Use of the foot in 3D interactions with mobile devices

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***Abstract*—With this paper, we report a novel wearable interface dedicated to provide new types of 3D interactions with mobile devices. Proposed interface is based on the fact that the foot can be exploited in the interaction with a virtual 3D world. By using several force sensors incorporated in the sole and an accelerometer attached to the shoe; gestures performed with the foot are interpreted in order to let the user interact with a 3D virtual environment. Being located inside a shoe this interface is fully compatible to constraints related to mobile devices. Indeed as a wearable and transparent device it can be carried everywhere and therefore can be exploited everywhere.**

***Index Terms*—Virtual Reality, Waerable interface, foot-based interactions**

I. Introduction

Full interaction within a Virtual Environment (VE) requires three components which are selection, manipulation and navigation. Selection and manipulation take place whenever a user interacts with an object of the virtual scene. Selection intervenes at the first step; it lets to specify the object of interest. Once selected, several modifications can be made on the properties of this object: they are named manipulation. Navigation defines the principles that help the user at exploring the 3D environment. It counts two main parts: way finding and displacement. Wayfinding involves cognitive efforts; it aims at determining the path that leads to a given point whereas displacement corresponds to effective changes of the position through time.

With conventional systems (workstations and virtual reality based architecture), interactions are usually performed by the mean of different interfaces ranging from tracking systems to haptic gloves. When dealing with mobile devices (phone and tablets) interactions are rather performed via a tactile screen. In this case, the interactions are said *indirect* since rendered objects are usually perceived above the display plane, and thus cannot be *touched* by touching the display surface [8].

Looking at results achieved in the last decades it seems to us that interactions with mobiles devices can be greatly enhanced by the mean of appropriate interfaces. For example, it is known that head tracking systems and haptic devices can help users at manipulating virtual objects as they were in a real environment [3]. In the same way, various studies have shown that gestures can be used to improve interactions with a numerical environment [24], [23]. Such results have motivated our work toward the design of an interface that can provide direct interactions with entities of a VE displayed on a mobile device.

A major challenge of work is related to the mobility aspect. Indeed, several characteristics inherent to mobile devices make it difficult to use existing input interfaces (joystick, 3d mouse, haptic device) when it comes to interactions with 3D VE displayed on mobile devices. Indeed, one may cite the screen size as well as the computational power. In the same way, one notes that mobile devices are used anywhere and anytime [6]. Therefore, it appears that such interface i) should require low computational and electricity power, ii) it should be transportable and be usable discreetly.

To provide better interactions with mobile devices, several researchers work toward the adaptation of 2D user interface techniques to the mobile context [22], [4]. Others have recently initiated the exploration of new interactions paradigms with mobile devices [1], [25]. Mainly, as an alternative to situations when the hand is busy or too dirty, they have investigated the use of foot and lower-leg gestures for interacting with mobile devices. However, to the best of our knowledge no work has yet targeted the design of an interface for direct interactions with objects of a VE displayed on a mobile device. In this work, we investigate this aspect via the design of a new interface adapted to constraints inherent to mobile devices.

The solution described here is an enactive sole used to enhance interactions with mobile devices. It is based on the fact that the foot can be exploited in interactions with a virtual 3D world. With the proposed solution, by using several force sensors and an accelerometer; gestures performed with the foot are interpreted in order to let the user interact directly with entities of a VE displayed on a mobile device. Being located inside a shoe this interface is fully compatible to constraints related to mobiles devices. Indeed, as a wearable and transparent device it can be carried everywhere and therefore can be exploited everywhere. In addition, being incorporated inside the sole of a shoe, this interface does allow discreet interactions with mobile devices; meanwhile the hands of the user can still be free for other tasks.

To demonstrate the usability of this solution for direct interaction with a VE displayed on a mobile device, we describe how this device can be exploited for selection and manipulation of virtual objects as well as for navigation. A preliminary experiment confirms the efficient of the proposed solution.

