From Room Instrumentation to Device Instrumentation: Assessing an Inertial Measurement Unit for Spatial Awareness

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Abstract

Current implementations of spatially-aware multi-surface environments rely heavily on instrumenting the room with different tracking technologies (e.g. Microsoft Kinect, Vicon Cameras). Prior research, however, has shown that real-world deployment using such approaches leads to feasibility issues and users being uncomfortable with the technology in the environment. In this work, we attempt to address these issues by examining the use of a dedicated inertial measurement unit (IMU) in a MSE. We performed a limited user study and present our results that suggest measurements provided by an IMU do not provide value over sensor fusion techniques for spatially-aware MSE's.

Author Keywords

Inertial tracking systems; inertial measurement unit; indoor navigation systems; gestures and interactions; HCI; multi-surface applications; API design.

ACM Classification Keywords

H.5.2. [Information interfaces and presentation]; User Interfaces; Input devices and strategies.

Introduction

Multi-surface Environments (MSE's) integrate a variety of different devices – smartphones, tablets, digital tabletops, and large wall displays – into a single interactive environment [6]. These environments allow for information and interaction to be spread across and between devices and enable users to take advantage of the distinctive affordances supported by each device. For example, information can be shared amongst different devices in the environment, but a device such as a digital tabletop can be used as a public sharing space for the information, while a tablet can be used for private components of the information. Spatially-aware MSE's use the spatial layout of the environment in order to support cross-device spatial interactions, such as flicking [3], or picking and dropping [5]. In the previous example, spatial awareness allows a user to perform a flick gesture with the tablet towards the digital tabletop to transfer information. To design such spatially-aware MSE's, the environment needs knowledge such as the location and orientation of devices in in the environment.

Building spatially-aware MSE's and interactions introduces a number of challenges from a system engineering perspective. A key challenge that motivates the work presented, is related to the choice of tracking sensors that can provide spatial awareness in MSE's. The choice of sensor tracking technologies impacts room instrumentation cost and set-up effort required, especially when using tracking technologies such as Vicon[1] Cameras or the Microsoft Kinect[2]. One potential solution is the integration of attachable high-precision inertial measurement units (IMUs) into the multi-surface environment. An IMU attached to a mobile device becomes responsible for calculating both position and orientation of the device in the MSE.

In the work presented, we evaluated an IMU to determine its accuracy for location and orientation tracking within spatially-aware MSE's. Specifically, we evaluated the applicability and usability of the SmartCube IMU, developed at the Alberta Center for Advanced MNT Products (ACAMP)[3]. Our work answered two major questions: How accurate are the position and orientation measurements returned by the SmartCube? And whether it is a feasible alternative to sensor fusion techniques?

The remainder of the paper is organized as follows: the next section is a literature review on the concepts and established research in the area of tracking within spatially-aware MSE's. The approach, design and setup of the experiment is introduced next followed by results of the experiment. Next, a discussion of the implications of these results is presented and possible future work.

Related Work

The research space of multi-surface environments has been well defined in the past few years, with a significant amount of research conducted from the human computer interaction perspective and the system engineering perspective. Multi-surface environments can be divided into two categories: non-spatially aware, and spatially aware environments.

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[1] Vicon – www.vicon.com

[2] Kinect – www.microsoft.com/en-us/kinectforwindows

[3] ACAMP – www.acamp.ca

Comparing Environments

Non-spatially aware MSE's do not have a model of the spatial relationships between the devices and the users in an environment. Consequently, selecting a device to interact with is either done explicitly - by selecting a device from a list, or implicitly - by always sending to a single device.

Alternatively, spatially aware MSE's are environments which have a model of the spatial relationships of the devices and the users in an environment. This creates opportunities for inter-device interactions that are more dynamic based on properties such as proximity or orientation. Spatial awareness in multi-surface environments is often achieved through the fusion of different sensor data at either an environmental level or at a singular level, with a user and their device.

When comparing these two approaches, non-spatially aware MSE's are typically less expensive to implement than their spatially aware counterparts since they do not require tracking hardware to identify the spatial layout of the environment. However, they provide a less engaging user experience as interaction flows in a manner that is less natural for users.

