28]. The phototransistor (PT) generates current proportionally to the light illuminance incident upon it. We develop a resistor amplifier circuit to amplify the current and to convert it to analog voltage. A microcontroller [10] captures the analog voltage and converts it to digital value. Figure 2a shows a snapshot of the experimental setup. We move a hand towards the coupling of the setup and capture outputs generated by the PT.

Figure 2b presents outputs generated by PT when hand is moving in front towards the coupling and then moving backward away from the coupling. Figure 2c presents the first-order and second-order deviations over outputs generated by PT. Here, the first-order deviation (or real-time deviation) refers to the difference between two consecutive outputs generated by the PT over temporal domain. The second-order deviation refers to the real-time deviation of the first-order deviation. In both figures, the leftmost regions with negligible real-time deviated outputs indicate absence of any hand movement. Next, when the hand is moving towards the coupling, a notable positive real-time deviation appears over the outputs. Subsequently, when the hand is moving backward away from the coupling after performing the movement towards the coupling, a notable negative real-time deviation appears over the outputs. Finally, the rightmost region with negligible real-time deviated outputs arrives indicating an absence of any hand movement.

While performing our experiment, we observe a noteworthy phenomenon. When we move hand away from the coupling, it can be moved in different alternative directions with respect to the coupling. Examples of the alternative directions can be backward, upward, downward, etc. However, in any case of moving away, we observe a similar pattern of having a significant negative real-time deviation irrespective of choice from the alternative directions. Figure 2d confirms the fact as it shows a similar negative real-time deviation when we move our hand upwards away from the coupling. The combined effect of inverse square law, lambertian reflection, and reflection area of hand is the rationale behind this phenomenon.

3.3 Gesture

Gesture generally refers to movement of a part (e.g., hand) of the body in a certain fashion. Here, we define the movement of hand in front of a coupling as a gesture. To avoid complexity, we consider two types of hand movement gestures: (1) moving towards the coupling, and (2) moving away from the coupling. A fascinating fact is that these two gestures are complementary to each other. When a hand is being moved towards the coupling (as shown in Figure 2a), the hand has to be moved away from the coupling afterwards eventually resulting in a complimentary "moving away" gesture. Figure 2b and 2d also confirm this fact. Besides, a hand has to be moved towards the coupling first in order to perform an intended "moving away" gesture. Nevertheless, moving away hand to any direction results in a similar pattern of significant negative real-time deviation over outputs generated by the PT, as we mentioned earlier. Consequently, it is strenuous to differentiate between intended "moving away" gesture and complementary "moving away" gesture. As a result, we mainly focus on the "moving towards" gesture only.

We observe another natural phenomenon of hand gesture in experimental results. When a person begins to move a hand towards a coupling, s/he accelerates or maintains a uniform speed of hand. Consequently, the second-order deviation over outputs generated by PT remains positive at the time of the initiation of hand movement towards coupling. Figure 2c confirms this fact. However, when s/he comes closer to the coupling, s/he starts to decelerate hand. Consequently, the second-order deviation goes down to negative at the time of the termination of hand movement towards coupling as shown in Figure 2c.

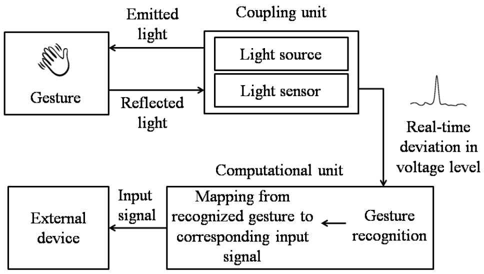


Figure 3: Block diagram of *Sporshohin*

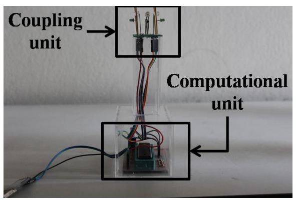
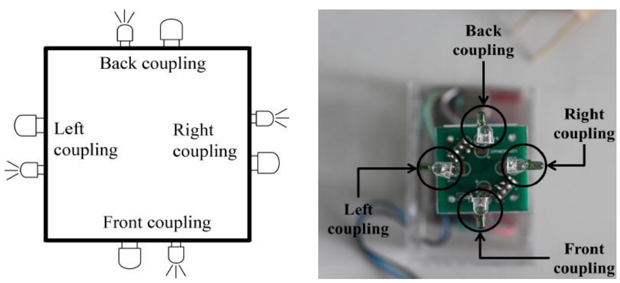


Figure 4: Snapshot of *Sporshohin*



(a) Drawing of coupling unit (b) Snapshot of coupling unit

Figure 5: Coupling unit

4. DESIGN OF SPORSHOHIN

In our proposed touchless input device, we emit light and capture illuminance of the light reflected from the hand performing a gesture near the device. Figure 3 presents a simplified operational block diagram of operation of *Sporshohin*. Figure 4 shows a snapshot of our device in operation while connected with a laptop. *Sporshohin* consists of two units: (1) Coupling unit and (2) Computational unit. We elaborate the units in the following subsections.

