Combining Wristband Display and Wearable Haptics for Augmented Reality

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Abstract

Taking advantages of widely distributed hardware such as smartphones and tablets, Mobile Augmented Reality (MAR) market is rapidly growing. Major improvements can be envisioned in increasing the realism of virtual interaction and providing multimodal experiences. We propose a novel system prototype that locates the display on the forearm using a rigid support to avoid constraints due to hand-holding, and is equipped with hand tracking and cutaneous feedback. The hand tracking enables the manipulation of virtual objects, while the haptic rendering enhances the user’s perception of the virtual entities. The experimental setup has been tested by ten participants, that expressed their impressions about usability and functionality of the wrist-mounted system w.r.t. the traditional hand-held condition. Subjects’ personal evaluations suggest that the AR experience provided by the wrist-based approach is more engaging and immersive.

Index Terms: Human-centered computing—Mixed / augmented reality;

1 Introduction

Augmented reality is expected to become an essential technology in the next future, because of its ability to enhance reality by adding informative or entertaining contents. However, its functionality is mostly unexploited due to the necessity of wearing additional hardware (e.g., during works or daily activities). Suitable prototypes for a massive deployment of AR devices can be envisioned in wearable lightweight interfaces, which do not isolate the user from the context or limit his movement, but provide support to the user’s activities. Smartphone respond appropriately to many of these requirements, and due to the fact that nowadays almost everyone owns one, we selected phones as core technology of our system to reach the largest number of potential users. Lack of realism and tactile interaction with virtual objects can be identified as current major limitations of Mobile Augmented Reality (MAR), together with the need to carry the device with one hand. In fact, most industrial scenarios and daily activities require both hands to be available at the same time.

Few researches succeeded in achieving hand-based interaction with virtual objects for Mobile Augmented Reality. Hand tracking through Leap Motion was exploited in [7] to display an avatar superimposed to the real hand on the smartphone screen. However, this approach lacked haptic feedback, and setup was bulky because Leap Motion data could not be streamed directly to the phone but required additional hardware. Instrumenting the whole hand through a glove for sensing and rendering contact forces using vibrations was the idea in [4], while [3] featured a combination of touch screen interaction and index finger tracking to address MAR issues.  

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2 Advantages of Wrist-Worn System

This work presents a proof-of-concept solution for MAR enabling hand-based interaction and tactile rendering of contact forces with virtual objects.

In order to manipulate virtual entities, the user’s hand has to collide with the objects mesh, displayed on the phone screen. Instead of capturing the hand pose with a camera approach, we decided to leverage on inertial measurements to reconstruct the hand posture. This way, we avoid the limitation of always having the real hand in the camera field of view, and we free the other hand from the burden of holding the device. The problem of locating the hand in the 3D space is addressed by positioning the phone on a wrist-mounted support. In fact, the ARcore library used to develop the app provides the distance of the fiducial markers from the rear camera, that is translated of a fixed amount from the hand. Thus, the hand avatar pose estimated with inertial measures and its position in the 3D space are integrated on a virtual avatar projected on the screen, which can interact with virtual objects.

The prototype we developed for testing consists of two wearable pieces of equipment: a display located on the forearm, that removes the constrain of handholding the phone without affecting dexterity, and small fingertip interfaces to virtually map the hand and to generate haptic cues. The final implementation of our system will feature a flexible display worn on the wrist to minimize encumbrance, and small fingertip haptic interfaces that have minimum impact on the user’s manipulation capabilities.

With the proposed system we aim at addressing the following limitation: (i) keeping at least one hand free, (ii) enhancing the experience with haptic rendering, (iii) providing an on-demand AR experience, and (iv) designing a low-budget wearable system based on smartphone.

Figure 1: Wearable haptics for Mobile Augmented Reality. An IMU-based system tracks the motion of the index finger while the haptic thimble provides the user with cutaneous stimuli. The proposed device creates the sensation of making/breaking contact with virtual objects. An Arduino microcontroller, powered by a Li-Po battery, is in charge of collecting data from the sensors and control the haptic device. The smart-phone shows the augmented environment to the user, computes the hand posture, and evaluates the fingertip contact force.
3 System Description

We present a prototype system composed of a wristband display and a wearable fingertip interface.

