An Interactive Augmented Reality System: a prototype for industrial maintenance training applications

Bassem Besbes * Sylvie Naudet Collette † Mohamed Tamaazousti ‡ Steve Bourgeois §
Vincent Gay-Bellile ¶

CEA, LIST, Vision and Content Engineering Laboratory, CEA Saclay, F-91191 Gif-sur-Yvette, France.

Abstract

In this paper, we present an innovative Augmented Reality prototype designed for industrial education and training applications. The system uses an Optical See-Through HMD integrating a calibrated camera and a laser pointer to interactively augment an industrial object with virtual sequences designed to train a user for specific maintenance tasks. The training leverages user interactions by simply pointing on a specific object component.
The architecture of our prototype involves two main vision-based modules : camera localization and user-interaction handling. The first module includes markerless trackers for camera localization, which can deal with partial occlusions and specular reflections on the metallic object surfaces. In the second module, we developed fast image processing methods for red laser dot tracking. By combining these processing elements, the proposed system is able to interactively augment in real time an industrial object making the learning process more interesting and intuitive.

Index Terms: MR/AR applications [industrial and military MR/AR applications]: ;— [Sensors]: vision-based registration and tracking—; User interaction [interaction techniques for MR/AR]: ;— [MR/AR applications]: MR/AR for art, cultural heritage, or education and training—;

1 Introduction

One of the key factors in integrating Augmented Reality (AR) technology into industrial applications is to provide assistance in maintenance procedural tasks. When faced with a complex object, the user takes considerable time to familiarize himself with spatial and mechanical aspects of various components, operations and procedures. In previous researches [2], it was shown that AR is a great tool that facilitates industrial task comprehension and execution. The impacts and effectiveness of AR were shown also in education and training industrial [1]. In order to take advantage of these features, the AR system must involve tools of wider applicability and must assure an intuitive interaction with the user.
This paper proposes an innovative AR system that features a tracked monocular optical see-through (OST) HMD offering an interaction prototype designed to provide dynamic overlaid instructions in response to the user's requests. Contrary to existing systems, requiring special infrastructure in the environment such as markers, emitters or additional positioning sensors, our solution is based on a markerless tracker. It uses only the integrated camera in the HMD and provides a simple user interaction at a distance. The training leverages user interactions by simply pointing on a specific object component by using a laser pointer. Many research and commercial systems have been investigated [4][3] where a laser pointer is used to interact with screens or architectural environments. In contrast to these systems, the problematic addressed in this paper consists in detecting laser on specular surfaces by using a mobile OST HMD equipped with a low-quality miniature camera. The findings show that this device is fast, precise, suitable for the training context and especially useful for selecting, from a distance, a particular object component.
The following sections provide a brief system description, introduces the developed vision-based modules and discuss the experimental evaluation.

2 Prototype description

We created a prototype to investigate the application of AR to industrial education and training application. It features a tracked monocular OST HMD that solves the 3D registration issues and allows to accurately superimpose virtual maintenance procedures on an industrial object. The training system guides a learner step-by-step through an assembly/disassembly procedure for a specific object of interest. The user can interact with the system, at a distance, by simply pointing to select a specific object component with an ordinary laser pointer. As depicted in Figure 1, the system is capable of interactively augmenting the selected component with an assembly/disassembly animated virtual sequence by using the 3D CAD model. Our prototype implementation includes real-time vision-based tools. A detailed description of the key components of our prototype implementation is provided in the next sections.

Figure 1: The prototype architecture description

3 Real-time vision processing

Interactive object-component augmentation requires a real-time, stable and an accurate tracking of the user viewpoint position and orientation. Once accurate camera localization is achieved and maintained, the virtual training sequences are correctly located and oriented in the view of the user.

*e-mail: bassem.besbes@cea.fr
†e-mail:sylvie.naudet@cea.fr
‡e-mail:mohamed.tamaazousti@cea.fr
§e-mail:steve.bourgeois@cea.fr
¶e-mail:vincent.gay-bellile@cea.fr

3.1 Camera localization and tracking

Real-time tracking for Markerless 3D object augmentation is a very challenging problem. It requires an accurate computing of the relative poses of the camera wrt this object. The adequacy of a model based tracking solution depends on the nature of the object and on its environment. The tracking of an industrial metallic object performance is strongly affected by specular highlights and its textureless surfaces. In order to address these problems, we implanted a tracking module, proposed in [5], combining SLAM and model-based tracking. The solution is based on a constrained bundle adjustment framework for keyframe-based SLAM algorithms that includes simultaneously the geometric constraints provided by the 3D CAD model and the multi-view constraints.