4.1 Coupling Unit

The Coupling unit contains four couplings, each consisting of a light source and a light sensor. The light source and light sensor of each coupling are faced at the same direction. We use white LED as the light source and PT [28] as the light sensor. Figure 5 shows a drawing and a snapshot of the Coupling unit. Here, four couplings are faced towards four different directions. The couplings are named as (1) Front coupling, (2) Right coupling, (3) Back coupling, and (4) Left coupling. The arrangement of coupling is derived from the intention of making gestures intuitive and harmonious to potential applications (e.g., input device of an information kiosk).

Function of this unit is to emit light and sense illuminance of the light incident upon it, which includes the light reflected from the nearby gesture-making hand. Here, each LED continuously emits light. The light incidents upon any object within a certain region ($\sim$ 40cm from each coupling) and gets reflected back from the object. The reflected light falls upon the PT. Each PT generates current according to the light illuminance incident upon it including environmental light and reflected light. The resistor amplifier circuit amplifies the current and converts it to analog voltage.

4.2 Computational Unit

A microcontroller [10] is used as the Computational unit. The unit collects analog voltages from each PT of the four couplings. Next, it invokes a gesture recognition algorithm to identify whether any predefined gesture is performed. Upon identifying a predefined gesture, the unit maps it to corresponding input signal. For example, when we use *Sporshohin* as a navigator for information kiosk emulating on PC, we map each gesture to a navigation signal, following a predefined mapping. Consequently, the unit feeds a navigation signal to a connected external device upon receiving the corresponding gesture. Here, the navigation signal is fed to the connected device through USB communication.

Moreover, Computational unit maintains a power-efficient duty cycle, at the time of gesture detection, to minimize the power consumption of *Sporshohin*. The Computational unit goes to sleep mode when user does not perform any gesture in front of *Sporshohin*. Computational unit switches on the LEDs, the most power draining components of *Sporshohin*, at the time of data collection only. The average power consumption of *Sporshohin* is: 4.19μW in sleep mode and 85.4μW in active mode, which is lesser than other vision and sensor based gesture detection technology [22, 35].

5. GESTURES FOR SPORSHOHIN

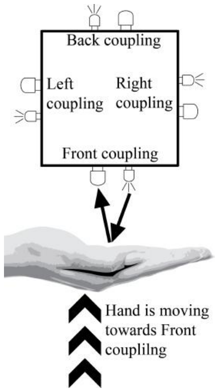
In this section, we introduce the gestures that can be recognized by *Sporshohin*. We perform all these gestures under various environmental lighting conditions- well-lit room light, asymmetric lighting condition, focused light, and daylight. Our cardinal target is to design gestures simple, intuitive, and harmonious to application, from Human Computer Interaction perspective. We present detail drawing and graphs to visualize these gestures carried out in well-lit room light.

5.1 Simple Gestures

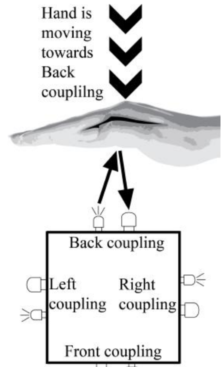
We define simple gesture as moving a hand straight towards a coupling. Hence, we can define four simple gestures by moving hand straight towards four different couplings of *Sporshohin*. We name the gestures using the first letter of the gesture type followed by gesture number (e.g., "S1" is the first simple gesture). Figure 6a represents the illustration of the first simple gesture. This gesture is performed by moving hand towards the Front coupling. Figure 6e shows a snapshot of gesture "S1" that is being performed in front of *Sporshohin*. Figure 6c represents an illustration of gesture "S2" that is being performed by moving hand straight towards Right coupling. Similarly, gesture "S3" and "S4" are performed by moving hand towards Back and Left coupling respectively (as shown in Figure 6b and 6d).

Figure 7a presents responses of PTs in absence of any gesture in front of *Sporshohin*. Here, no significant real-time deviation ($\leq$ 24mV) over two consecutive outputs generated by any of the PTs is observed. We term the extent of such non-significant real-time deviation as *Idle deviation.* A notable fact is that outputs generated by four PTs do not provide same values. This happens due to asymmetric environmental lighting conditions around the Coupling units of *Sporshohin*, owing to their orientation towards different directions.