The remainder of this paper is organized as follows: Section 2 provides an overview on work related to our contribution. Section 3 describes the designed solution. Section 4 describes how proposed interface can be exploited for selection, manipulation and navigation. Section 5 details the preliminary experiment realized on the proposed input device. Section 6 concludes the paper.

II. Related Work

In the domain of immersive VEs, to enhance the sensation of immersion, various works have exploited interactions based on foot for communication. For example Rovers et al. have used foot interaction styles in haptic interpersonal communication [17]. In the same way, Vissel et al. [21] have proposed the use of foot to navigate in a virtual environment with floor-based touch surface interfaces. Nevertheless, in the Human Computer Interaction (HCI) domain, when compared to exploitation of hands or other parts of the body, it is clear that foot have received little attention as a controller for input device. To the best of our knowledge, no work has been made regarding the use of foot for 3D interactions within a VE on a mobile device. In what follows, we first review the use of foot for selection, manipulation, navigation with standard displays; thereafter we detail the use of foot in interactions with mobile devices.

A. Foot-based 3D interactions (selection, manipulation and navigation) with standard VR systems

The literature of foot-based 3D interactions within a numerical environment (virtual world, graphical user interface, mobile operating system etc.), can be divided into two main groups. These are selection, manipulation and navigation.

Regarding selection and manipulation, first works back to eighties. First studies about this subject were conducted by Pearson et al. in [16]. They have investigated the use of foot-operated computer input devices. Even through such interfaces were less accurate than their hand counterpart, they have the merit to leave the hand free for additional task. Later, based on psychophysical study, Hoffmann reported that the execution time for foot movements is generally about twice as long as the equivalent arm movement [10]. Recently, Pakkanen and Raisamo [15] have investigated alternative methods for manipulating graphical user interfaces with a foot. In their experiment a large trackball is operated by both hands and feet to perform actions like *selection of a given folder* or *relocation of a folder to a given position*. Results have shown that users were able to complete proposed tasks, with feet, with acceptable accuracy and execution time when compared to the hand condition.

In order to provide users with a more natural interaction, instead of using a joystick (hand controlled interface) several studies have examined the use of feet for navigation. Some works have employed treadmills [11], [19]. Because of multiple technical and ergonomic issues these types of interfaces were limited to one direction of walking. Changes of direction are usually supported via steering handle or similar devices. Other solutions have exploited mechanical moving platforms [13] or moving tiles [12] in order to let the user perform the physical gestures for going up or down, right or left while maintaining his physical position. Recently, in [18] multi-touch hand gestures and foot gestures are combined to perform navigation tasks within spatial data on a large-scale interactive wall. Others approaches are based on the Wii balance board. While standing on the board, feet gestures are mainly exploited for 2D navigation in a virtual environment [5].

Although these works do not address interactions with mobile devices, they have the merit to prove that feet can be exploited for 3D interactions within a VE.

B. Foot-based gestures for operating Smartphones

Last years have been marked by a huge integration of mobility into modern societies. These devices are carried and used everywhere. A recently study supports the idea that they can be associated to a form of habits [14]. Nevertheless, many situations of the everyday life restrict such a usage. For example, it is not well accepted to receive an incoming call during a meeting. As a result, in the last five years, several research teams have investigated the possibility of using foot gestures to operate a cell phone when the hand is too dirty or busy [1], [25]. In [1] they have investigated foot gestures that can be in replacement of hand gestures for interactions such as: answering/ignoring incoming calls, lock/unlock a phone, play/pause music. In the same way, Han et al. [9] have studied how kick gestures (as kicking a ball) could be exploited in interactions with a mobile device. In order to detect the *kick* a Xbox Kinect camera was used. In the same way, Bailly et al. [2] have attached a *Xbox Kinect* camera to a shoe in order to detect hand gestures performed by a user. Detected gestures are then interpreted as interactions with the phone. One of the advantages claimed by the authors resides in the fact that gestures can be performed without visual attentions. Similar studies are performed by Scott et al. [20] through the use of foot gesture as mean of communication to provide hand and eyes-free access to a device's features.