Building Spatially Aware Environments

Building a spatially aware environment requires the integration of a number of components such as the tracking hardware and the software running on the different surfaces in the environment.

INSTRUMENTING AN ENVIRONMENT

Current implementations of spatial MSE's rely heavily on instrumenting the environment using sensor fusion techniques, where sensors track users or marked objects within the environment. An example of an API for building such environments is the Multi-surface Environment API (or MSE-API) developed by Burns et al [1] which uses fusion of lower-end tracking systems (such as the Microsoft Kinect) and device-embedded sensors. Proximity Toolkit by Marquardt et al [4] is another toolkit that builds spatially aware environments, using the higher precision but marker-based Vicon Motion Tracking technology. A significant drawback for these types of toolkits for system engineers, however, is that sensor fusion approaches require continually instrumenting the environment and calibrating applications, thus making them difficult to scale to a larger area. Another challenge, from a usability perspective, is that users feel uncomfortable and unfamiliar with technologies that track their movements [7].

INSTRUMENTING FOR USERS AND THEIR DEVICES

Instrumenting for users and their devices is an alternative, but is a largely unexplored implementation technique for building spatially-aware MSE's. It relies on equipping the devices with dedicated specialized sensors to create a spatially-aware environment. A recent example of this approach, is Project Tango[4] by Google, where a mobile device is equipped with customized sensors and software that track the motion of the device in 3D space. This custom design provides real-time position and orientation information of the device, creating a 3D model of the environment.

Using purely dedicated and specialized sensors on individual devices to replace sensor fusion techniques is an approach that has not been deeply evaluated for

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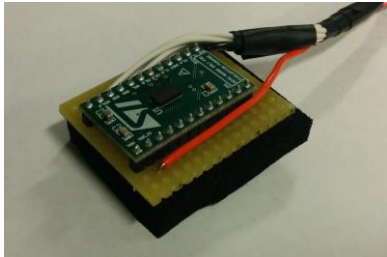[4] Project Tango – www.google.com/atap/projecttango

Figure 1: The experimental SmartCube Inertial Measurement Unit

multi-surface environments in the research literature. This provides the motivation for the work presented in this paper to evaluate the applicability and approach for using purely dedicated device sensors to provide spatial awareness in multi-surface environments.

The SmartCube IMU

In collaboration with the Alberta Center for Advanced MNT Products (ACAMP), we chose to evaluate the Smartcube IMU (Figure 1) for providing spatial-awareness in MSE's. The SmartCube is a 2 cm^3 IMU module that incorporates IMU functionality with pressure, positioning and temperature sensing. The cube uses a modular design, where the different components are stacked vertically as layers. Each layer in the cube is segregated by function and is developed individually. The IMU layer provides access to 3 independent acceleration channels and 3 angular rate channels through the embedded 3D digital accelerometer and gyroscope.

User Study

The primary goal of our initial user study was to evaluate a dedicated inertial device tracking approach (specifically the SmartCube) for spatially aware MSE's. The tasks of our user study are based on prior research by Voida et al., which focused on moving content between devices [8], a common task in MSE's [6, 9]. Specifically, we looked at the accuracy of orientation and position data from the SmartCube and its impact on tracking within multi-surface environments.

Apparatus
The study was conducted using ACAMP's Smartcube, serving as the dedicated tracking device. A specialized C# application was written to display a set of targets on a large wall-display connected to a PC. This application allowed us to simulate sending content from a tablet to the shown targets.

A Microsoft Surface tablet application was also created in order to communicate data from the SmartCube. Data was recorded from the tablet application to capture detailed spatial information - position, tilt and orientation, at each of the performed tasks. To consider distance consistently, pre-determined locations were marked on the floor and participants were instructed to move between these locations for certain tasks.

Participants
Ten unpaid volunteers participated in the study. Participants were recruited using word of mouth. All participants had a background in computer science and no participants were excluded based on experience with tablets or motion tracking systems.

Procedure
The user study conducted addressed a content-sending task, which allows the accuracy of the SmartCube to be evaluated in spatially-dependent interactions between devices in the environment. Figure 2.a illustrates the primary scenario for this user study. At the start of each experiment, an application is started on the large wall-display, a mobile application is started on the tablet and the user is asked to stand at a marked calibration point in the room.