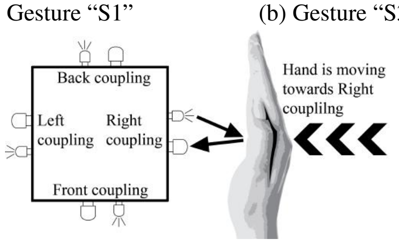
Figure 7b shows responses of four PTs when gesture "S1" is performed. As gesture "S1" refers to moving hand towards the Front coupling, the PT of Front coupling generates similar pattern of outputs as already shown in Figure 2b. Responses of other three PTs are similar to the case of having no significant real-time deviation



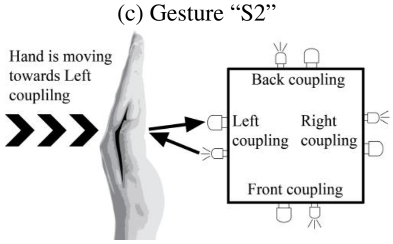
(a) Gesture "S1"



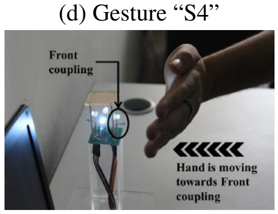
(b) Gesture "S3"



(c) Gesture "S2"

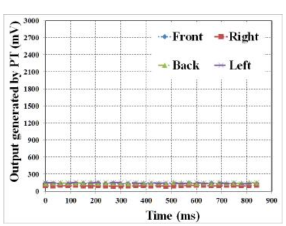


(d) Gesture "S4"

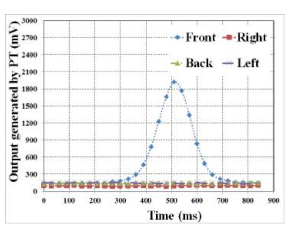


(e) Gesture "S1" in real implementation

Figure 6: Four simple gestures for *Sporshohin*



(a) No gesture



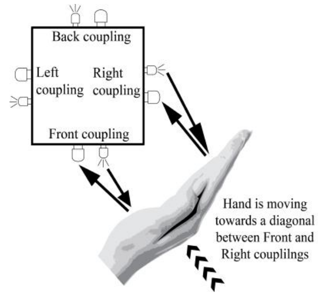
(b) Gesture"S1"

Figure 7: Responses of PTs to absence of any gesture and simple gesture

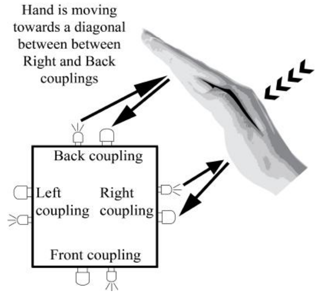
that we have found in absence of any gesture. Besides we observe similar response patterns for other three simple gestures in outputs, generated by corresponding coupling.

5.2 Diagonal Gestures

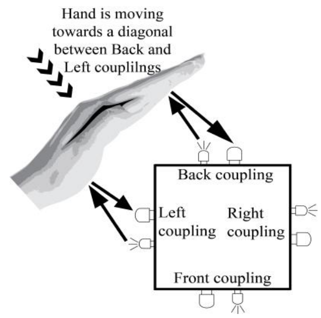
Up to this point, our considered gestures (i.e., simple gesture) provoke only a single PT. Now, we look forward to define a gesture in such a way that it provokes two PTs at the same time. Here, we move a hand towards a diagonal between two adjacent couplings. Consequently, we define four diagonals pertinent to four different pairs of two adjacent couplings. Figure 8a presents a diagonal gesture. This gesture demonstrates moving hand towards both Front



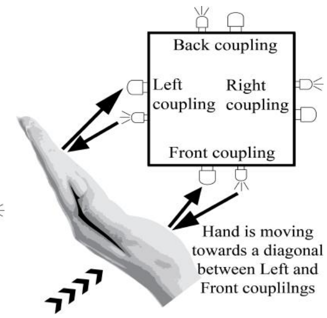
(a) Gesture "D1"



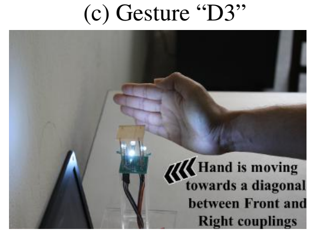
(b) Gesture "D2"



(c) Gesture "D3"



(d) Gesture "D4"



(e) "D1" in real implementation

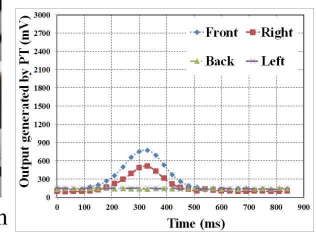
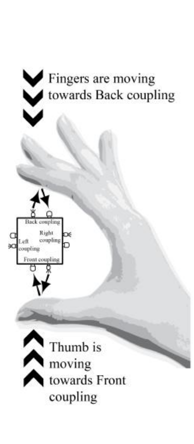
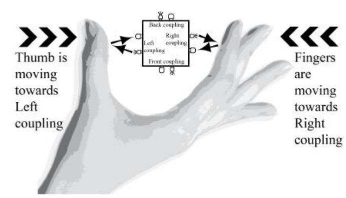