III. Proposed Interface

The core design constraint is to propose an interface that could be easily installed in different shoes, without changing its structure nor its appearance and comfort. To achieve this goal, we proposed to use a hardware interface which incorporates basically an insole wherein electronics is embedded. The proof-of-concept prototype described here includes an ADXL335 accelerometer located over the shoe and five FSR401 force sensors distributed inside the insole of the shoe (see Fig. 1). This section presents the hardware configuration and the main advantage of using this wearable device in mobile applications.

A. Proposed hardware

The first prototype owns an instrumented insole as well as an acquisition system with a wireless transmission capability.

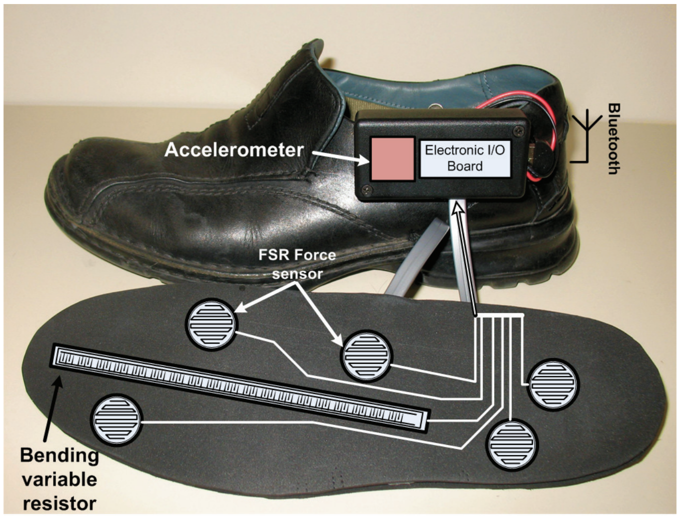

Fig. 1. Hardware of the interface.

The acquisition system contains a Microchip microprocessor PIC24 which enable a first stage signal processing and data analysis coming from raw data measurement. This allows computing some features such as spectral density and frequency components using FFT without using mobile device processing time. Especially, those features are useful to classify motions and gestures of the foot. After a first processing stage, it transmits information to the mobile device via a Bluetooth wireless communication at a sampling frequency of 100 Hz as shown in Fig. 2. Inside the mobile device, a service interprets the raw data and pre-computed features into useful information which is then analysed by an end-user application. According to the information used in the digital environment, it can change the digital entity properties (including position, velocity and acceleration).

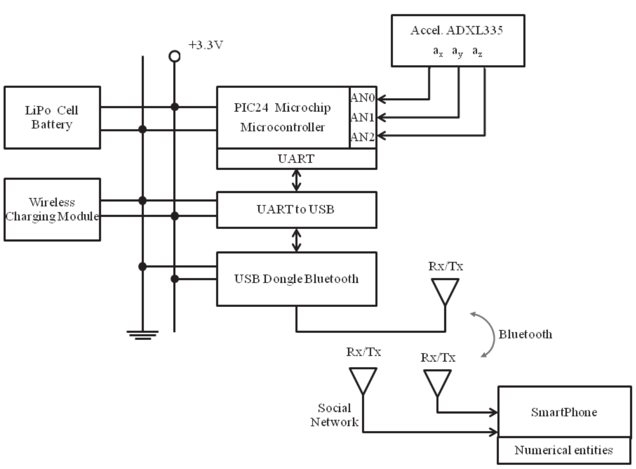

Fig. 2. Electronic of the interface.

