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Interacting with Spatial Augmented Reality

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ABSTRACT
Moving from flat screens into the physical world is an ongoing trend of HCI. Spatial augmented reality (SAR) augments the real world using projectors. It is used in multiple disciplines, especially in design and creative environments such as prototyping and artistic installations. Still, interaction with SAR is little explored. The objective of this thesis is to study SAR and its rich space for interaction, and find novel techniques to take advantage of it. First, previous work on SAR must be studied, then experimental prototypes have to be implemented and evaluated. This paper presents a brief introduction to technical aspects that need to be addressed, in addition to a study of the design spaces related to SAR. A first proof of concept is provided: using augmented objects in front of the screen, as part of a standard desktop environment workflow. Future work will involve iteratively creating prototypes exploring the identified strengths and weaknesses of SAR, analyzing the viability of such prototypes via dedicated user studies.

Key Words
Mixed reality; Spatial Augmented Reality; Interaction techniques; Tangible User Interfaces.

ACM Classification Keywords
H.5.1. Information Interfaces and Presentation (e.g. HCI): Multimedia Information Systems.

INTRODUCTION
Augmented Reality (AR) [4] combines virtual and real information, in a cohesive manner. In contrast with traditional See-through Augmented Reality (STAR), which requires devices such as glasses or mobile phones, Spatial Augmented Reality (SAR) [38] generates the augmentation directly onto the physical environment. This opens a new realm of possibilities.

Moving the augmentation from a fixed window in front of the user (i.e. glasses or screens) to the environment creates the illusion that the a real object has different physical characteristics (material, behavior, and to a lesser extent, geometry). The augmentation can also be shared by multiple users, and over a wide range of sizes: from a single bean of rice[1], small surfaces and objects [2], rooms [3, 24] to whole buildings (e.g. 20.000 square meters on the iMapp Bucharest 555 project[2]).

The restrictions imposed by the fixed nature of projectors have been overcome on the previous years, using either self contained devices such as PlayAnywhere [59], or using moving projectors [58] or mirrors [34]. With the creation of small portable laser projectors, called pico projectors, new possibilities arise [56, 55, 20, 30, 57]. Cellphone prototypes with embedded projectors[3] provide on-board computational power, and extended interaction spaces (i.e. where and how the human-computer interaction takes place). This allows to envision wereable, self contained, smart devices that can project information into the surrounding space (e.g. SixthSense [29]).

Closely related with Spatial augmented reality are Tangible user interfaces (TUIs), which give physicality to virtual information and operations, taking advantage of the human natural skills for interaction with physical objects. Another feature of TUI is reducing the distance between input and output devices, enhancing the embodiment [13]. Moving to physical objects opens new possibilities, in particular the use of materials with different characteristics, providing not just passive haptic feedback, but also rich expressiveness (for example, non-rigid interfaces). As a result, it provides more intuitive interaction techniques, which facilitate collaboration and learning.

Also related with SAR and TUI are smart objects, as envisioned by ubiquitous computing [54], organic user interfaces [19] and radical atoms [21]. They envision a world where objects have advanced capabilities for displaying, holding information, communicating with each other and providing interactive functionality [17] and dynamic shape [14]. Such technologies can enhance the human communication and thinking process [51]. SAR allows us to prototype such objects with technology that is already available.

SAR is also called “projected augmented reality”, to differentiate from spatial augmentations that focus other senses, such as aural or haptic feedback. The combination of multisensorial spatial augmentations generates rich and immersive experiences, similar as the ones created on Virtual Reality (VR) CAVEs [6], but anywhere.

The design space for spatial augmented reality is broad and hold great potential, but it is also heterogeneous and complex. Studying the technical requirements and also the possible interaction techniques, while identifying the

[1] https://vimeo.com/130165596
[2] https://vimeo.com/107203878
[3] http://www.cnbc.com/id/102713692

ones suited for each case, is the objective of this work. This will enable the creation of new techniques and systems to interact with SAR.

TECHNICAL ASPECTS

The generated illusions by SAR hold great potential, when everyday surfaces gain new aspect and functionality on an almost magical way: a clear example of this is the amount of artistic performances involving Spatial augmented reality (on this context, SAR is called projection mapping). But the illusions are fragile. In order to generate the augmentation is required to align a virtual scene with the real world, and in some cases take into account the user(s) head position. The basic issues to address are:

- Calibration: Scene elements, such as cameras and projectors, have different positions and orientation, and an unifying coordinate system is required. Additionally, optical devices are not perfect and possess lens distortion, which needs to be accounted for [1].
- Geometry: Knowing the surface geometry is indispensable to align the virtual and real information. This requires a 3d model, which can be generated either manually or by scanning [7, 43].
- Position: knowing the geometry is not enough, it is also required to know where the geometry lies in relationship with the real scene. This can be measured manually, using sensors [27, 37] or tracking, either with [40] or without markers. Geometry and position can be obtained simultaneously using SLAM [26, 22].
- Material: the color and reflectance of the surface where a pixel is projected will affect the observed color. A nice example of how to overcome this is IllumiRoom [25].
- Light condition: Similar to the material, ambient light would affect the final result, and it will compete with the projector luminosity.
- Shadow casting: when a pixel path from the projector reaches an object, it stops traveling. This produces shadows. More than one projector can be used [47], which requires additional considerations.
- Dynamic environments: any of the previous factors can change over time, and the system requires to take this into account. On highly dynamic environments, it can be required to predict the change, taking into account any computation delays.