Figure 8: Four diagonal gestures for *Sporshohin*

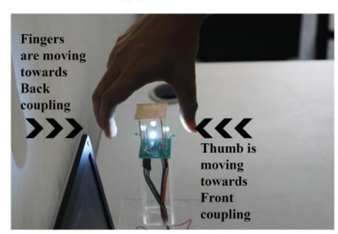
Figure 9: Responses of PTs to diagonal gesture "D1"



(a) Gesture "A1"

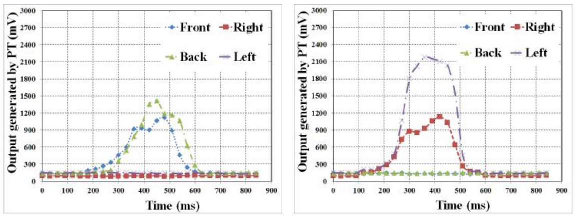


(b) Gesture "A2"



(c) Gesture "A1" in real implementation

Figure 10: Two across gestures for *Sporshohin*



(a) Gesture“A1” (b) Gesture“A2”

Figure 11: Responses of PTs to across gestures

and Right couplings keeping both of them nearly at the same angle with the direction of approaching. This gesture is marked as gesture “D1”, i.e., the first diagonal gesture. Figure 8e shows a snapshot of gesture “D1” in real implementation. Similarly, Figure 8b, 8c, and 8d represent gestures “D2”, “D3”, and “D4” respectively.

Figure 9 shows responses of corresponding PTs when we perform gesture “D1” in front of *Sporshohin*. As shown in the figure, this gesture provokes the PTs of Front and Right couplings. Consequently, outputs generated by each of the PTs follows the pattern similar to that we have already found in Figure 2b. We observe two noteworthy facts in Figure 9. The first one is the relatively lower values of real-time deviations in comparison to simple gestures. This happens following the fact that the illuminance of reflected light varied proportionally with the area of the reflection. Here, the area of reflection pertinent to the Front coupling is lower than that in case of the simple gesture “S1”. This happens as the reflector object , i.e., the hand, remains in an angle with the orientation of the Front coupling exposing a smaller effective area of reflection in case of the diagonal gesture. Consequently, the real-time deviations over outputs generated by the PT of Front coupling are lower than the real-time deviations observed for simple gesture “S1”. Similar reason applies for real-time deviations over outputs generated by the PT of Right coupling.

Another notable fact is that both PTs of Front and Right couplings do not generate similar outputs. The outputs generated by PT of Front coupling have higher values than that generated by the PT of Right coupling. The effective area of reflection again influences this fact. Here, when the hand is being moved along a nearly diagonal direction between Front and Right couplings, the larger area of hand gets illuminated by the LED of Front coupling. The other way around is also possible when the larger area of hand gets illuminated by the LED of Right coupling. This happens as it is nearly impossible to ensure the same angle between the direction of movement and the orientation of the PTs for both coupling. Owing to the difference in angle, the corresponding effective area of reflection gets varied, which in turn results in the variation in the outputs. Nonetheless, we observe similar response patterns for other three diagonal gestures.

5.3 Across Gestures

Diagonal gestures provoke two adjacent couplings at the same time. To stretch the diversity in gestures, further, we define another gesture in such a way that provokes two non-adjacent couplings at the same time. Here, we perform an across gesture through simultaneously moving fingers towards two non-adjacent couplings that are faced at the opposite directions. We can exploit two pairs of such non-adjacent couplings: (1) Front and Back couplings, and (2) Right and Left couplings. Figure 11a presents the first across gesture covering the Front and Back couplings. We perform this gesture by simultaneously moving thumb towards the Front coupling and moving other two fingers adjacent to the thumb towards the Back coupling. We can make the same gesture placing the hand in an opposite direction with respect to Front and Back couplings. We mark this gesture as gesture “A1”. Figure 10c shows a snapshot of gesture “A1” in real implementation. Similarly, Figure 10b represents the gesture “A2”.

Figure 11a shows the responses of PTs when we perform gesture “A1”. The figure depicts that the gesture provokes PTs of Front and Back couplings. Here, similar to the diagonal gesture, we again observe relatively lower values of real-time deviations, in comparison to simple gestures. This happens owing to the smaller area of reflection exposed by the fingers. Here, the area of reflection exposed by the thumb to the Front coupling is lower than that exposed by the hand in case of the simple gesture “S1”. Consequently, the real-time deviations over outputs generated by the PT of Front coupling remains lower than that found for the simple gesture “S1”. Similar reason applies for real-time deviations over outputs generated by the PT of Back coupling. Besides, the area of reflection exposed by the two fingers moving towards the Back coupling is larger than the area of reflection exposed by the thumb moving towards the Front coupling. As a result, the outputs generated by the PT of Back coupling exhibit higher values than that of the Front coupling. We observe similar response patterns in Figure 11b for gesture “A2”.