The experiment accomplishes four objectives: In the first objective, the user is instructed to walk to a number of different marked points in the room - as shown in Figure 2.b, with the application recording the position measurements at each point. The goal of this
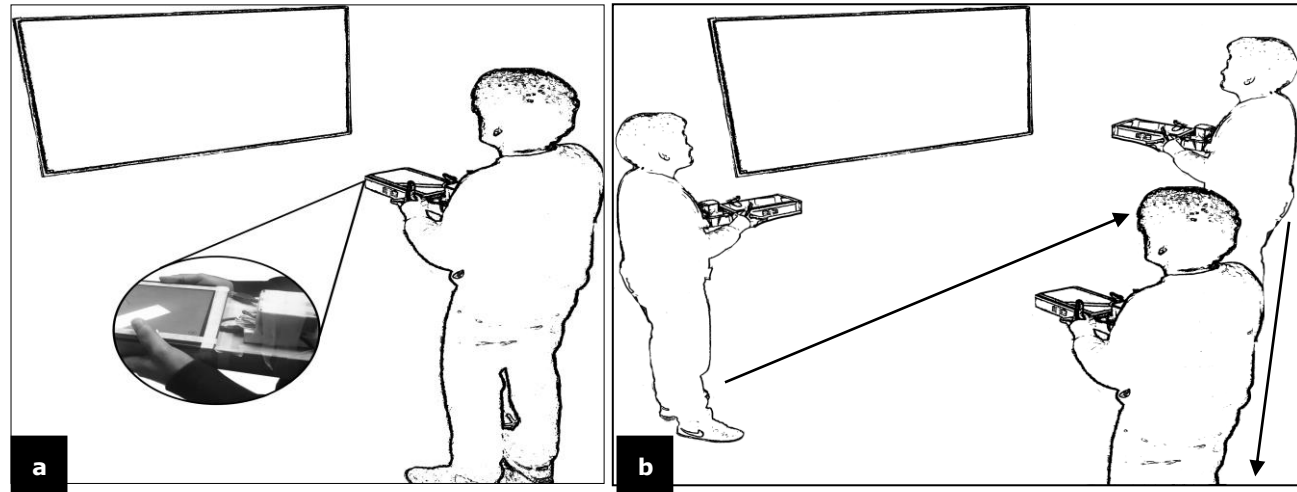
Figure 2: Study participant performing the study tasks. Figure 2 (a) provides an overview of the user study scenario setup, highlighting a participant holding an IMU connected to a Microsoft Surface tablet and the wall-display surface. Figure 2 (b) illustrates the different objectives of the study, with the user starting at the calibration point, then walking to marked points.

objective is to evaluate the accuracy of the position measurements returned by the SmartCube independent of all other interactions.

In the second and third objectives, the user is instructed to send content to a number of visual targets that are shown on the display - one target at a time, by rotating the device in the 3D space. The application records the success or failure of each attempt. The goal of these objectives is to evaluate the accuracy of targeting based on the orientation measurements returned by the SmartCube independent of the user's position. We provided two conditions, one with visual feedback and one without. This was to examine the issues with error and how tolerant users could be with position and orientation accuracy.

In the fourth objective, the user is instructed to walk to a random point in the room each time a new target is shown on the display. The user is, then, instructed to send content to the shown target, with the application recording the success or failure of each attempt. The goal of this objective is to evaluate the accuracy of the combined measurements of the SmartCube.

We used the sensor information to compute the virtual intersection of a beam coming from the tablet with the wall display.

Results

From our 10 participants, we collected a total of 480 readings (10 participants × 12 commands × 4 objectives). These were classified based on the objectives discussed previously.
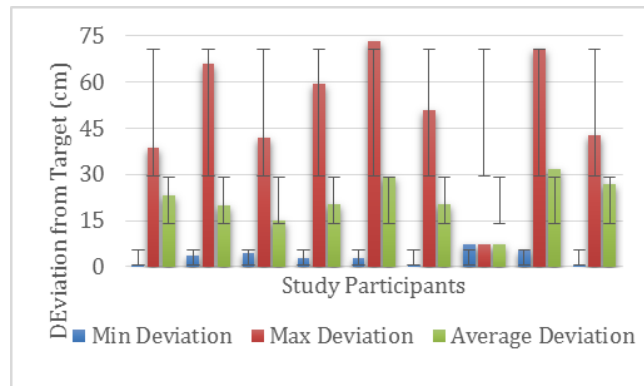
Figure 3: Degree of error in unsuccessful attempts (without visual feedback)

