Abstract. Augmented Reality technology provides an intuitive user interface for engineering support systems, increasing productivity and decreasing the chances of operation errors in engineering tasks. Using Markerless Augmented Reality technology, any part of the real environment may be used as a marker that can be tracked in order to place virtual objects. Therefore, there are no intrusive markers that are not part of the world. This work aims to sketch some scenarios of using Markerless Augmented Reality in engineering, such as corrosion inspection and civil construction support. A prototype of the corrosion inspection application using fiducial markers and tangible interfaces is presented, along with directions on how markerless tracking could be used for this purpose.

Keywords: Augmented reality, Markerless tracking, Applications in engineering
1. INTRODUCTION

Engineering tasks are often complex and require specific knowledge in order to be accomplished. Engineers have to be trained to acquire this knowledge, which can be very expensive and time consuming. Another troublesome factor is that some tasks rely entirely on engineer expertise. It would be remarkable to have a tool to train and assist the work of the engineer, providing the needed information for job completion. Augmented Reality (AR) can be useful for this purpose, providing instructions about the procedures to be done, as well as the identification of components with related data (Azuma, 1997). This data is superimposed over the captured image of the environment in real-time. Such a tool would lead to an increase in the efficiency of task execution, reducing costs, risks and time needed.

This work aims to specify some scenarios of AR technology applied in engineering, specially Markerless Augmented Reality (MAR), where there is no need to have fiducial markers placed along the real world, since natural landmarks are used to perform tracking. Two application scenarios are discussed in this work: corrosion inspection and civil construction support.

This paper is organized as follows. Section 2 presents some work related to AR for engineering, and more specifically for corrosion inspection and civil construction. Section 3 details the main concepts of AR and explains the MAR taxonomy. Section 4 describes how MAR techniques can be used for corrosion inspection and civil construction support. The results obtained with a corrosion inspection prototype using fiducial markers are shown in Section 5. Section 6 discusses some final remarks and future work.

2. RELATED WORK

Civil construction and corrosion inspection are two engineering fields with great potential for applied AR and its variant called MAR. Part of such non-ignorable potential was discussed and exploited in different levels of complexity and refinement. Some of those works are briefly presented next.

Since the early days of AR technology the civil construction field has caught some researchers’ attention. With the aim of developing solutions for aiding engineering tasks, works like (Webster et al., 1996) arise. Their work is focused on the experiences on developing an AR system to improve methods for the construction, inspection, and renovation of architectural structures. Actually, it devoted huge importance to an application for spaceframe construction manipulation, which looks naive nowadays, but represented a big challenge over a decade ago.

Around the last five years, more sophisticated applications have appeared. Two of them are (Clothier & Bailey, 2003) and (Clothier & Bailey, 2004), which have the aim of getting closer to the corrosion inspection field, although they just achieved results on visualization for aiding in structures maintenance. In (Clothier & Bailey, 2003), they focused on the preliminary efforts done for developing an AR system to give support to the maintenance of bridges and buildings. The authors present briefly how it was made possible to turn an indoor AR application into an outdoor one. Although the application itself is very simple, it represents a relevant effort in adapting a marker-based application into a markerless one. (Clothier & Bailey, 2003) can also be seen as a preparation to (Clothier & Bailey, 2004), since it discusses in its future work the aim of developing a system to aid bridge maintenance, collecting sensor network’s information and translating it into visual augmented information. (Clothier & Bailey, 2004) is a step towards a truly corrosion prevention system. In this work relevant studies about techniques for visualization of bridge stress from sensors network data
are presented. It brings two main contributions: the first one is the study about useful visual representations of data collected by sensors (accelerometers) that include the use of color scales, 2D colored grids and 2D colored planes among others; the second one is the integration of such planned representations into an AR system that overlays the synthetic content generated from the sensors network data, on the real environment. The application was approved by specialists that report the enhancement on the understanding of data when compared to a previous traditional waveform analysis approach.

The mobility requirement taken into account in the last two cited works is also present in (Neilsen et al., 2004), in which a mobile AR system called SitePack is described. This system aims to support architects in visualizing 3D models in real-time on site, instead of requiring a prepared lab. The authors say that architects were benefited in the decision making process by taking into consideration the visual impact assessment. Their AR system runs on a tablet PC with a webcam, without site preparation or accurate initialization. This is possible due to the combination of automatic and manual techniques. The system exploits MAR techniques and needs an initial user intervention for selecting traceable features and for adjusting the initial registration.