We observe similar deviations for the performed gestures for all three lighting conditions. We utilize all the above-mentioned finding to develop algorithms for successfully recognizing gestures performed towards *Sporshohin*. We present the algorithm in the next section.

6. ALGORITHM

In this section, we present our gesture recognition algorithm carried out by the Computational unit for recognizing predefined gestures.

At first, the algorithm collects a data set of four outputs, a single output from each of the four PTs. An interval of 30ms is given before collecting every next data set. Upon collecting two data sets, algorithm calculates the real-time deviation over two consecutive outputs of each PT. The algorithm now compares the recently calculated real-time deviations in outputs of each PT to *Idle deviation*, i.e., $24mV$. The deviation lower than the *Idle deviation* is regarded as an absence of any gesture or the situation when hand is moving away from the coupling. This is reported as a *Bad news* for that coupling and the deviation is discarded. However, the algorithm always keeps track of the latest sensed data in these kind of situations. Hence, in case of a *Bad news* situation, it keeps the current data in and shifts the old data out of data set for corresponding PT. This helps in taking care of the situations when deviation gets influenced by sudden environmental lighting condition change. However, if two *Bad news* reports are found for a PT, the algorithm erases all old data and deviations, storing only the latest data of that PT. Algorithm keeps track of stored data from each PT in a variable named *dataCount*.

The algorithm now checks if *dataCount* of any PT has reached 4. If the *dataCount* of none of the PT reaches 4, then it is registered as no gesture is performed on that iteration. The algorithms continues to collect data. If the *dataCount* of any PT reaches 4 and the corresponding data set corroborates the background physics mentioned earlier, it is registered as a gesture is performed in front of that PT. Now, it is checked if any other PT is experiencing a gesture, as the performed gesture might be diagonal or across. For such gestures, we have already mentioned earlier that the illuminated area of reflection can be different in front of two couplings. Consequently, the value of *dataCount* for any one of two PTs may reach to 4 earlier than the other. Thus, the gesture would be wrongly recognized as simple gesture. The algorithm now searches for a PT with *dataCount* value of 3. If any such PT is found and the corresponding data set corroborates the background physics, it means a gesture is also performed towards that coupling. If no other PT is found with *dataCount* 3 or 4, then it can be understood that a simple gesture is performed.

Upon detecting a predefined gesture, the Computational unit maps it to corresponding input signal and sends the input signal to the connected external device. After an interval of 100ms, the algorithm loops back to initial state by resetting all the variables. We find the chosen values of the stated intervals, the *Idle deviation*, and the *dataCount* as optimal by iterative experimentation involving different users and lighting conditions.

7. ROBUSTNESS AGAINST VARYING LIGHTING CONDITIONS

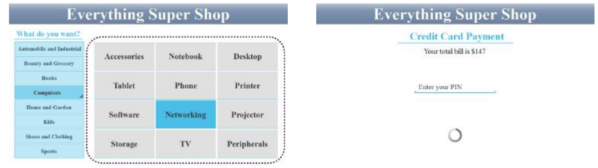
To ensure pervasive usage, *Sporshohin* has to work under several lighting conditions and the lighting conditions could be changed even at the time of performing gestures. Lighting conditions can severely influence the efficiency of visible light based touchless input device. In this section, we present varying environmental lighting conditions and how the varying conditions are addressed by *Sporshohin*.

Abrupt change in lighting condition: Switching the room light on or off can cause an abrupt change in lighting condition. To address such changes, the methodologies followed by *Sporshohin* is not to depend only on threshold value of sensed data during its operation. Rather, it utilizes real-time deviation over the sensed data resulted from the change in illuminance of the light reflected from the gesture-performing object. Switching on a light exhibits a key fact that this deviates the illuminance of light very fast within a very small period of time. Such short-lived deviations get identified and subsequently eliminated by our proposed algorithm.

