Gestural Control of Household Appliances for the Physically Impaired

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Abstract

Household appliances such as dishwashers, televisions and radios are an indispensable part of the modern household. Yet, people who have some form of physical impairment often find that they are unable to make use of these commonly available appliances, to the detriment of their lifestyle. This paper proposes a gesture interface for home appliances that can be used by people with physical impairments. Two simulated gesture controlled appliances are developed and evaluated by physically impaired people. The results show that this interface is able to allow physically impaired people to make use of modern appliances by gesture.

Introduction and Motivation

The ability to live a satisfying, independent life can be difficult for people who are physically impaired. While there are tools and technology that can assist physically impaired people in various ways, there are few practical solutions to assist with the operation of home appliances. Modern home appliances provide a great deal of convenience, comfort and information to our lives. We depend on appliances such as dishwashers, ovens, televisions and vacuum cleaners to assist with keeping our homes clean, preparing meals and for information and entertainment. While most people give little thought to the physical control of an appliance when operating it, there are some people who often find that they either cannot use or require some form of assistance to use modern appliances due to the physical impairments they have. For example, a person confined to a wheelchair will have difficulties in reaching for appliance controls, especially if they have spinal muscular problems that prevent or severely restrict upper body movement.

In this paper, we explore the use of gesture recognition as a method for physically impaired people to control home appliances or any device in their environment through investigation and development of a gesture recognition system and a set of easy-to-use gestures. The goal of this work is to design and demonstrate a gesture interface that will provide people with physical impairments the ability to use common home appliances. To achieve this goal, the gesture interface will need to meet the following objectives:

Invisible The interface should not be the focus of the user's attention when controlling the appliance. The user should feel as if they are controlling the appliance itself. It ideally should be embedded within the appliance and not be an external, discrete device.

Simple The set of gestures should be simple enough to be used by any person and with any appliance. Simple gestures will accommodate a wider range of impairment and ability.

Intuitive Gestures should be relevant to the functions they control, and the user should directly interact with the desired appliance.

Ambient The appliance and interface can be ignored until it is explicitly required. Also, the appliance will not respond or activate until needed.

Gesture-Based User Interface

Ambient Intelligent (AmI) systems have been identified as a possible way of home automation. The usual methods for user interaction proposed for AmI systems is a combination of speech recognition and environmental sensing through cameras, motion sensors and similar devices. Recently, the use of cell phones, PDAs, multi-touch screens and, last but not least, gesture interfaces (Sainz Salces et al. 2006; Starner et al. 2000; Raisinghani et al. 2004; Magerkurth et al. 2006) has been advocated as alternatives to interaction with an AmI system. Considering that direct-manipulation interface devices, such as light pens, have been found to be easier to use (Charness, Bosman, and Elliot 1995), it would seem that a gesture interface system would also be similarly useful for people with physical impairments, since gestures are an integral part of communication and are developed at an early age before the acquisition of language skills (Butcher and Goldin-Meadow 2000).

There are a number of different methods to implement a gesture system, including the use of plush toys (Mori and Igarashi 2007), whole body movement (Bien et al. 2005), eye winks (Wei-Gang, Huang, and Hwang 2007), hand movements (Starner et al. 2000; Sepehri, Yacoob, and Davis 2006) and the use of a remote "wand" (Wilson and S. Shafer 2003; Wobbrock, Wilson, and Li 2007). The problem with all of these approaches is that they require a customised hand-held device and/or fixed cameras in the environment to record and recognise the gestures being made. The hand-held devices that have been proposed are only usable with the control systems they are designed for, making them a specialised system and therefore expensive to produce. Additionally, almost all of the proposed systems use a set of cameras in the environment to record the location and orientation of the device, with the hand-held device sending movement information to the computer system that represents the gesture made by the user. The system then performs a series of image analysis tasks from the camera data and combines the results of this with the gesture data from the hand-held device to identify the appliance being addressed and the action to be carried out. The computer system must then instruct the appliance to carry out the requested action. This set of complex operations, to be carried out by a large set of equipment, is expensive in terms of cost and computing power.