In the last years some interesting works were carried, e.g. (Wang & Dunston, 2007), which provides information on AR and its potential use in heavy construction equipment operator training. Training is a classical application domain for AR technology and, like inspection applications, it can benefit construction industry. The motivation of their work is similar to that found in aerial training; that is to say, guide the operators with close to real world conditions with non-expensive solutions. The use of Virtual Reality (VR) was cited in their work as insufficient for training purposes and having a lack of realism due to being conducted on a pure synthetic environment.

There is also (Honkamaa et al., 2007), which presents a novel application for integrating Google Earth synthetic content insertion with outdoor on site registering. They utilize an interactive camera estimation approach (through feature tracking) for mobile outdoor AR, working in real-time on miniPC devices. Such application is not only a visualization tool, since working with Global Positioning Systems (GPSs) allows the correct definition of the viewing location in both camera and world coordinates. This work represents one more step towards truly mobile outdoor AR, or even a tendency on AR researches, which could be very useful for the engineering field, since its tasks are generally carried out in such environments.

The work described in (Sá et al., 2007) points another tendency on AR research that is the use of Computer-Aided Design (CAD) models with AR applications. This is due to the new possibilities arisen with modern CAD systems that on the last years have become not just computer drawing tools, but reach geometric modelers. The appliance of such models on engineering AR is stupendous, since the design step is done with the aid of a CAD system. It means using existing CAD models instead of having an extra work on designing them for AR systems. But for dealing with CAD usage benefits, some challenges must be taken into account, and this work focuses on them.

Finally, (Schoenfelder & Schmalstieg, 2008) present an AR system for building acceptance, which in the AR context is an inspection application that can save great amounts of money and time of experts. This is due to the fact that non-aided building acceptance is carried out using accurate measurements with expensive devices, but when using AR it is possible to achieve enough accuracy by a given distance from the inspected structure, avoiding both waste of resources and unacceptable building structures.
3. AUGMENTED REALITY

The concept of Mixed Reality (MR) concerns the coexistence of real and synthetic elements. Depending on how this combination occurs, specially the level of reality and virtuality that is present, the applications are classified in different subareas, such as VR and AR. While in VR there is a dominance of virtual objects and the entire world is generated by a computer, in AR the real world is mixed with some synthetic artifacts, added in real-time, in a way that they seem to be part of the environment (Milgram & Kishino, 1994).

The task of positioning virtual objects correctly relative to the real environment is called registration. This is made possible through the use of sensors that perceive the characteristics of the world and, based on the obtained data, establish when and how the scene should be presented. For that end, many tracking technologies may be exploited, such as thermal imaging, ultrasound, magnetic sensors, GPS and movement sensors. Moreover, video capture devices are commonly used for tracking in AR systems. They rely on the use of fiducial markers that are placed strategically in the world. Markers are easy to be identified and there are many freely available libraries that perform this task. These factors favor low cost computational AR solutions. However, it is not always possible or desirable to use markers, since sometimes they can be considered intrusive to the environment and make task accomplishment harder. They are also susceptible to registration failures, illumination changes and occlusions (Azuma, 1997).

MAR uses natural landmarks instead of fiducial markers in order to perform tracking. In this paper, we address an online monocular MAR approach, since it is the most popular one. Optical tracking presents some advantages when compared to its counterparts, such as higher precision and less sensibility to interference. Besides that, the use of a single camera allows lower cost and more compact systems. Calibration issues are also easier to be managed (Azuma et al., 2001).

Regarding system visualization by the user, AR systems are classified in two ways: optical systems and video based systems. In optical systems, the user utilizes an optical see-through Head Mounted Display (HMD), obtaining a direct vision of the world where the virtual scene is superimposed to. In video based systems, the user sees the real environment through a video overlaid with synthetic elements in a common monitor or an opaque HMD (Azuma, 1997).

3.1 Markerless Augmented Reality

MAR systems integrate virtual objects into a 3D real environment in real-time, enhancing user’s perception of, and interaction with, the real world (Bimber & Raskar, 2005). Its basic difference from marker based AR systems is the method used to place virtual objects in the user’s view. The markerless approach is not based on the use of traditional artificial markers, which are placed in the real world to support position and orientation tracking by the system. In MAR, any part of the real environment may be used as a marker that can be tracked in order to place virtual objects. Therefore, there are no ambient intrusive markers that are not really part of the world. Another advantage is the possibility of extracting from the surroundings characteristic information that may later be used by the MAR system for other purposes. Nonetheless, tracking and registration techniques are more complex in MAR systems. Another disadvantage emerges in online MAR applications since it presents more restrictions.

Techniques developed for online monocular MAR can be classified in two major types: Model based and Structure from Motion (SfM) based (Fig. 1), as described in (Teichrieb et al., 2007). With model based techniques, knowledge about the real world is obtained before
tracking occurs and is stored in a 3D model that is used for estimating camera pose. In SfM based approaches, camera movement throughout the frames is estimated without any previous knowledge about the scene, being acquired during tracking.