We also address the situation of switching off or dimming a light during the time of performing a gesture, by our algorithm. Note that, in addition to the LEDs, the room light also illuminates the hand, while performing a gesture. Now, if the room light suddenly goes off, this might result in a negative real-time deviation. When the algorithm processes data, it identifies this negative real-time deviation during an ongoing gesture and eliminates that deviation. Nonetheless, it keeps the current sensed data and puts a flag, indicating this event, for corresponding PT. When the next set of data is collected, the algorithm checks whether the real-time deviation of that PT is fine now. If it is fine (i.e., greater than *Idle deviation* value), the function puts a reward point for that PT and removes the flag. This reward point carries a mark of this incident (i.e., switching light off) while checking for the corroboration of background physics in corresponding data set and keeps that gesture free from the influence of this incident. Note that, the *Bad news* (value of deviation lower than *Idle deviation* value) due to the absence of gesture and moving hand away from the coupling, can not take the benefit of rewarding process. Because, if algorithm finds two *Idle deviation* reports for a PT, the algorithm erases all old data and deviations out.

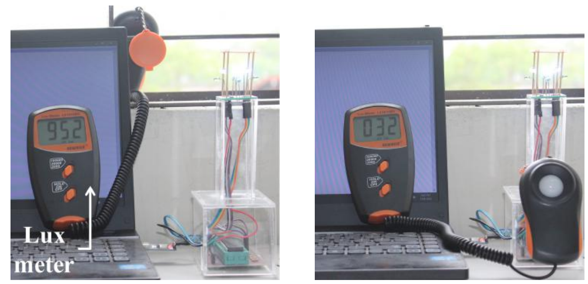
Breakage of LOS from a focused light: It may happen that the PT of a coupling is in a line of sight (LOS) with an external highly-illuminated light source. When we perform a gesture in front of that coupling, the LOS will be broken. However, the impact of this breakage of LOS is separately addressed and suppressed accordingly by the algorithm. Here, at the time of placing hand over the LOS, some negative deviations will appear. These negative deviations get discarded by the algorithm.

Asymmetric lighting conditions: Our proposed system can be exposed to asymmetric lighting condition. Such scenario can arise in case of placing *Sporshohin* nearby the window at daylight. Here, one side of the Coupling unit experiences high illuminance of daylight and other side experiences relatively lower illuminance of room light. This situation results in a substantially varying outputs generated by the PTs. *Sporshohin* suppresses the impact of such varying outputs through not depending on only absolute values of sensed data, during its operation. Rather, it utilizes real-time deviation over the sensed data. Hence, difference in the absolute levels of outputs generated by different PTs does not influence the operation of *Sporshohin*.



(a) Product browsing page (b) Bill payment page

Figure 12: An emulated information kiosk



(a) Back coupling experiences the illuminance of 9520lx (b) Front coupling experiences the illuminance of 320lx

Figure 13: Experimental setup under asymmetric lighting condition

Undefined and noisy gestures: People cannot be resisted from generating different non-specified gestures such as moving hands or objects here and there around the Coupling unit in random directions. As *Sporshohin* cross checks a real-time deviation pattern of performed gesture with the patterns of predefined gestures, it is nearly impossible to match the pattern of an undefined gesture with any predefined gesture. Accordingly, *Sporshohin* can successfully identify undefined and noisy gestures, and discard them thereby.

In summary, *Sporshohin* adopts such a mechanism that remains resilient to varying environmental condition and noises. Next, we validate such robustness along with accuracy in recognizing gestures by *Sporshohin* through user evaluation with real experiments.

8. USER EVALUATION

In this section, we present a user evaluation to demonstrate the efficacy and usability of *Sporshohin* as an input device for information kiosk.

8.1 Experimental Setup and Results

For performing real experiments with *Sporshohin*, we connect it with a laptop, which is emulating an information kiosk for a super shop (as shown in Figure 12). We operate *Sporshohin* in two different modes: (1) A navigator mode and (2) A number pad mode. When a user is browsing any product, *Sporshohin* acts as a navigator (as shown in Figure 12a). To make gestures natural and intuitive in navigator mode, we map “S1”, “S2”, “S3”, and “S4” gestures to

Figure 14: Experimental setup under daylight of 24300lx

User	Age (year)	Hand size (inch)	Palm size (inch)	Gender	Profession
1	12	5.2	2.6	Male	Student
2	15	5.6	2.7	Female	Student
3	18	6.4	3.1	Female	Student
4	18	6.3	3.2	Male	Student
5	19	5.4	2.6	Female	Student
6	19	6.9	3.2	Female	Student
7	19	6.8	3	Male	Student
8	19	5.5	2.6	Male	Student
9	19	6.5	2.8	Male	Student
10	25	6.9	3.1	Male	Research asst.
11	36	6.6	3.3	Male	Driver
12	39	6	2.9	Male	Driver
13	42	6.3	2.8	Female	Housewife
14	44	5.8	2.9	Female	Housewife
15	48	6.6	3	Male	Security guard
16	49	6.1	3	Male	Accountant
17	54	6.4	3.2	Male	Public servant
18	61	6.5	3.2	Male	Businessman

Table 1: User demography

"up", "left", "down", and "right" navigations respectively. Similarly, each diagonal gesture is mapped to corresponding diagonal navigation. On the other hand, "A1" is mapped to "Select" action (e.g., selecting a product tab or option) and "A2" to "Go back" action. Nevertheless, *Sporshohin* automatically switches to number pad mode when a user needs to type PIN for bill payment (as shown in Figure 12b). In number pad mode, simple and diagonal gestures, in an anticlockwise pattern around the Coupling unit, are mapped to digits $0-7$. Mapping starts with "S1" to 0 and ends up with "D4" to 7. "A1" and "A2" gestures are mapped to digits 8 and 9 respectively.