The goal of our project is to find simpler and cheaper ways to build gesture interfaces. Modern household appliances now contain embedded microcontrollers which allow appliances, such as washing machines, televisions and dishwashers, to provide a wide range of sophisticated functions and intelligence. With this level of electronic sophistication in the appliances, it becomes possible to add in a gesture recognition system that does not require complex image analysis techniques or expensive, customised devices to produce the gestures. An example of this is the Gesture Pendant (Starner et al. 2000), which used a simple arrangement of infrared LEDs surrounding a camera that only received infrared light. This allowed the researchers to implement a simple image-analysis system as only black-and-white images needed to be examined and orientation did not need to be determined. However, it relied on either unique gestures, an embedded infrared transmitter or a set of infrared LEDs on the controlled appliance in order to be able to identify and control each appliance.

By taking the Gesture Pendant, or a similar device, and placing it in the controlled appliance itself, we will be able to provide a gesture interface that only relies on the user to make a gesture within sight of the appliance. No hand-held or worn device is required as the user only has to make the gesture using their hands. Addressing the correct device is inherent in this system as the user must be close enough to been "seen" by the appliance, and any other appliances nearby will either not be in range or the orientation of the user's gesture will be such that it will not be recognisable by any other appliance. Another advantage of this approach is that no additional computing infrastructure is required to be installed, and therefore the system can be implemented very easily and cheaply.

Prototype System

For our prototype system, we used off-the-shelf hardware, augmented with some simple and cheap electronic components. The base of our setup is a Nintendo Wii remote, which contains an IR camera and can be connected to a computer via Bluetooth.[1] Usually the Wii remote is used directly by moving it in front of an IR LED panel. However, it can also be used indirectly by using an object, such as a finger, to reflect the light emitted from the LED panel into the Wii remote.[2] Figure 1(a) shows our setup schematically while Figure 1(b) has a photo of the actual prototype. Since IR light is not reflected well from any surface, we use an "enhancer", such as a reflective tape or a baton, which the user either wears on their wrist or holds in their hand like a pen. This is potentially a serious shortcoming, since it might make the interface the focus of the user's attention. We hope that this shortcoming can be overcome once more advanced technology is available.

The software component of our system consists of a gesture recorder and a gesture recogniser. The gesture recorder makes use of the WiiRemoteJ[3] Java library to capture the user's gesture, and the SwingStates[4] Java library to implement the state machine behaviour of the gesture recorder. The SwingStates library is also used in the gesture recogniser, as it implements the $1 Gesture Recogniser (Wobbrock, Wilson, and Li 2007), which is a small and accurate algorithm that is designed to be simple and easy to implement. It is ideal for researchers and developers who wish to get a gesture system up and running without any great programming effort or large system requirements. Because of its simplicity and size, it is believed that this recogniser will be well suited for use in an embedded system. However, the $1 Gesture Recognizer has the shortcoming of not properly handling one-dimensional gestures, since it matches gestures against geometric templates independently of rotation, scale and orientation. This is adequate for two-dimensional gestures, but in the case of one-dimensional gestures, which are movements aligned to one axis, we need to distinguish between a horizontal and a vertical stroke for instance. We therefore have to treat one-dimensional gestures separately and only pass two-dimensional gestures to the $1 Gesture Recognizer.

Since the system is continuously scanning for gestures, we need a mechanism to distinguish between movements that are gestures and those that are not. In addition, we want to make sure that the user is deliberately referring to a specific device when making a gesture. To achieve these goals, we divide the viewable window of the Wii remote into three zones: ignore zone, gesture zone and attention zone (see Figure 2).

The ignore zone is a 125 pixel wide border region where the gesture recorder ignores any movement. This area reduces the chance of an accidental gesture being recorded by ensuring that the user is deliberately gesturing at the sensor and not performing some other activity that happens to be in the view of the sensor. The ignore zone allows the gesture system to slightly overlap the view of another continuous gesture system without it incorrectly responding to movement.

