Chapter 2
A Practical Setup for Projection-Based Augmented Maps

Filippo Bergamasco
Dipartimento di Scienze Ambientali, Informatica e Statistica, Università Ca’ Foscari di Venezia, Italy

Andrea Albarelli
Dipartimento di Scienze Ambientali, Informatica e Statistica, Università Ca’ Foscari di Venezia, Italy

Andrea Torsello
Dipartimento di Scienze Ambientali, Informatica e Statistica, Università Ca’ Foscari di Venezia, Italy

ABSTRACT
Projected Augmented Reality is a human-computer interaction scenario where synthetic data, rather than being rendered on a display, are directly projected on the real world. Differing from screen-based approaches, which only require the pose of the camera with respect to the world, this setup poses the additional hurdle of knowing the relative pose between capturing and projecting devices. In this chapter, the authors propose a thorough solution that addresses both camera and projector calibration using a simple fiducial marker design. Specifically, they introduce a novel Augmented Maps setup where the user can explore geographically located information by moving a physical inspection tool over a printed map. Since the tool presents both a projection surface and a 3D-localizable marker, it can be used to display suitable information about the area that it covers. The proposed setup has been evaluated in terms of accuracy of the calibration and ease of use declared by the users.

INTRODUCTION
The landscape of Augmented Reality systems proposed in literature is very varied and includes a wide range of different techniques. However, most setups are built upon three fundamental blocks: a positioning system, a display device and an interaction model (Feng, Been-Lirn Duh & Billinghurst, 2008). The positioning system is often composed of a camera and a set of artificial or natural markers. Within this kind of setup the camera is used
to acquire images of the markers and computer vision algorithms are applied to them in order to find the pose of the imaging system with respect to the world (Lowe, 1991; Davis, & DeMenthon, 1995; Lan & Zhong-Dan, 1999). All these pose recovery techniques require the determination of a number of correspondence between features on the scene and their images on the projective plane. In principle such correspondences can be recovered from naturally occurring features in the image such as interesting point on a planar surface (Simon, Fitzgibbon, & Zisserman, 2000), ellipses (Qian, Haiyuan, & Toshikazu, 2004), straight lines (Elqursh, & Egammal, 2011) or even the user’s hand (Lee, & Höllerer, 2009). In practice, for many real-world applications, this approach is not always feasible, since robust features cannot be guaranteed to exist in the scene, and even when found, their accuracy strongly depends on scene-dependant factor such as illumination, contrast or texture. To overcome these limitations, a number of artificial markers have been proposed over the last two decades. The goal of a fiducial marker design is to introduce elements in the scene that are easy to detect and that can be located with good accuracy. Some approaches rely on the invariance of conics such as concentric discs (Gartell, Hoff, & Sklair, 1991) or regularly arranged circles (Cho, Lee, & Neumann, 1998; Claus, & Fitzgibbon, 2005). In fact, under a generic projective transformation, circles always appear as ellipses, that are shapes easy to find and whose centers can be inferred with high precision. Other approaches exploit the invariance of straight lines, usually arranged to build high-contrast square boxes, that can be recognized by means of image-based recognition (Wagner, Reitmayr, Mulloni, Drummond, & Schmalstieg, 2010). or decoding of the marker content (Fiala, 2010).

The display device can be a screen, a head-mounted display, a portable device or even the real world, as some approaches adopt projection techniques to overlay information to real objects. Head-mounted displays can be used in conjunction with front cameras and trackers to offer an immersive experience to the user. By contrast, augmented environments can be displayed and navigated through desktop interfaces. Both approaches have been shown to have advantages and disadvantages (Sousa-Santos, et al., 2009). A popular intermediate solution between dedicated helmets and desktop navigation is represented by adopting portable devices such as mobile phones or tablet (Wagner, Reitmayr, Mulloni, Drummond, & Schmalstieg, 2010). This latter approach is very practical since these devices are becoming ubiquitous and come equipped with high resolution cameras and screens.

Finally, interaction models include both traditional computer-based controls and body mounted sensors or even more complex physical haptics. Recent approaches include wearable gestural interfaces (Mistry, Maes, & Chang, 2009), tangible interfaces (Pittarello, & Stecca, 2011) and virtual mirrors (Bichlmeier, Heining, Feuerstein & Navab, 2009).

In this chapter we develop a setup for projection-based augmented maps that is based on a projective-invariant marker design which is used for four different purposes: the detection of the physical controller moved by the user, the localization in the 3D space of the display surface and, finally, the calibration of both the camera and the projector. In the following sections the system will be described in depth and the calibration procedure will be defined. The concept of augmented maps is not new per se, in fact this concept has already been explored using both head-mounted (Bobrich & Otto, 2002) and projected displays (Reitmayr, Eade, & Drummond, 2005). Nevertheless, in the following sections we will introduce two novel contributions: an interaction model that involves the use of the exploration device in the entire 3D space,