To perform user evaluation, we invited 18 participants with diversified ages, genders, hand sizes [31], palm sizes [31], and professions. Here, note that, hand size and palm size refers to two different dimensions as pointed out in Table 1. To make familiar with movements to be made with different gestures, we presented a short demonstration to each participant. Table 1 presents the user demography of invited users. We evaluated accuracy of *Sporshohin* in three different lighting conditions through analyzing participation of those users. In a particular lighting condition, a list of products and an arbitrary PIN was provided to each user. Each user bought the products given in the list browsing the emulated information kiosk and finally paid bill using provided PIN. In a particular lighting condition, a user performs 22 gestures on average.

To enrich the interaction of *Sporshohin* with user, we add another feature. After every successful gesture detection, *Sporshohin* enables blinking of LED, in front of which the gesture is performed. For example, after the detection of gesture "D1", *Sporshohin* enables blinking of the LEDs of Front and Right couplings. Additionally, this feature enables us to observe whether the gesture, the user intends to perform, is correctly recognized by *Sporshohin*.

Three different lighting conditions that we have adopted are:

1. Room light, where environmental or ambient light illuminance is uniform around the Coupling unit in a well-lit room. The illuminance was $296-321$lx during the evaluation. Figure 15a presents results found in this lighting condition through a confusion matrix. *All values of confusion matrices are shown in percentage.*
2. Asymmetric light, where environmental or ambient light illuminance varies around the Coupling unit. We have ensured the asymmetric light by placing *Sporshohin* nearby the window at daylight, as shown in Figure 13. Here, one side of the Coupling unit experiences high illuminance (9520lx) of daylight and the other side experiences relatively lower illuminance (320lx) of room light. Figure 15b presents the result found in this lighting condition through a confusion matrix.
3. Daylight, where the device is exposed directly to sunlight. Figure 14 shows a setup under daylight in an open field. Here, we have found the light illuminance to be $24300-28463$lx. Figure 15c presents the results found in this lighting condition through a confusion matrix.

All the confusion matrices demonstrate that the diagonal entries of simple gestures have the maximum value of 100%. We can observe only a few non-diagonal entries with very small values (below 4%), in case of diagonal and across gestures. To further analyze the performance of *Sporshohin*, we calculate its classification accuracy. We define classification accuracy as a ratio between sum of correctly classified gestures and the total number of gestures performed. We observe that accuracy of *Sporshohin* in recognizing gestures is 98.7% under room light, 98.6% under asymmetric light, and 98.6% under daylight. Alongside, considering all the results as a whole, we find the overall accuracy of *Sporshohin* in recognizing gesture to be 98.6%. The accuracy of other recent air gesture recognition techniques varies from 80% to 100%. Nevertheless, we request each user to perform some undefined random gestures in front of *Sporshohin*. We have found that, *Sporshohin* does not get influenced by any of those undefined random gestures, and does not provide any signal to the laptop in response to these gestures.

8.2 User Feedback and Analysis

Some noteworthy user feedbacks are:

"There's a security risk in entering PIN using this device in public places. Someone may observe my gestures and tap my PIN."

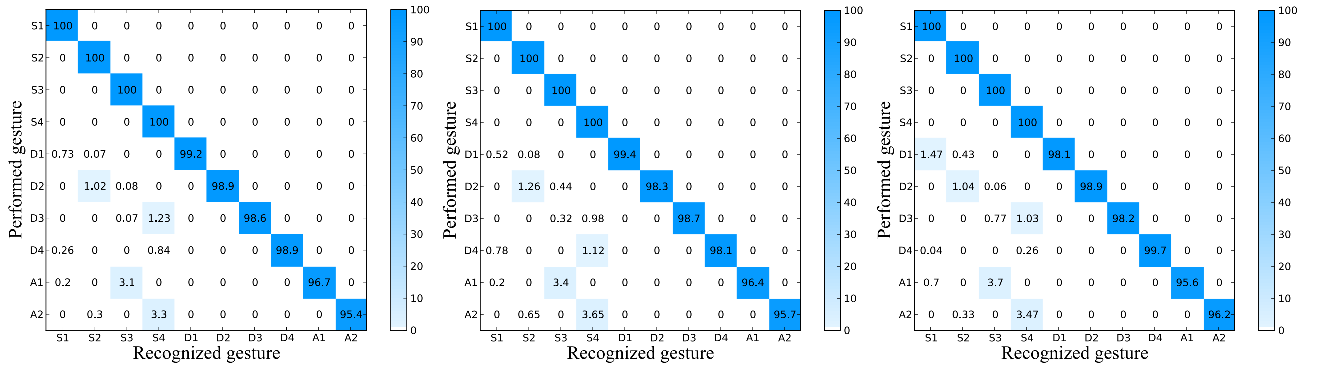
"It's interesting to interact with a cube-shaped device. Blinking lights seems interesting too. Colorful light would make it cool."