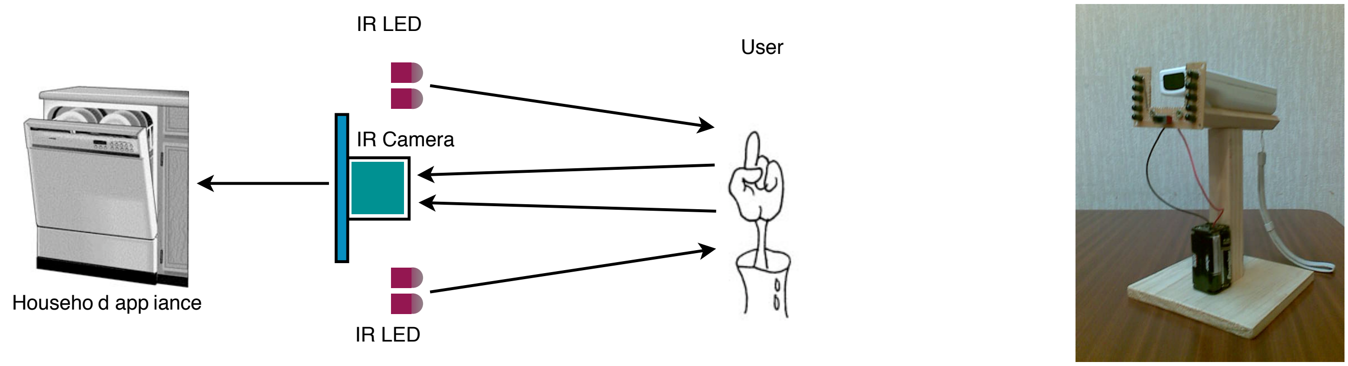
The gesture zone is an area 774 pixels wide by 518 pixels

[1] See http://www.nintendo.com/wii, 2 November 2011.

[2] See http://johnnylee.net/projects/wii/, 2 November 2011.

[3] See http://code.google.com/p/bochovj/wiki/WiiRemoteJ, 2 November 2011.

[4] See http://swingstates.sourceforge.net, 2 November 2011.



(a) (b)

Figure 1: (a) Appliance controlled by gestures. (b) Prototype of the infrared LCD panel with the Wii controller.

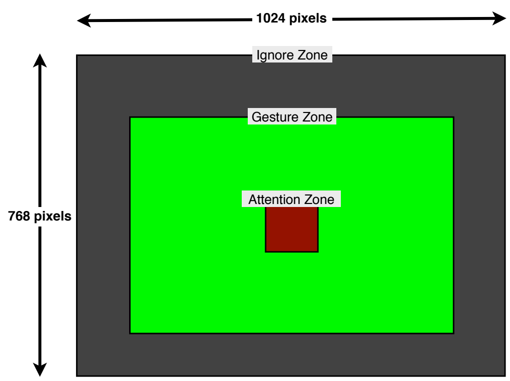


Figure 2: Zones of the viewable window of the Wii remote.

high where any movement of an IR light causes the gesture recorder to record a gesture, once the user has gained the systems attention by entering the attention zone. The attention zone is a 125 pixel high by 125 pixel wide area in the middle of the viewable area of the IR camera on the Wii remote. In order for a gesture to be recorded, the user must point at the attention zone for a short period of time (∼0.5 seconds).

When the gesture recorder notices that the user is pointing at the attention zone, it signals to the user that they have its attention and that they can now begin their gesture movement. The gesture recorder delays the accumulation of data by a short amount of time (∼ 0.5 seconds) to give the user time to move their hand to the correct starting position for the gesture. Once the gesture recording process is under way, any further movement into, through, out of or any lingering within the attention zone is ignored, as it becomes a part of the gesture zone.

To end the gesture, the user can either stop moving their hand for a short time (∼0.5 seconds) or they can finish the gesture in the ignore zone. As soon as the user moves into the ignore zone, or the user stops movement in the gesture zone, then the accumulated data is sent to the recogniser. To make another gesture, the user must get the systems attention again by pointing in the attention zone. The length of the delay and the size of the zone can be adjusted to suit the needs and capabilities of each specific user.

