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GAINE – A portable framework for the development of edutainment applications based on multitouch and tangible interaction ☆,☆☆

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A B S T R A C T

In the last few years, Multitouch and Tangible User Interfaces have emerged as a powerful tool to integrate interactive surfaces and responsive spaces that embody digital information. Besides providing a natural interaction with digital contents, they allow the interaction of multiple users at the same time, thus promoting collaborative activities and information sharing. In particular, these characteristics have opened new exploration possibilities in the edutainment context, as witnessed by the many applications successfully developed in different areas, from children's collaborative learning to interactive storytelling, cultural heritage and medical therapy support. However, due to the availability of different multitouch and tangible interaction technologies and of different target computing platforms, the development and deployment of such applications can be challenging. To this end, in this paper we present GAINE (tanGible Augmented INteraction for Edutainment), a software framework that enables rapid prototyping and development of tangible augmented applications for edutainment purposes. GAINE has two main features. First, it offers developers high-level context specific constructs that significantly reduces the implementation burden. Second, the framework is portable on different operating systems and offers independence from the underlying hardware and tracking technology. In this paper, we also discuss several case studies to show the effectiveness of GAINE in simplifying the development of entertainment and edutainment applications based on multitouch and tangible interaction.

1. Introduction

The integration of Multitouch and Tangible User Interfaces is a powerful approach to improve the way users interact with digital information. Multitouch Interfaces (MTIs) provide a direct and more natural interaction with on-screen contents through the use of multiple fingers and gestures. Tangible User Interfaces (TUIs) enable the interaction with digital information through the manipulation of physical objects of the real world [50]. The integration of these two approaches offers a seamless information representation and interaction that spans both digital and physical worlds [48]. This is particularly relevant in edutainment contexts for enhancing learning and discovery activities, especially in applications featuring shared displays, which allow the interaction of more than one user at a time and, thus, promote collaboration, information sharing and the rise of social experiences.

A body of literature explores the opportunities offered by MTIs and TUIs to edutainment and entertainment in various fields, from classroom collaborative learning [12,40,2] to children's decision making and cooperation support [8], interactive storytelling [13,14], pervasive games [15] and museum exhibits [16,17]. While most of these approaches rely on large interactive displays, commercial MTI–TUI games developed for mobile devices are becoming increasingly available [49,51]. A large variety of works have started exploiting these technologies to improve the accessibility to edutainment and entertainment applications of different categories of users, like children and the elderly [39] or people with physical or psychological disabilities. For instance, interactive tabletops games have been used to teach, improve and exercise social and communicational skills among children with autism spectrum disorders [5–7]. The potentialities of such games in supporting medical therapies have been also explored. Examples can be found in [10], which describes a game developed for children with cerebral palsy, or in [11], where Virtual Reality training based on a tabletop game was found to be a viable adjunct

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to conventional physical therapy in facilitating motor learning in patients with traumatic brain injuries.

Despite the capabilities offered by interactive displays and tangible objects, developing applications that fruitfully exploit them presents some inherent difficulties and requires complex technical and programming skills. To this end, we have designed and implemented a software framework called GAINE (*tanGible Augmented INteraction for Edutainment*), aimed at simplifying the prototyping and development of interactive applications in educational and entertainment contexts, which integrates both MTI and TUI approaches. The contribution of our work is threefold:

– providing an abstraction layer that hides the complexity of the underlying hardware architecture and software libraries necessary to manage a tangible augmented interactive game;
– supporting a "write once – deploy everywhere" development model, which enable the portability of the application on a variety of platforms, from large interactive tables to mobile devices like tablets;
– offering developers advanced features and a large set of high level constructs, which can be easily integrated for the rapid development of edutainment applications.

While GAINE shares some characteristics with other toolkits presented in the literature, such as [19,25,27,36], our framework further simplifies the application design by offering developers a reusable, semi complete application that can be totally customized through an XML-style scripting language. The effectiveness of using GAINE in the design and development process is demonstrated through several case studies discussed in the paper.