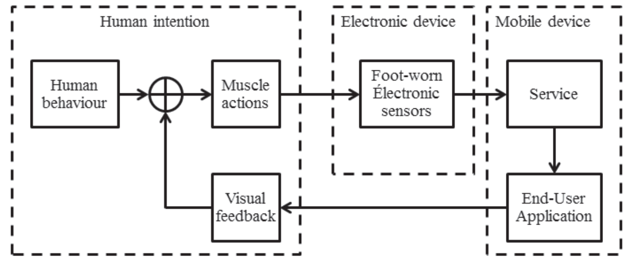

Fig. 3. Interaction loop between human and the software in a mobile device.

B. Main advantages of the proposed interface

Proposed wearable device gathers several advantages, here we present some of them.

Transparent wearable device. Since we want to target interactions with mobile devices, it was crucial for us to come up with a device that can be used anywhere and anytime (for example both in public transports and in the park). Knowing that people generally wear a shoe then it is quite appropriate to think that this interface can be used in many situations of everyday life. Moreover, being mainly located inside the shoe, the interface is quasi transparent for the user and others.

Comfortable wearable device. It is known that comfort aspects play an important role when dealing with wearable devices [7], an interesting aspect with this device resides in the fact that it is very light. Indeed this interface weight less than 10% of a shoe weight. Furthermore this device does not necessitate any particular attention from the user and it does not represent any danger for the user.

Low cost interface The hardware that constitutes this interface does not represent a major investment. When compared to devices such as Wii Remote® it appears that the proposed interface may be considered as a less expensive or low cost interface.

Not affected by the condition of the environment Regardless the environment (crowded, noisy, different conditions of lighting) capabilities of this interface will not be affected. This aspect represents a major advantage when compared to the ShoeSense system [2], whose performances can be altered by the environment: with occlusions problem for example.

Natural interaction within a 3D virtual environment As mentioned above, there are various situations where using the foot for interactions with mobile devices could be best suited than the hand. This interface fits into this lineage. For example, this interface can offer a more natural way for playing a virtual soccer on a tablet.

IV. Gestural input with this interface

By exploiting the sensors included in this interface, all the three basic interactions can be realized with the foot. Based on a pretrial experiment, a set of foot gestures is defined in other to enable foot-based direct manipulation of 3D entities. In this section, we describe the realization of selection, manipulation and navigation.

A. Selection

For the selection, we use a paradigm where the user just has to trample the entity of interest as in a real world situation. For this, an entity is selectable only if it is located in the vicinity of the position explored by the user. Once being selectable, to realize an effective selection the user just has to raise his dominant-foot at a height h which allows to eliminate contact points with the ground, once this height h reached, it must put back his foot as quickly as possible on the ground.

B. Manipulation and navigation

In our everyday life, one of the most common ways used to manipulate objects with feet is via kicking (for example, to kick a ball). In this view, one may consider such an interaction as an interesting metaphor for object manipulation in a virtual world. Nevertheless, when considering the accuracy that such an interaction paradigm can offer, we have preferred a more direct manipulation process. As in the case of a joystick, rotation angles of the foot with respect to a neutral position are directly mapped to linear and rotational displacement of the selected object. This neutral position corresponds to the situation where the plantar part of the foot rests on the ground as at the mid stance of the stance phase of the gait.

1) Linear displacement: A set of six gestures are defined for displacement along the three principal axes. Four of these gestures that should be performed with the dominant foot are represented in Fig. 4. If we consider a reference defines by the three fingers of the right hand, starting from neutral position, a dorsiflexion gesture (see Fig. 4.a) indicates a forward movement (in the +Z direction) whereas a gestures toward to a position similar to the propulsion phase of the gait (only the metatarsals touch the ground) is rather a backward displacement (toward -Z direction). In the same way, rotation of the plantar part toward the left (see Fig. 4.b), respectively right, initiates a leftward respectively a rightward displacement. To go upward, the user has to pull up a little his foot just in order to decrease the pressure exert on the sole. On the contrary, pressing the sole with the foot produces a downward displacement.