A smart-phone (P20 lite, Huawei Technologies Co. Ltd., CN) is the central processing unit, but also serves as visual input source and visual display. It is secured to the arm using a 3D-printed ABS support attached to a thermoplastic splint.

The fingertip interface is equipped with: i) an Inertial and Magnetic Unit (MPU6050, Invensense Corp. USA) to estimate the index finger pose w.r.t. to the palm, and ii) a servomotor (HS-35HD Ultra Nano, HITEC Inc. USA) to render interaction forces through a pulley mechanism. A clip system enables users to easily fasten the device on the finger. The servomotor can provide a maximum torque of 0.8 kg cm−1. The cutaneous force is generated by the device considering the force generated by the servomotor and the resistance given by the three springs and the human skin. Interested reader is referred to [6] for further details on the force feedback generation.

On top of the servomotor is firmly attached an IMU sensor board that contains a triaxial accelerometer/gyroscope and an FIC interface. For what concerns the finger tracking, since the aim of this work is providing a proof of concept and not to present a hand-tracking approach, we exploited the algorithm presented in [5]. To estimate the relative motion of the finger w.r.t. the hand, we placed an additional IMU in the back of the hand. We decided to use a simplified kinematic model of the hand, which requires a reduced number of sensors to estimate the finger pose. To reconstruct the finger pose, the developed Android app combines the orientation estimated by two sensor boards and biomechanical constraints [1].

An ATmega 328p microcontroller (Arduino Pro Mini 3.3 V) is in charge of communicating through a Bluetooth connection with the smart-phone to control the servomotor and to transmit data coming from the inertial sensors.

The Android application is based on the ARcore library [2], which provides online estimation of camera position and distance from fiducial markers, that are used to accurately locate virtual objects in the mixed environment. Anyway, the real hand cannot be in the smart-phone camera field of view, because it would cover the scene below. Thus, we decided to dislocate the display close to the wrist and place a virtual representation of the real hand at the bottom of the smart-phone screen.

4 Experimental Evaluation

The prototype system was tested in a manipulation and exploration task to collect users’ evaluations on functionality and usability. The device was tested in two layouts: wrist-mounted (WM) and hand-held (HH). Ten participants (8 males, age range 23 - 45, mean 32) were tasked to perform a weight evaluation on three virtual spheres, rendered on the top of virtual ramps. The users were able to visualize the virtual environment superimposed to the real world through the smart-phone display, and interact with virtual objects to retrieve informative contents. Visual and tactile information played complementary roles for the correct execution of the task, because the sphere mass could be estimated only by means of haptic feedback.

After the experiments, participants were asked to describe their personal impressions on a 15-questions survey1 regarding mental effort, manipulability, and embodiment perceived. Participants rated the system on a seven-point Likert scale (0 means that the participant “completely disagrees” with the sentence, 6 means “completely agrees”).

Questionnaire answers (here reported as mean ± standard deviation) were analyzed by means of paired sample t-tests. Statistical analysis showed that subjects’ preference for the wrist-mounted display was significant for what concerns Embodiment ($HH = 3.52 ± 0.92$, $WM = 4.67 ± 0.66$), while the condition did not have significant effects on the self-perception of Mental Workload ($HH = 3.80 ± 0.80$, $WM = 4.16 ± 0.79$) and for what concerns the Manipulability ($HH = 3.52 ± 0.77$, $WM = 4.20 ± 0.96$). Statistically significant difference was registered also for the Overall score ($HH = 3.69 ± 0.66$, $WM = 4.34 ± 0.68$).

5 Conclusions and Future Works

The prototype developed to test the wristband display requires several improvements, mainly from the design and technology point of view. Lowering the form factor of the fingertip interface will reduce the obtrusiveness during real-life activities, and a flexible displays would transform the forearm device in an accessory. Increased computational power would open the way to multiple-fingers (and two-hands) virtual interaction. The delocalization of the virtual hand avatar may be exploited in embodiment studies, reinforced by the haptic feedback.

References


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1http://sirslab.dii.unisi.it/wristbandhaptics/