A preliminary version of this work has been presented in [41]. The main extensions introduced in this paper are the following:

– the original framework was designed for interactive tables only and could be ported only on the main desktop operative systems (Windows, Linux, MacOs); here, we integrated GAINE into the Unity 3D environment to target other computing platforms (i.e., devices running iOS or Android);
– we extended the range of tangibles that can be used by the framework by designing an extensible low-level interaction layer capable of managing MTI and TUI data acquired with different technologies;
– we increased the functionalities offered by GAINE and, thus, the opportunities offered to developers to design novel and compelling applications.

The rest of the paper is organized as follows. In Section 2 we review the current state of the art related to the recognition and tracking of tangible widgets and to the toolkits supporting tangible-augmented interaction. In Section 3 we describe the GAINE framework and Section 4 and Appendix A discuss the implementation, on different platforms, of several applications using GAINE. Finally, conclusions and future works are outlined in Section 5.

2. Related works

2.1. Object tracking for tangible interaction

The problem of using physical objects to control or manipulate virtual items on big interactive touch screens has been initially tackled using optical technologies [18]. Recent studies demonstrated the possibility of porting this specific user interaction to other devices relying on capacitive or magnetic tracking techniques. These works are particularly interesting since they allow extending TUIs to portable screens like tablets (e.g., iPads or Android based devices).

With optical techniques, tangibles objects are tagged with fiducials and both touch and fiducial recognition rely on an infrared light (IF) illuminating the table surface and being reflected towards an IF-camera when fingers or fiducials hits the surface. The images of the IF camera are then processed to extract interaction data. Tabletop illumination can use either Diffused Illumination (DI) or Frustrated Total Internal Reflection (FTIR) techniques. With DI, the table surface is illuminated from IF emitters placed below the surface [21], while with FTIR [22] the lights come from the side and is transmitted into the surface material, which is usually a special Enlighten acrylic.

Since tablets and other capacitive displays cannot rely on vision-based tracking, a vast majority of researches have directly exploited the touch screen capacitive sensing technology whilst others have explored the use of magnetic tracking. Most of the capacitive widgets discussed in the literature are passive, i.e. they need human contact to be sensed. CapWidgets [43] are little aluminum knobs with two conductive touch points on their base working as markers. Gestures with the knob, like rotation or placement in hot spots, can be translated into specific actions within the application. Capstones and Zebra Widgets [42] are based on a similar approach. Top and bottom surfaces of Capstones are equipped with 2×2 or 3×3 matrices of conductive markers and the number of active markers sensed by the screen can be changed by stacking Capstones one on top of the other. The 3×3 layout also enables to detect the tangible orientation and two unique IDs. Zebra Widgets are a slider and a knob, which are characterized by two different marker patterns that enable as well the detection of rotation and sliding gestures. TUIC [48] uses a combination of passive material and active modulation circuits to create a hybrid of spatial and frequency tags. Spatial tags use three passive markers for conveying position information. Frequency tags use a single marker per widget connected to an active circuit, which delivers contact at a given frequency. While allowing a hand-free use and requiring a single contact point, the time encoding of the information increases the latency of marker data and the tangible requires an external power supply. Passive Untouched Capacitive widgets (PUC [47]), are another type of active widget. PUCs ground themselves by electrically connecting multiple active and inactive intersections of the touch screen grid. While the active intersection is scanned, the inactive intersection serves as ground and the active one is sensed as a touch. The obvious shortcoming is that PUCs require a larger size compared to other passive markers.

A different approach is the one based on magnetic sensing. Gauss Bricks and Gauss Stones [44,45] are basic blocks composed by two magnets enclosed in a transparent plastic case. Individual blocks can be connected together via magnetic joints to form complex shapes. The position of each magnet is sensed by a Hall sensor grid attached on the back of the display platforms. A similar approach has been implemented in Pico [31].

Recently, alternative techniques for finger tracking were proposed (such as those relying on acoustic, radio waves and force sensing data). Hence, we can expect the availability of tangibles exploiting such technologies as soon as they will become mainstream.

2.2. Software toolkits for tangible-augmented interaction

Various toolkits have been explicitly developed to simplify the creation of applications based on MTI and TUI. Most of them have been designed for devices relying on optical techniques and they are all centered on the idea of allow developers to focus on the design of their applications by abstracting (i) the underlying hardware level and (ii) the complexity of the core interaction functionality, i.e. touch and fiducial identification and tracking.