The selected strategy for each item will depend on the complexity of the required solution. Basic video mapping installations use controlled light conditions and static objects [8], while highly interactive spaces require more robust approaches [24]. Either way, the process has not yet reached the point where it can be done completely automatically. These are key research areas to explore on the future.

INTERACTION TECHNIQUES

Related work has provided both classifications of the application space, and detailed technological solutions for interaction with augmented spaces. A brief overview is presented below.

Application space

In order to know more about a system it is required to answer some basic questions. Here are the questions on the context of SAR:

How is it done?

Ens et al. [12] presented a thorough study of augmented spaces with planar interfaces, finding seven key dimensions (Perspective, movability, proximity, input mode, tangibility, visibility and discretization) grouped in three categories (frame of reference, spatial manipulation and spatial composition). A factor not taken into account is the scale of the augmentation. Objects small enough to be handled can benefit of direct interaction. Reaching the room size, whole body interaction could be preferable. Larger augmented spaces might require indirect approaches, such as maquetes or pointing techniques.

Dubois and Nigay [10] study where the focus of the task is (either the virtual or real object) and what the nature of the augmentation (evaluation or execution). They show the interaction technique and augmentation mode will depend on these factors. Tangibility is closely related with execution, while the graphical quality is more important for evaluation.

What does it mean?

Fishkin et al. [13] presented a semantic space for TUI, taking into account metaphor and embodiment of the interface. Abstraction is also relevant when talking about interfaces. Burner [5] presents three learning levels: enactive, iconic and symbolic, each one with increasing abstraction, which are closely related with Fishkin's taxonomy. TUI involves more natural and intuitive interaction[23], less abstract than traditional I/O systems. TUIs specificness simplifies the interface, but it also reduces its flexibility. Conversely, highly abstract systems such as desktop computers, while harder to learn, have proven to be flexible and empower the users for precision tasks.

How long will it last?

The lifespan of the interface is also a factor to take into account. Doring et al. [9] study the design space for ephemeral interfaces, that is, interfaces where at least one component is created to last a limited amount of time. This kind of interfaces have strong emotional impact. Working with SAR implies working with light, which is itself an ephemeral element, and it can be combined with other ephemeral materials, such as soap, fog [32] or ice [52]. Interfaces can also be created by a temporary arrange of otherwise persistent objects [53].

Input techniques

The interaction space is rich, and several alternatives are available, with complementary characteristics.

Manipulation

This input technique is the one used on TUIs, but is not reduced to simply manipulate rigid bodies. The possibility to directly touch anywhere, and to do so on an expressive way, is an ongoing area of research using both on-object sensors [44] and vision [60]. Also, the interaction with non-rigid materials is currently being studied, with great advances both on technology (tracking deformable objects with [61] and without [33] a rigid scan) and the application space [49, 19, 36, 50].

Augmented tools provide augmented behavior. They can be either specific [28] ("workbench metaphor") or generic [53], and provide a range of abstraction according to the degree of embodiment.

The main drawback of this technique in SAR is that shadows are harder to avoid when two objects are close together, but it has not prevented this technique from providing applications, such as Illuminating clay [35].

Body and speech

Elepfandt et al. [11] studied the interaction space around the user, and concluded that gaze, gestures and speech are best suited for SAR. Gestural interaction has become more popular since the release of commodity depth sensors, such as Microsoft Kinect [46]. Hand based interaction can be implemented using either sparse approaches or dense position estimation using kinetic models (Leap Motion and kinect2 [45]). Such natural interaction could be incorporated easily on our everyday interaction with agents and artistic performances, but might fall short for intense or precise activities.

Pointing

Interacting on a higher level of abstraction can be done by controlling a cursor. Direct pointing is frequently used in VR [18] and have been used in SAR, either using tools [2, 48] or fingers [42]. Relative pointing in space have been studied for flat [31] and arbitrary surfaces [16], proving to be a valid option to remote and/or precise tasks leveraging standard 2D/3D input devices. Flexible switching between absolute and relative pointing has also being studied, but only for flat surfaces [15].

Desktop-based augmented spaces such as "the office of the future" [39] and augmented surfaces [41] extended the "desktop metaphor" to the environment, while preserving the potential of the WIMP paradigm (windows, icons, menus, pointer).

The presented interaction techniques allow to interact with augmented reality on different levels of abstraction. The selected interaction technique will strongly depend on the task nature. Allowing the user to switch between interaction techniques could provide an unifying interaction framework.

INTEGRATED AUGMENTED DESKTOP

As a first proof of concept of unified interaction with SAR, we created an augmented working space in front of a standard desktop computer[4]. Using perspective cursor [31] allows us to point on real objects. By restricting the cursor influence to a window in front of the screen, a seamless space is created, where a tangible objects can be reached by a cursor, as if they were virtual 3D objects. Such objects are not virtual, and can be handled outside of the screen space, enabling direct and gestural interaction. This system enables to iterate back and forth between precise and powerful desktop applications and natural interaction, in order to create rich interactive tangible objects.

[4]The mentioned work was submitted to TEI'16

CONCLUSIONS

On this work, the interaction space with SAR was studied. The key taxonomies and the available input techniques were selected from the bibliography, in order to understand the exploration space. Also, the technical issues to tackle were considered, and the currently available solutions were presented.

Once the context of interaction with SAR is defined, the next step is to study the presented techniques in action, by constructing prototypes, and to explore novel interaction techniques and uses cases for the rich possibilities of SAR. A first prototype is presented. In the future, we will continue exploring novel and integrated ways to interact with SAR.

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