Prototyping Input Controller for Touch-less Interaction with Ubiquitous Environments

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Abstract
In ubiquitous computing environments, the information processing is integrated into everyday objects that are ideally small, inexpensive and wirelessly networked devices. Contemporary human-computer interaction models are not adequate to control miniaturized devices, which are distributed throughout everyday life and activities. This post-desktop model requires natural gesture-based interaction with distributed devices in an egocentric manner as opposed to the current device-centric interaction. In this work, we have utilized the recently proposed touch-less gesture-based interaction method based on magnetic field to provide a hardware basis for a wearable input controller. Furthermore, we have discussed how the proposed device can allow natural interaction with other devices within a ubiquitous computing environment such as personal area network.

Keywords
Around Device Interaction, Magnetic Field Sensor, input Controller, Ubiquitous Computing Environments

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces. Input devices and strategies; B 4.2 Input Output devices.

General Terms
Algorithms, Design, Human Factors

Introduction

As mobile, smart devices become ubiquitous, the traditional techniques for interacting with remote devices face great challenges. Necessity of a direct line of sight between transmitter and receiver, requiring several control units for different instruments in general, limited range of communication, limited amount of space on the remote control which generally results in small keys, necessity of visual contact with the remote controller to select a function, lack of rational relationship between the allocation of keys and their corresponding functions, and difficulty of selecting a small key among others for people with shaky hands are some of the limitations inherent with traditional control units. When we use a remote control for changing the TV channels, locking/unlocking a car, opening the door of a parking lot or piloting a toy helicopter, inevitably we are caught by the limitations introduced by classic remote controllers. This immense application of human-device interaction in our real life calls for a novel, natural and multimodal interaction technique that can address the shortcomings of the current methods.

Thanks to recent developments in electronics, the computational capacity of mobile devices has increased significantly, while their size keeps shrinking. However, interactive devices always need to have an input medium (e.g. microphones, keypads) and an output medium (e.g. touch screen, speaker). Most of the contemporary mediums prevent the described miniaturization process due to human limitations such as eyesight and finger size. For that reason, we propose that spatial interaction with multiple devices in a ubiquitous computing environment can be done remotely through a wearable input controller. This method allows human-centered interaction, which is more natural than device-centered type, and supports the miniaturization of ubiquitous devices by transferring their interaction medium to a single wearable interface. Due to its wearable nature, the device itself should be ideally small, especially in order to blend invisibly in arbitrary surfaces. Therefore, interaction with such device still needs to be performed in the 3-dimensional (3D) space around the device in a touch-less way. Several techniques, which are based on gestures recognized through (e.g. motion, proximity, optical) sensory input [2,8,13], are proposed for Around Device Interaction (ADI) to extend the interaction space beyond the physical boundary of devices. The use of embedded magnetic field sensor for touch-less interaction in the 3D space around mobile devices has been recently proposed [1,4,5]. In this method, users interact with mobile device by making coarse gestures around the device holding a permanent magnet. This approach is evaluated in variety of use cases and overcomes several limits posed by other interaction methods [6,7,10].

In this work, we have proto-typed a wearable input controller using touch-less and gesture-based magnetic interaction to remotely control (possibly miniaturized) devices within a ubiquitous computing environment. The proposed device can pair and communicate with ubiquitous devices via Bluetooth allowing a contact-less user interface through gesture recognition where the magnet triggers the gesture and the device then sends commands to another mobile device, such as a smart phone. To demonstrate this approach, we have also implemented an example scenario of where the input and output medium of a smart-phone is transferred to the proposed device to and a Bluetooth headset respectively. Finally, we have roughly discussed the hardware technology, protocols and algorithms for achieving the digital compass/magnetic stylus based interactions.