Model based techniques can be classified in three categories: edge based, where camera pose is estimated by matching a wireframe 3D model of an object with the real world image edge information (Comport et al., 2006); optical flow based, which exploits temporal information extracted from the relative movement of the object projection onto the image in order to track it (Basu et al., 1996); and texture based, which takes into account texture information presented in images for tracking (Uenohara & Kanade, 1991). Edge based methods can be divided in two subcategories: point sampling, which comprises methods that sample some control points along the edges of the wireframe 3D model and compare their projections with strong gradients present in the image (Comport et al., 2006); and explicit edge detection, which encloses methods that detect explicit edges on the image and match them with the model projection (Koller et al., 1993). Texture based techniques are also classified in three subcategories: template matching, which applies a distortion model to a reference image to recover rigid object movement (Jurie & Dhome, 2001); interest point based, which takes into account localized features in the camera pose estimation (Vacchetti et al., 2004); and tracking by detection, where features invariant to scale, viewpoint and illumination changes are extracted from the object image at every frame (Skrypnyk & Lowe, 2004), making it possible to calculate the pose without any previous estimate, which is not true for other techniques.

Figure 1 – Online monocular MAR taxonomy.
Model based MAR approaches may be evaluated according to their applicability to the scenario. Edge based methods are more suitable when tracked objects are polygonal or have strong contours. If objects are textured, optical flow based techniques should be used (in case of constant lighting and not very large camera displacement). If optical flow is not a good option, texture based methods may be the best solution, as they are more accurate. If the textured object is planar, template matching presents good results with low CPU load; if not, interest point based methods should be used. Tracking by detection techniques suffer from jitter when they estimate each pose based only on current frame information. Taking temporal information into account reduces this problem, but tracking by detection tends to be less accurate than recursive tracking, due to lack of precision on feature matching.

SfM is a classic technique used in computer vision to perform 3D reconstruction (Pollefeys, 1999). Its traditional implementation follows a suggested pipeline, and is not concerned with real-time constraints. Usually, the SfM pipeline is composed of the following phases: feature tracking, camera pose hypothesis generation, pose evaluation and refinement, self-calibration and 3D reconstruction (Fig. 2). SfM produces great results relative to the final mesh generated, but some algorithms present in its pipeline require a lot of processing time to finish their work, and are thus unsuitable for real-time applications. In order to work in an online way, the former SfM pipeline needs some modifications to remove some bottlenecks and speed up the entire process. This minimizes the delay in reconstructing a rigid scene, getting closer to real-time 3D reconstruction (Gomes Neto et al., 2008).

SfM based methods can be divided in two categories: real-time SfM, which skips or replaces some phases of the original SfM to support real-time constraints while still maintaining the robustness of the technique (Nistér, 2005); and Monocular Simultaneous Localization and Mapping (MonoSLAM), where images from a single camera are processed by a probabilistic framework that builds a sparse map of 3D features representing the environment (Davison et al., 2007).

![SfM pipeline overview](image)
4. APPLICATION SCENARIOS

In the following subsections, two scenarios illustrating the utilization of MAR technology in the engineering context will be presented: corrosion inspection and civil construction support. It will be highlighted the advantages provided by MAR that can help engineers in task accomplishment.

4.1 Corrosion inspection

The engineering domain demands working with structures that must overcome bad or even awful weather conditions. But these structures are planned for a specific purpose: some for heritage, like Egyptian pyramids; other for real world problems, like cruising an entire riverbed. Independently of the purpose and the weather surrounding the subject, all of them are exposed to agents that promote damages, fractures and fatigue. The effect of these engineering structures corroder agents can be attenuated but not stopped and if their action is relegated, the structures' reliability will be severely compromised.

A corrosion inspection scenario consists in an interdisciplinary system in which the user can navigate among several stages of dated stress on a given material or structure. Corrosion inspection is very useful, for example, for predicting building collapse due to fatigue of beams and pillars. The proposed system applies AR techniques to allow users to freely move around the subject and adjust the visual aspect of the model accordingly to the desired date of stress, as exemplified in Fig. 3. It leads to speed up the learning curve of beginners, and for experts it decreases the time spent on determining how corroded a material is, since it is possible to predict its lifetime by just visually approximating the aspect of real and synthetic objects.

The use of AR instead of VR is due to the higher degree of users' immersion and familiarity reported in literature. A prototype using fiducial markers and tangible interfaces is presented in Section 5. The implementation using MAR techniques is the next step on the development and the availability on handheld platforms is planned in order to allow using this solution on a scenario of intensive mobility, as discussed in Section 6.