One of the main advantages of this metaphor resides in the fact that it can also be used for the navigation. Indeed, if no entity is selected, proposed gestures are rather mapped as displacements of the position explored by the user.

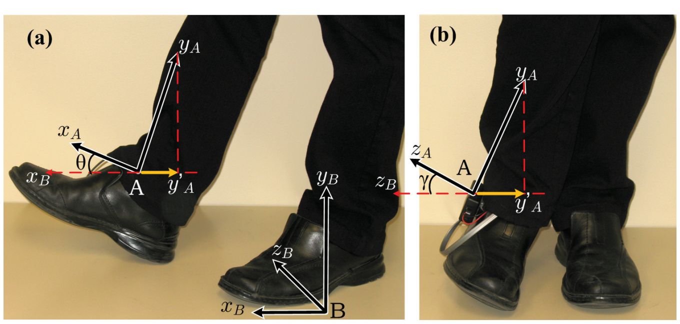

Fig. 4. Two of the gestures used for manipulation and navigation metaphors.

2) Rotational displacement: To rotate the selected object, both feet are exploited. Same gestures described previously are used and at the same time the non-dominant foot should be set in the propulsion phase of the gait position. Once this neutral position detected, position variation of the dominant foot are conveyed into orientation modifications of the selected object.

C. Gesture detection

As seen previously, the three core interactions (selection, manipulation and navigation) are assumed through a set of seven static and dynamic gestures. In the case of static pose of the foot represented in Fig. 4, information coming from the accelerometer can be used to determine the gesture. Indeed, each of these gestures is determined by the tilt (angle from gravity vector) of the accelerometer. For each static configuration, the angle can be determined using (1). In this case, V_{out} represents the output of the accelerometer at the current position, V_{offset} the output at a position where the effect of the gravity has vanished. $\frac{\Delta V}{\Delta G}$ defines the sensitivity of the accelerometer. For more information, one can refer to application note AN3107 from Freesacle semiconductor.

After the computation of that angle, for each direction, let P^n be the position at the discrete time n, it can be computed by the mean of a Hooke constant k_θ as described in (2).

$$\theta = arcsin\left(\frac{V_{out} - V_{offset}}{\frac{\Delta V}{\Delta G}}\right) \quad (1)$$

$$P^n = P^{n-1} + k_\theta \theta \quad (2)$$

Regarding the two other gestures, employed for the selection interaction, the force sensors do provide useful information that allows the detection of these dynamics gesture. Indeed, to detect the position of the foot we have to analyze the value of the force sensor. Greater the force measured by the sensor, closer to the ground the foot of the user is.

V. Case of Study

As a preliminary study, we want to assess whether the device can be exploited for the three interaction tasks as proposed previously. For this study, 6 persons (5 male), aged between 23 and 34, have participated. All of the participants reported being right-handed and no had prior experience with foot-based interactions with a numerical environment. Equipped with the proposed interface, stand on both feet, users have to mimic gestures described previously in order to select and manipulate some objects, as well for navigating in the virtual scene displayed on a Samsung Galaxy 10.1 tablet. Namely, first users have to navigate towards a colored-cube. Once located in the vicinity of the cursor position, users have to select the entity. Finally users have to bring the selected entity at a specified position. Fig. 5 shows the scene of the experimentation, where we observe three colored cubes distributed in space and three colored walls containing each one a hole.