Methodology

The recently proposed magnetic interaction allows wireless, unpowered and high fidelity magnetically driven 3D input, through the movements of a magnetized stylus held by the user, for pointing or recognizing coarse movement-based gestures. The sensor to be used for interaction is already embedded in many mobile devices and available in small and inexpensive varieties. This type of interaction perfectly matches human ergonomics and motor control as the sensor is worn and the effecter held by the user. The proposed method has been tested in a variety of applications such as gesture recognition [5], handwriting recognition [6], user authentication [7] and music performance [10]. The experimental results show that the proposed interface not only elevates the convenience of user-device interactions, but also shows very promising accuracies in a wide range of applications requiring user interactions. To sum up, this type of interaction is reliable, resource efficient and has larger input space and more degree-of-freedom concerning wearable interfaces, in comparison with other around device interaction methodologies; while, it helps saving cost, complexity and physical space in design of the proposed input controller. Finally, the wearable device can be hidden below the user's clothing or other objects might conceal it since the magnetic field can penetrate through occluding objects.

Accordingly, we have employed the recently introduced interaction method based on an embedded magnetic field sensor (digital compass). For that reason, we have embedded a 3-axis magnetic field sensor to our proposed wearable device to sense the magnetic field that surrounds it. The movement of a properly polarized magnet by the user, in vicinity of the proposed wearable input controller, deforms the sensors original magnetic field pattern whereby constitutes a new means of communication between the user and the worn device. By this way, the magnetic field encompassing the device plays the role of a communication channel and encodes the hand-movement patterns of the user into temporal changes in magnetic field around the device sensed by the sensors. In the back-end of the communication, an engine samples the momentary status of the field during a trial and recognizes the user's pattern by matching it against some pre-recorded templates.

The mobile device, then, translates the recognized gesture to a command and sends it over to the target device that can be a large display, a TV/Video set, etc. This allows merging several controllers into one unique unit. To this end, an initial, also gesture based, command specifies the target device to be in the listening mode and then the command itself follows. The selected device, then, remains vigilant to the commands until the next selective (hyper) command pops out. This possibility of integrating different controllers into one device allows the user to use a same gesture to invoke the corresponding command for different remote devices.

Wearable Input Controller

In this section, we propose a prototype that we have designed to be a wearable input controller device using a permanent magnet as an input medium. The ultimate aim of the input controller is to process the magnetic field data and recognize movement-based gestures as an independent hardware that can communicate with various devices within a ubiquitous environment via Bluetooth. The device is able to collect data from the 3-axis magnetic field sensor module called MicroMag3 [11] using Serial Peripheral Interface Bus (SPI) and processes the incoming sensor data to provide an absolute pointing or recognize movement-based coarse gestures using measurement or pattern based recognizers. The beginning and the end of each gesture can be detected by pressing a toggle key, performing a pre-defined simple pattern or putting a variance threshold, which signifies if a gesture is being performed or not, on both end of the movement. Data coming from each axes of the sensor during this time interval forms a sequence of 3D vectors, which replicates the trajectory of the performed gesture. The proposed device uses the resulting vector sequence to recognize user's gesture and send intended command to the target ubiquitous device.

To recognize hand gestures in real-time, we have utilized STM32F100RB (32-bit, 24 MHz, 128-kB, 8-kB RAM) [12]. For each sampling period (of minimum 1.5 ms), the magnetometer gives 16-bit output on each axis. If the 8-kB memory is insufficient concerning the maximum duration of a gesture, the sampling rate of the magnetometer should be reduced to prevent the loss of valuable information that would cause inaccuracy during the recognition. Multi-Layer Perceptron (MLP) [9] is employed for recognizing hand gestures, as it is recommended by [5], due to its capacity on recognizing large number of complex gestures and its resource and algorithmically efficient testing phase. The training phase of MLP is performed with the help of a personal computer and then resulting weights are transferred to the wearable device's memory. Thus, a UART-to-USB converter is used to transfer data between the transmitter/receiver (TX/RX) pins of the microprocessor and the USB port of the computer. In order to further accelerate the testing phase, we have used a very simple feature vector, which is composed of the cross-correlation values between derivatives of signal along X-Y, X-Z and Y-Z axes of the magnetic field, concerning the resource constraints.