From the 3D CAD model, we extracted and sampled sharp edges in a set of short 3D segments. During the tracking process, these segments are used to directly constrain the camera poses by minimizing a cost function-based 2D/3D associations between the 3D segments extracted from the model and edges in key-frames (For more details, please refer to [5]). This camera localization solution shows very good reliability since it deals with the problems of accurate coordinate frame registration and scale factor setting, jittering, occlusions and real-time performance.

3.2 Image-based laser pointer localization

Laser pointer interaction is a fast and precise technique for interacting over distances. In our prototype, the laser dot is detected by the same tracked camera of the HMD. Once the 3D position of the object is estimated by the tracking module, a 2D Region of Interest (ROI) is defined. Then the red laser dot is localized in the ROI. By using the 3D CAD model and ray tracing techniques, the intersected object component with the laser spot is determined. Note that a spatio-temporal verification stage is included in order to confirm the user's request. When an object-component is selected, the system superimpose registred overlaid instructions concerning the selected object component.

For most applications, the center of the laser spot is detected from the weighed average of the image bright pixels after using a simple thresholding operation. Since our object of interest is subject to specular reflections, this method could not be reliably applied. An alternative way to handle the above problem is to detect and mask out, during the first frames, red-colored and high-lighting areas in which the detection is not possible. In our detection module, a red filter in HSV color model is first applied. Then, isolated pixels are removed with a simple morphological operation. Finally, the laser dot is detected by applying a blob detection algorithm. It is important to mention, that we applied the same algorithm to detect user's hand finger as a mode of interaction. The experimental results were very promising, but less effective than laser based interaction. The limitation of the finger based interaction arises when the user is pointing with more than one finger.

4 Prototype implementation and evaluation

The prototype incorporates a monocular OST HMD, an ordinary laser pointer (slimline) and a DELL PC (Intel quad-core Xeon X5482 3.2GHz , 3.25 GB RAM). The OST HMD can easily display additional information such as 3D CAD objects or simple virtual animated sequences on the natural field of vision of the user. The object of the interest is a textureless metallic object representing the back of an Upper-limb exoskeleton and subject to specular reflections. The laser pointer used is compact and projects red dot up to 50 meters.

Our AR prototype is evaluated through various real-time experiments and by different users. The experiments differ in their complexity regarding user movement strength, important changes in scale, partial occlusions and lighting condition. Figure 2 presents a 3D augmentation concerning an assembling procedure that was activated in response to the user's laser-based request. The results of our prototype evaluation were very satisfactory. The overall system runs at 25 fps. The tracking module shows high performance under various challenging scenarios. As the results of the feed back collected from end-users, the interaction module is easy to handle because it does not take a lot of special time or effort. Besides, it proved to be intuitive and very useful for industrial maintenance training applications, especially for selecting dangerous components. Comparing with finger based interaction, the users found that laser pointing is less natural but is more precise specially for selecting small components. However, when they are close to the object they prefer a direct interaction without the need of intermediate devices.

Figure 2: Laser based user interaction

5 Conclusion and future work

In this paper, we described an interactive AR application prototype for industrial education and training applications. The system provides dynamic registered overlay instructions on an OST HMD in response to the user's interactions. We applied our prototype to a simple virtual demonstration of assembling/disassembling procedures concerning Upper-limb exoskeleton components. Our experimental evaluations show the robustness of the system to viewpoint changes as well as its ability to achieve good accuracy with a textureless and a lightweight object. Besides, it allows to assure a fast, precise and useful interaction for industrial training applications. In our future work we will continue investigating existing and new methods of interaction such as visual gesture interfaces to virtual environments using only the embedded camera.

Acknowledgements

The authors wish to thank LASTER Technologies company for providing us the Optical See-Through HMD device.

References

[1] I. Farkhatdinov and J.-H. Ryu. Development of educational system for automotive engineering based on augmented reality. In *ICEE & ICEER 2009 Int. Conference on Engineering Education and Research*, 2009.

[2] S. J. Henderson and S. Feiner. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In *Procs. IEEE International Symposium on Mixed and Augmented Reality*, pages 135–144, 2009.

[3] D. Kurz, F. Hantsch, M. Grobe, A. Schiewe, and O. Bimber. Laser pointer tracking in projector-augmented architectural environments. *Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 1–8, 2007.

[4] D. R. Olsen, Jr. and T. Nielsen. Laser pointer interaction. *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 17–22.

[5] M. Tamaazousti, V. Gay-Bellile, S. N. Collette, S. Bourgeois, and M. Dhome. Real-time accurate localization in a partially known environment: Application to augmented reality on textureless 3d objects. In *The 2nd International Workshop on AR/MR Registration, Tracking and Benchmarking*, 2011.