Measurement 57 (2014) 53–70

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Review

State of the art and future developments of the Augmented Reality for measurement applications

Pasquale Daponte, Luca De Vito, Francesco Picariello *, Maria Riccio

Department of Engineering, Laboratory of Signal and Measurement Information Processing, University of Sannio, Benevento, Italy

ARTICLE INFO

Article history:
Received 2 February 2014
Received in revised form 10 June 2014
Accepted 17 July 2014
Available online 1 August 2014

Keywords:
Augmented Reality
Measurement system
Smartphone
Tracking system

ABSTRACT

Augmented Reality (AR) is a technology that enriches the sensorial perception of a person by adding virtual contents directly on the user's surrounding environment. The modern AR platforms, such as smartphones and head-mounted displays, are moving the application fields of this technology from research centers to a wide range of application domains. The aims of the paper are to highlight the role of measurements in an AR system and the AR as support to the measurements. In the first part, the evolution of AR concept and platforms that can implement AR systems, are presented. An AR system requires measurements of user and objects position and orientation, for this reason, several tracking systems and some calibration procedures are described. A survey of applications using the AR as user interface of measurement system is presented. Furthermore, future trends for researches oriented on the development of calibration procedures for tracking systems are discussed.

Contents

* Corresponding author.
E-mail addresses: daponte@unisannio.it (P. Daponte), devito@unisannio.it (L. De Vito), fpicariello@unisannio.it (F. Picariello), riccio@unisannio.it (M. Riccio).

http://dx.doi.org/10.1016/j.measurement.2014.07.009
0263-2241/

1. Introduction

The Augmented Reality (AR) is *an emerging technology with which a person can see more than others see, hear more than others hear, and perhaps even touch, smell and taste things that others cannot* [1]. This definition highlights the potential of this technology because it enriches the sensorial perception of a person by adding augmented information into the user real environment. By these considerations, a logical contribution of this technology can be seen in the measurement field, as a matter of fact, an enrichment of sensorial perception corresponds to increase the measurement capabilities of user (e.g. displaying measurements provided by sensors). An AR system can communicate with a measurement system or a Wireless Sensor Network (WSN) [2,3] for displaying to the user measurements of physical quantities that cannot be perceived with five senses. Nowadays, the technology advances are moving the AR from laboratory into the consumer markets (e.g. the smartphone market [4] and the promising system proposed by Google, called Google Glass [5]).

The first AR system appeared in 50s when Morton Heilig, a cinematographer, thought that the cinema is an activity that should allow a person to interact with the environment by taking all the senses in an effective manner. In 1962, Heilig created and patented a simulator called Sensorama with visuals, sounds, vibrations, and smells [6]. In 1968, Sutherland was the first one to create an AR system using an optical see-through Head Mounted Display (HMD) [7]. Myron Krueger introduced the interaction between a user and some virtual objects for the first time in the 1975 [8]. Later, Tom Caudell and David Mizell from Boeing coined the term "*Augmented Reality*" and they developed an AR system that helped workers assemble wires and cables for an aircraft. Paul Milgram and Fumio Kishino defined the reality–virtuality continuum (see Fig. 1) in the 1994. It is a continuum that spans from the real to the virtual environment [9]. In 1997, Ronald Azuma wrote the first survey in AR field providing the following definition of AR: "*The AR combines real and virtual environment while being registered in 3D and interactive in real time*", available in [10]. In 2000, Bruce Thomas developed the first outdoor mobile AR game, called ARQuake [11]. In 2005, it was predicted that AR technologies will emerge more within the next 4–5 years, and as to confirm that, camera systems and position measurement devices were developed in the same years for handheld devices such as smartphone and tablet. In the following years, more and more AR applications were developed especially for mobile and medical applications. In 2008, Wikitude AR Travel Guide was launched for the first generation Android phones [12].

Nowadays, with the new advances in microelectronics, an increasing amount of AR systems and applications are produced [13]. This technology is becoming closer to the user because even more mobile devices integrate sensors and have processing performances that allow to implement AR systems (e.g. smartphone, tablet, glasses, etc.). For example, modern smartphones have all the necessary features for various types of visual AR applications: a video camera, an Internet connection, GPS, and Inertial-Measurement Unit (IMU) [4]. In [14], the authors present five AR application fields based on smartphone: (i) sports, games, and edutainment, (ii) cultural heritage, (iii) medical, (iv) education and training, and (v) marketing. In the next year, it can be predicted an exponential growth of AR applications due to the coming on the market of the Google Glass, which is an optical see-through HMD with modern smartphone capabilities.

Several Augmented Reality applications have been developed for smartphone platforms, especially oriented to user navigation. For example, Milan Metro Augmented Reality [15] is a AR navigation application which guides the user to find underground stations by using the camera and the user location. Another navigation application is Junaio Augmented Reality [16], which provides to the user several information about local events, offers and listings, directly overlaid on the image captured by the smartphone camera. Otherwise, Happy Measure [17] is an AR application that helps the user with room planning for interior decoration and interior design. By using a marker placed on the object and the image captured by the smartphone camera, this application allows to measure the size of the object. In this way, it allows to create a 3D model of the object according to the previous measurements. Thus, the user can place the captured object on several positions of the room.

All of this shows a growing interest of the market for technologies and applications based on AR. For the implementation of AR systems, the measurements of the user and objects positions have a fundamental role. For this reason, after a brief introduction of these platforms, the paper highlights the importance of measurements in the intrinsic