The approach described above requires that the user makes a very deliberate motion within a specific area, but they do not need to be aware of the different zones or what the zones mean. The user only needs to place their hand within sight of the camera and recognise the ready signal from the gesture system.[5]

Gesture Sets

The natural development of gestures tends to reduce complex, multi-limbed gestures down to simple, one or two handed gestures, which are performed within a relatively restricted, centralised space (Kendon 2004). Kendon also notes that during this transformation, the only elements of the original gesture that are retained are those that are distinct from all other gestures. In the following, we refer to the set of reduced and distinguishable gestures as the gesture set recognised by the system.

When designing a gesture system for people with physical impairments, a number of issues have to be considered that lead to the following guidelines:

1. The gestures do not rely on any specific timing. The shape of the gesture is what is important, not the speed with which it was made.
2. The gesture interface system allows for any amount of delay during the preparation phase and between the preparation and stroke phases. This delay is tailored to each user depending on any delays caused by the impairment.
3. The gesture interface system is able to learn any unique gestures of a particular user and is able to map them to the required action. These user-defined gestures replace existing gestures in the system and are not be added to existing gestures.
4. All gestures are transitive gestures. Transitive gestures are gestures that reference an object. Intransitive gestures do

[5]Needless to say that this approach fails if two systems are directly facing each other, since they will both see the same gesture.

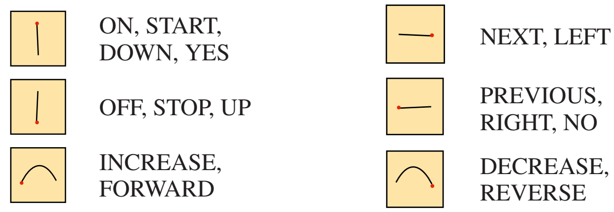


Figure 3: Some of the basic gestures used in the system.

not make such a reference and are therefore not suitable for controlling devices.

5. Each gesture starts with a preparation phase that consists of a deictic gesture aimed at the gesture interface itself to get its attention. As this gesture is aimed solely at the device the user wants to command, all other devices will not pickup this gesture, which reduces any potential for accidentally issuing the wrong command to the wrong device.
6. The preparation phase is immediately followed by a stroke phase that consists of the gesture itself.
7. The stroke phase is followed by a recovery phase that consists of any user movement that transits from gesture zone to the ignore zone and then leaves the ignore zone.
8. A gesture is deemed to be complete when there is a post-stroke hold detected or when the recovery phase is begun.
9. The gesture is a single-path stroke, able to be performed by the use of one finger, hand or any object that shows a single point to the gesture system. This is in keeping with the observation that gestures will eventually be refined down to a simple single-stroke gesture, which can be used more easily by people with physical impairments.

A set of basic gestures is shown in Figure 3, along with a number of associated commands. These gestures are a minimal set that allow for a wide variety of control while still being familiar and easy to associate with a concrete idea or object. In these diagrams, the (red) dot represents the start point of the gesture and the (black) line shows the shape of the gesture stroke, with the direction of the stroke being away from the dot. These gestures do not represent all of the possible gestures required to control a device or appliance nor will they map to all functions of a device. This is deliberate for two reasons: firstly, a small number of gestures will not overwhelm the short-term or working memory (Miller 1956), especially if that memory is degraded, and secondly, some functions of the device may not be understandable by a person suffering form Alzheimer's disease due to a combination of cognitive degradation and the complexity of the function.

Figure 4 shows two examples of how the basic gesture set can be used to control a household appliance: a radio and a light source. Note that the examples are not independent of the cultural background of the person. For example, a person from North America would find an upward (downward) flick of the finger a natural gesture for switching on (off) the lights, while someone from Australia or New Zealand would interpret this gesture the other way round.[6] A person from Europe probably would not have a preference either way, and therefore we can only use the gesture to indicate a change (either from on to off or off to on, depending on the current state of the lights).