Sending content to the display from a fixed location, without visual feedback, showed a success rate of 7%, deviating 21.4 cm from the target on average (Figure 3). Performing the same task with visual feedback of position on the large wall-display had a higher success rate 21%, with target deviation averaging at 20.6 cm (Figure 4).

Tasks that depend on the location measurements, returned by the SmartCube, showed negative results and proved to be unusable, with a success rate of 0%, and deviating from the target by 1 to 3 meters.

In general, the early feedback received from the study participants indicated that attaching an external module to the tablet was impractical and that it reduced the tablet's mobility. The participants thought that the visual feedback was crucial in order to understand the system's perspective of the room. They, however, commented on the measurements returned by the SmartCube – through the visual feedback – being

inconsistent, and were, generally, uncomfortable with the idea of facing wrong directions in order to send to the target on the large wall-display.

Discussion

An interesting observation revealed from the study and comments from participants was the use of visual feedback to offset sensor inaccuracy. This may suggest that providing visual feedback for multi-surface interactions is valuable and will allow users to compensate for potentially inaccurate tracking technologies or multi-surface environments that require constant calibration.

Overall, our results although initial, resurface discussions on purely sensor-based approaches and sensor-fusion based approaches for spatial awareness in multi-surface environments. In both approaches, there is still a need for environment setup, from both an infrastructure level as well as an application level.
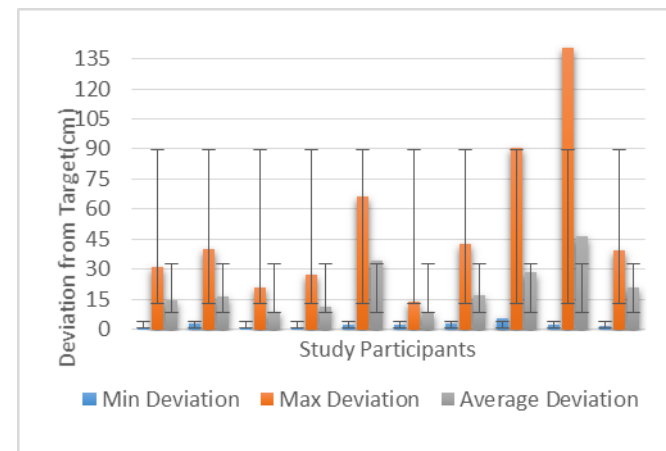

Figure 4: Degree of error in unsuccessful attempts (with visual feedback)

Comparatively however, the setup time required for the purely sensor based approach is significantly less than those of sensor fusion based techniques, and initial comments from the participants indicate that prior issues related to practical real-world feasibility and comfort for users are solved [7]. Looking forward, self-contained integrated sensor approaches that are more accurate (e.g. Google's Tango) may also provide a more feasible alternative to inertial tracking and room instrumentation.

Future Work
Our future work following this initial study is multi-faceted. A potential research direction will be to utilize the modular approach of the SmartCube to use additional sensors - such as compass and GPS sensors, together with the gyroscope and accelerometer in a mobile device, in order to provide potentially more accurate spatial information. Secondly, we intend to do a full comparative study of spatial awareness in multi-surface environments using both the SmartCube and a sensor-fusion based approach. Finally, we also intend on comparing different types of pure sensor based approaches, such as Googles Tango.

Conclusion
In this paper, we explored the use of a purely sensor based approaches as an alternative to the typical room instrumentation based approaches for providing spatial-awareness in MSE's. This was based on prior research indicating the challenges with room instrumentation based approaches [7]. We approached this problem by collaborating with ACAMP and using their SmartCube IMU as the tracking device. Our results indicated additional work needs to occur in order for this technology to be more feasible alternative to room instrumentation techniques, however, we hope this initial work will trigger greater interest in using purely sensor based techniques in the multi-surface research community.

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