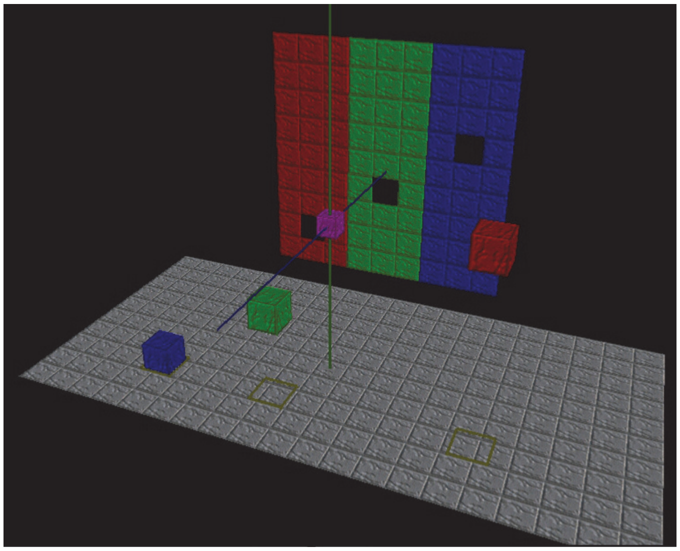

Fig. 5. The virtual scene of the experiment.

User	rank
A	4
B	5
C	4
D	5
E	5
F	4
mean	4.5
σ	0.5

TABLE I
HOW DO USERS EVALUATE THE EASE OF MEMORIZATION OF PROPOSED GESTURES.

	forward	back	left	right	down	up	selection
A	5	5	4	3	4	3	2
B	5	5	5	5	5	5	3
C	4	4	4	2	2	5	4
D	4	4	2	5	3	5	5
E	4	5	5	4	3	5	4
F	5	4	4	4	3	4	3
mean	4.5	4.5	4	3.83	3.33	4.5	3.33
σ	0.5	0.5	1	1.06	0.94	0.76	0.94

TABLE II
HOW DO USERS EVALUATE THE EFFECTIVENESS OF EACH GESTURE.

A. Experimental procedure

Before the experiment, participants receive a brief description about the goal of the experiment, and also about gestures they will have to perform. For this study, only linear displacements are exploited. Thereafter, participants are invited to wear the system. The test phase starts right after the familiarization phase, and lasts until the user estimates that the task is completed.

After the completion of the experiment we asked users about the ease of memorization of proposed gestures as well as their effectiveness. In each case, users are invited to rank the ease on a scale from "1" to "5". In this notation, "1" represents a minor appreciation while "5" denotes the biggest one. Moreover, they are invited to give their general comments about the system.

B. Results and discussion

All participants did perform the test without any noticeable difficulty. Table I shows how each user evaluates the ease of memorization of proposed gestures. With an average of 4.5 on 5 and a standard deviation of 0.5, we observe that all users estimated that proposed gestures where easy to memorize. Table II reports about the effectiveness of each gesture. Only two gestures have an average around 3.33 over 5. This supports the idea that the proposed interface tend to be effective for enabling foot-based interactions within a 3D environment.

User's comments were generally positive: all of them did really appreciate being part of the study. Having the opportunity to interact with a 3D scene via the foot gestures was particularly engaging. On the other hand, two of them did notice a difficulty in the selection whereas two others reported this difficulty in the going down movement. Though discussion with the participants, it turned that these concerns could be alleviate through an appropriate calibration. Indeed, one has to note that both the going down gesture and the selection are detected through an analysis of force sensors. Since the output of these force sensors is directly proportional to the weight of the user, this explains why some users had faced some troubles in these gestures. Another point highlighted by a user was about the gesture proposed for the selection, he noticed that taping with the forefoot or the heel could represent interesting means for the selection. This aspect will be investigated in a future work.

VI. CONCLUSION

Here we have proposed a wearable interface that allows direct interactions with entities of a VE displayed on a mobile device. The proposed interface is a comfortable, transparent and low cost; being located in the shoe its performances are not affected by the condition of the environment. To demonstrate the usability of this interface a set of foot gestures has been designed and evaluated in experimental task.

In near future we plan to run a formal evaluation of the system. Even through proposed gestures were really appreciated by users, we would like to evaluate a large number of gestures in order to identify those that can suit at best the characteristics of this interface.

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