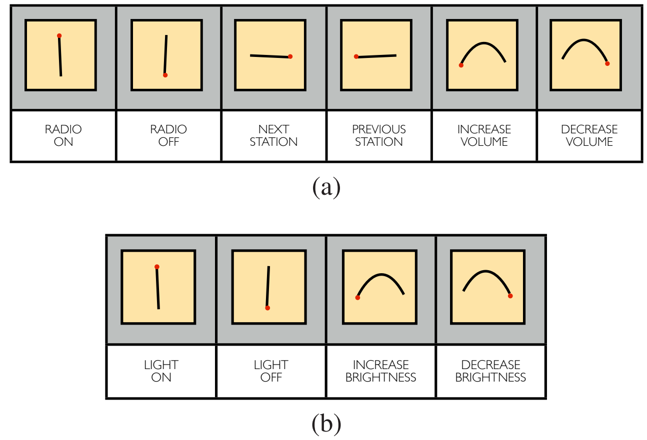


Figure 4: Controlling appliances by gestures: (a) radio, (b) light source.

Evaluation

Six participants were recruited to evaluate the implemented gesture interface. The participants were aged between 17 and 25 and all had health conditions that resulted in diminished strength, dexterity and range of movement to their upper bodies, specifically the arms, hands and fingers. The participants' physical impairments all resulted from health conditions either acquired at birth or developed later in life. None were the result of any accident or injury. The severity of the impairments ranges from mild (has an effect on daily life but tasks can be accomplished with minimal assistance) to severe (inhibits daily activities, tasks cannot be accomplished without the assistance of another person or cannot be accomplished at all). Table 1 summarises the participants, their impairments and the severity of those impairments.

The study used two simulated appliances: a lamp and a radio. To control these appliances, two infrared pointers were used. The first is a hand-held pointer that can be held and manipulated like a pen. The second is a wearable pointer, attached to the participants wrist with a small strap. One purpose of these two different pointers is to ensure that all participants are able to use the simulated appliances and to investigate the users preferences in performing gestures, either by using the hand or arm. This study consisted of three tasks in which each participant carried out a list of instructions, using the gestural interface to control the selected appliance, and each task was carried out twice, first using a hand-held infrared pointer and then using a wearable pointer attached to their wrist. Each task was designed to investigate a particular aspect of the design of the gesture system. The first task investigated the basic mechanics of getting the ap-

[6] This is due to how light switches work in these different zones.

Participant	Condition	Severity	Impairments and effects of impairments
A	Cerebal Palsy/Scoliosis	Moderate	Requires a powered wheelchair for mobility; diminished strength; diminished dexterity; tires easily; difficulty in reaching or stretching for objects
B	Muscular Dystrophy	Very severe	Requires a powered wheelchair for mobility; diminished strength; diminished dexterity; very limited arm, hand, finger movement; assisted breathing; heart problems
C	Muscular Dystrophy	Severe	Requires a powered wheelchair for mobility; diminished strength; diminished dexterity; difficulty in reaching or stretching for objects; limited ability to move arms, hands and fingers
D	Fibromyalgia	Moderate	Full physical range of movement in arms, hands and fingers; movement is limited to chronic pain; extended periods of activity also limited due to chronic pain
E	Arthritis	Mild	Stiffness and pain in joints; can walk on own for very short distances but needs a walker or mobility scooter for travel for moderate or greater distance; fatigues easily; diminished strength
F	Freidreichs' Ataxia	Severe	Requires a powered wheelchair for mobility; reduced reaction time; greatly diminished dexterity

Table 1: Summary of the participants' physical impairments.

pliances attention and successfully operating it. The second task extended the investigations of the first task into the full range of gestures available for use. It examines the feasibility of physically impaired people being able to use complex household appliances by gestural control. Task 3 investigated the gesture system's ability to prevent accidental activation and the participants' ability to select and command an appliance of their choosing. After each task was completed, a short interview was held with the participant to solicit their impressions and opinions concerning the gestural interface of the appliance. The interviews for Task 1 and 2 focused on the use of the interface, the appropriateness of the gestures themselves and how using the gestural interface compared to their normal method of controlling these appliances. The interview for Task 3 focussed on the participants' ability to select and operate a particular appliance. At the end of each study, the participants were asked a set of questions regarding their overall impressions of using the gestural interface and gestural control of appliances in general.