"It's captivating. But, it would be nice to reduce the height of the device, it's making trouble to perform those two gestures involving fingers. Also try to increase the (recognition) range."

"I prefer touchscreen to this device. For me, touchscreen is quicker and easy-to-use."

"My phone supports air gesture. But, in most of the cases, it don't get my gestures or incorrectly get it. I don't get the region where to perform gesture. In your device, it's easy for me to get the region by getting the light of LEDs on my hand."

"It's like a table lamp. LEDs make it more attracting. I would like to have it on my computer table, as a mouse and a lamp."



(a) Room light (b) Asymmetric lighting condition (c) Daylight

Figure 15: Confusion matrix showing the results of user evaluation under different lighting conditions

On a different note, we observe some notable facts throughout the user evaluation process. The first notable fact is that users utilize both sides of both of their hands at the time of performing gestures. The second fact is that the diagonal and across gestures were recognized erroneously as simple gestures in some cases. This happened because of imprecise placement of hand at the time of performing a diagonal gesture. The user imprecisely moved almost entire hand towards a single coupling instead of moving towards diagonally between two adjacent couplings (see Figure 8e). Consequently, the gesture is recognized as a simple gesture. On the other hand, the reason behind erroneous recognition at the time of performing an across gesture is the imprecise movement of fingers only towards a single coupling instead of movement by fingers towards two opposite couplings. Here, we observed that an untrained user initially intended to move index and middle fingers more than moving the thumb. Consequently, the gesture gets recognized as a simple gesture instead of an across gesture.

9. APPLICATIONS AND FUTURE WORK

Sporshohin can be adaptable to diversified applications through modifying the number of couplings and their arrangement. The gesture set size of *Sporshohin* can be customized by tuning the number of couplings. Hence, one may customize *Sporshohin* based on the required gesture set for a certain application. For example, a single coupling, consisting a LED and a PT, can be used as a switch, which required a single gesture to operate, in public places (e.g., elevator, hospital, etc.). Another immensely used and extremely hygiene threatening public switch, that can be operated using a single gesture, is "Press for Green Man", which is used by pedestrians to cross the road. Besides, in thriving smart public restroom concept, *Sporshohin* can be easily used as a low-cost input interface through making requirement-oriented modifications.

According to user feedback, two potential future improvements of *Sporshohin* are enhancement of security and increment of recognition range. From the perspective of security concerns, it can be noted that hand gestures performed in front of *Sporshohin* are visible to nearby observers. This can cause security concern in some cases. For example, a user will not want to enter his/her password using *Sporshohin* as the password may be observed by others as per design presented in this paper. This is an important concern, and has to be resolved before deploying *Sporshohin* in public application requiring private information. A potential solution of this problem is to make the mapping of gestures to digits dynamic rather than adopting the current static one. In dynamic mapping process, the mapping will be random and different for each individual user. This dynamic mapping will be exposed, through a small visible layout, to the individual user only. Besides, another possible future enhancement of *Sporshohin* is to increase its recognition range. It is easy to do through using more powerful LEDs with higher intensity at the cost of more power consumption.

10. CONCLUSION

Usage of touchless input devices is an emerging research in nowa-days, as it offers a hygienic framework of interaction for public usages like information kiosks. This hygiene problem is getting intensified with the popularization of touch-based information kiosks, in developing countries having dense population. Moreover, according to previous research literature, it is inappropriate to use touch-based input interfaces in public usages, such as information kiosks, from various perspectives including cost-effectiveness. Existing touchless technologies exploiting camera, radio frequency wave, etc., are not reasonable choices, from the perspective of cost effectiveness, in case of applications requiring a small set of gestures to be recognized.

Therefore, in this paper, we propose a novel low-cost visible light based touchless input device named *Sporshohin*. A robust gesture recognition mechanism against diversified environmental lighting condition makes it a pervasive solution. A power-efficient duty cycle makes *Sporshohin* low power consuming solution compared to others. Besides, we verify efficacy and usability of *Sporshohin* with user evaluation under different environmental lighting conditions. The results of user evaluation confirm potency of *Sporshohin* to be a ubiquitous input device in diversified applications.

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