The device might be powered either using a removable or rechargeable coin cell; however, a 3.7V Li-poly battery is used in our design considering the required time for recharging the device. In case of removable battery, the USB connection is not necessary once the device is programmed. Thus, the UART-to-USB converter is extracted from the device by designing a PCB just for programming purposes. Yet, the device can also be programmed via this particular PCB by making external connections to TX/RX, +Vcc and GND pins available. In case of rechargeable battery, the USB connection is also used to charge the device through a charger controller. The battery level is monitored using one ADC pin of the microprocessor and comparing this to a reference value that depends on the Brown-out reset voltage level of the processor. The battery level is checked with a low interrupt rate, as the continuous monitoring is not necessary, to warn the user when the battery level is low.

Bluetooth PAN Control

In this method, the input for each controlled object is given using the proposed wearable interface through a wireless ad-hoc (without preexisting infrastructure) network. The controlled object utilizes the same decentralized network to forward its feedback to other devices. The feedback is forwarded to the wearable interface itself or to a projector (or public display) or to a Bluetooth headset, in the case of tactile or visual or audio feedback respectively. Accordingly, we have used a Bluetooth Personal Area Network (PAN) protocol, which is a network for interconnecting devices centered on an individual person's workspace. In our implementation, the wearable input controller is able to connect 8 active ubiquitous devices in a master-slave relationship. The wearable device plays the role of a master within the PAN, and all other devices are slaves. The authentication protocol between objects and feedback providers in the personal area network of the user can also be controlled as a side effect of the interaction.

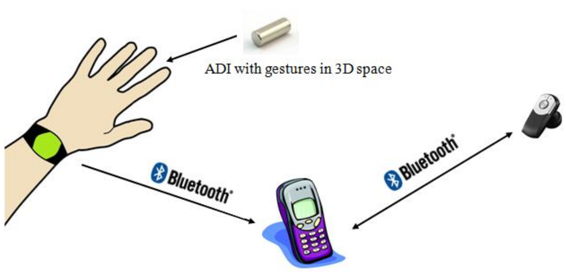

Figure 1. Example usage scenario where the user interacts with a smart-phone using through the proposed device

Example Usage

In order to demonstrate the proposed method and the wearable input controller in a real-world scenario (Figure 1), we have implemented a prototype application on the Google Android operating system with the help of Amarino toolkit [3]. Amarino discovers nearby Bluetooth-enabled devices and pairs with them; then it runs as a background service to broadcast received events from the device to other Android applications using Android intents. Also, the service can listen to the events generated by any Android application and pass to the device. Using Amarino as a service, we have developed a custom Android application for making calls using the wearable controller's input rather than Smartphone's actual input. Once the device recognizes a series of digits bounded by special characters on both end for marking the beginning and end of a phone number, it sends an event to the Amarino daemon including the phone number data. Amarino broadcasts the event to the custom application that we have implemented which listens for that specific intent and finally dials the received phone number once the intent is received.

Similarly, the status of the phone (e.g. ringing, hang-up) or the result of the phone call (e.g. success, busy), can be obtained by the Amarino service through Android phone event and then passed to the wearable device or any device within the personal area network of the user and can be shown as any type of feedback. For instance, the user can perform a gesture in the vicinity of the wearable device for accepting or rejecting a received call after a ringing event is received. For the sake of simplicity, we have simulated the audio feedback, which may also be the initiated phone conversation, using Android's built-in Bluetooth headset functionality instead.

Conclusions

In this work, we have explained design choices of a hardware design for the proposed wearable input controller and demonstrated a concept of human-centered touch-less interaction in ubiquitous computing environments. The demonstrated scenario is simple but powerful as it shows that one can think of a miniaturized mobile phone (without touch-screen or num-pad) that receives input only through the proposed wearable device. Such small mobile phone can be obtained also by embedding a GSM module directly to the wearable device itself. Yet, we have preferred to control the mobile phone instead as we propose the wearable to be a universal controller for all of the other devices within the ubiquitous world.

Accordingly, the proposed wearable input controller along with magnetic interaction may open a very large space of novel designs of ubiquitous devices. The complete implementation and comprehensive user evaluation study of the device is planned for near future. After we have implemented the Bluetooth module, we have decided to switch to a removable coin cell battery and remove USB connection and charger controller from the device to further miniaturize the proposed device, as we are able to program the device via the Bluetooth network as well. Finally, we intend to implement the proposed design into a miniaturized wearable wristwatch-like object, after establishing all of the proposed functionalities.

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