For Task 1, each participant was first asked if they were able to use the lamp appliance, and if so, did they make use of any assistive devices or technologies when using it. They then carried out the following set of instructions, first using the hand-held pointer, then with the wearable pointer:

1. Turn the Lamp on
2. Turn the Lamp off

All of the participants found that getting the appliance's attention was difficult to do and this was the main reason for tasks not being completed. In particular, participants A and B found that keeping their arm or hand steady enough to get the appliance to react was the main difficulty. However, with the exception of participant E, all participants commented that their main difficulty in getting the appliance's attention was the difficulty in aiming the pointer at the correct part of the sensor. This was due to them being unsure of exactly where they were meant to aim the pointer relying, instead, on the response of the appliance to tell them when they were aiming correctly. All of the participants that could successfully get the appliance's attention found making the gesture to be easy to do, even though some of them took some time to get used to the gesture system. There was no consistent opinion about whether or not controlling a lamp or similar appliance would be easier or more difficult than using controls, this being due to the nature of the individual participant's own impairments and their personal preferences. Overall, this task shows that the gestural interface can be used by people with physical impairments to their upper body. However, people with very severe physical impairments may lack the strength or mobility in their arms or hands to be able to get the appliance's attention or perform the gesture, as was the case with participants A, B, C and F.

In Task 2, each participant was first asked if they were able to use the radio appliance, and if so, did they make use of any assistive devices or technologies. They then carried out the following set of instructions, again, first using the hand-held pointer, then the wearable pointer:

1. Turn the radio on
2. Select the next station
3. Increase the radio volume
4. Select the previous station
5. Select station number
6. Decrease the radio volume
7. Turn the radio off

As with Task 1, the main reason for the lack of successful task completion was caused by the difficulty encountered by the participants in getting the appliance's attention. Of the participants who fully or partially completed this task, all of them found the gestures easy to learn and that they were relevant to the function they performed. There was no clear agreement regarding whether any particular gesture was more or less difficult to perform than the other gestures, with the choices being made based on the individual participant's own personal preferences and limitations due to their physical impairments.

For the last task, each participant would attempt to operate the two appliances with their sensors both facing the participant. The participant was required to get the attention of a specific appliance and command it without the other responding in any way. This task was accomplished with the following instructions:

1. Turn the radio on
2. Turn the lamp on
3. Increase the radio volume
4. Select the previous station
5. Turn the lamp off
6. Turn the radio off

Participants D and E were able to successfully completed this task using both pointers, while participant A completed this task with the wearable pointer. Again, the primary issue was with getting the appliance's attention. The participants were either unable to position the pointer overall; for those participants who completed the task, they were able to get the attention of, and operate the appliance that they wanted. There was only one incidence where the incorrect appliance responded, and that participant immediately recognised this fact and corrected his aiming accordingly. There were no incidents of an appliance incorrectly responding to a participants command. Those participants that completed this task also understood exactly which appliance they were working with because they were either focussing their attention on the location of the appliance they were using (left or right side) or they used the feedback from the appliance to confirm which appliance they were using. Likewise, there was no confusion regarding the operation of the correct appliance. The only appliance that responded to a command was the appliance that the command was intended for.

Conclusion

In this paper, we have discussed a user interface for ambient intelligence systems that is based on gestures. We believe that such an interface can overcome the difficulties that people with physical impairments experience when interacting with an ambient intelligence. In particular, we believe that by embedding the gesture recognition system into household appliances and using a simple set of gestures, a gesture system can be developed that significantly improves the quality of life for these people.

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