Figure 3 – Corrosion inspection application scenario.
4.2 Civil construction support

Using markers for tracking a construction site presents some problems. In order to be possible to estimate the pose at a given frame, a marker has to be visible on camera field of view. Since the environment has a wide range, several markers have to be spread along the construction site. In addition, each marker has to be calibrated with the building pose. Marker tracking can fail due to partial occlusion by any elements present on site, such as structures, tools and vehicles. It can also fail when markers appear too small on camera frame, requiring that the camera cannot be too far from the tracked target or that markers with increased size have to be used, which are limiting factors. Beyond, important parts of the building may be hidden by markers. They also cannot be positioned at places where there is a risk of being damaged by the constant handling of construction materials. All of these cited issues suggest the use of a markerless tracking approach.

In civil engineering, MAR can be used to give useful information for guiding the work. Figure 4 shows a building under construction augmented with graphics that indicate its future aspect in subsequent project phases, along with relevant data about how it is going to evolve. The project plan, stored in CAD plants, is exploited for both tracking and visualization purposes. It provides a 3D model of the building, which can be used by the system to perform camera pose estimation. The pose estimation makes possible for the engineer to visit the building and visualize in real-time the augmented information. The CAD model is also the source for the information to be displayed over the construction image.

Figure 4 – Civil construction application scenario.
5. RESULTS

A corrosion inspection application using AR was implemented as a proof of concept, which uses fiducial markers as a tangible interface. Tangible user interfaces (TUIs) exploit the physical environment to represent specific actions in order to interact with digital information (Bowman et al., 2004). Physical representations, which are called tangible interaction devices (TID), are perceptually bounded to the application and embody mechanisms for controlling it (Ullmer & Ishii, 2001). When using TIDs, the user is frequently able to interact with the system with both hands. VR systems often use TIDs for controlling proxies in the virtual environment. In AR, tangible interfaces based on fiducial markers are very common. In the corrosion inspection application, the Magic Cube tangible interaction metaphor was used (Zhou et al., 2005), which consists in using a cube that has a different marker on each face for performing commands. They are determined by the markers that are visible to the camera and the movements done with the cube, such as rotation.

The application consists in rotating a Magic Cube for visualizing the evolution of corrosion of a steel surface. The surface pictures were obtained by exposing it to water contact on a pool for different intervals of time. There are three distinct rust grades, each one associated with a specific marker, as depicted in Fig. 5 (a, b and c). As the user rotates the cube between two markers, the steel surface image gradually shows the transition between the correspondent rust grades, as shown in Fig. 5d.

![Figure 5](image)

Figure 5 – Corrosion inspection prototype showing different rust grades on steel surfaces: (a) Initial state; (b) After 614 hours of water contact; (c) After 816 hours of water contact; (d) Intermediate state between (b) and (c).
In the prototype implementation, marker tracking was performed using the ARToolKit library (Kato & Billinghurst, 1999). The OpenGL library (Shreiner et al., 2005) was used for 3D rendering tasks, such as background/steel surface display and blending between images with different rust grades. More specifically, the OpenGL Utility Toolkit (GLUT) was utilized for window handling and bitmap loading was performed using the OpenGL Auxiliary Library (GLAUX). Camera capture was done using the DsVideoLib library (DsVideoLib, 2008).

6. CONCLUSIONS AND FUTURE WORK

It has been discussed how AR, specially MAR, can help to resolve some problems encountered in the engineering field. In this context, MAR offers many advantages when compared to marker based AR and brings features that enrich applications, such as using the 3D model of the real object for occlusion and physics interaction with virtual elements. However, MAR techniques utilize mathematical and statistical methods that are not very accessible making its implementation a difficult task.

As future work, a prototype of the civil construction support application will be implemented using MAR. Edge based techniques seem to be the most adequate for this purpose, since most of the objects to be tracked are poorly textured. Due to the fact that many of the elements present at construction sites have curved surfaces (pipes, pillars, etc.), it should be used a technique that takes into account the occluding contours of the targets, such as the ones described in (Rosten & Drummond, 2003) and (Li et al., 2007). The corrosion inspection prototype will also be extended for using MAR technology. Since the system consists in an outdoor solution for field activities, using a mobile and autonomous platform such as a handheld or a wearable computer should be considered. A real object would be used as a TUI instead of a Magic Cube, or even the bare hands of the engineer could be tracked in order to enable the application control by gestures. (Stenger et al., 2006) presents an interesting technique for hand tracking. The steel surface could also be registered to any object present in the user environment, such as a desk or a paper, facilitating the manipulation and the visualization of the corroded materials.

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