Augmented Reality Interactive System to Support Space Planning Activities

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Abstract. The Space Planning (SP) is a process that allows making an environment more ergonomic, functional and aesthetically pleasing. The introduction of Computer Aided tools for this kind of practice led to an increase of the quality of the final result thanks to some versatile support used for the generation of different options to consider for the evaluation. In particular, those based on Augmented Reality (AR) technologies allow evaluating several options directly in a real room. In this paper, an AR system, developed with the aim of supporting Space Planning activities, is proposed. The system has been developed in order to overcome some problems related to the tracking in wide environments and to be usable in different typologies of Space Planning environments. The paper also presents a qualitative evaluation of the AR system in three different scenarios. The positive results obtained through these evaluation tests show the effectiveness and the suitability of the system in different Space Planning contexts.

Keywords: Augmented Reality, Space Planning design, HCI.

1 Introduction

The Space Planning (SP) is a process that leads to arrange buildings, rooms, factories or other generic environments in a practical manner. Very often, this process involves more than a single category of specialists (interior designers, architects, ergonomists, engineers, etc.), who have to collaborate together to define an optimal layout of furniture and equipment, so as to correctly arrange an environment. The definition of an optimal layout implies taking into account several aspects, which depends on the environment that has to be arranged. In a working space, for instance, safety and ergonomics are issues that have to be assessed to guarantee liveability to the employees. Usually, these aspects are regulated by specific guidelines that allow correctly defining the right furniture and equipment positioning [9]. More in general, skilled professionals follow several other guidelines to optimize the furniture layout. These guidelines have been elaborated, over the years, starting from the personal experience and often are regulated by the common sense [11, 18].

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Nowadays, this process is supported by Computer-Aided tools that allow the easy rearranging of virtual furniture and equipment in a virtual environment. Simplest tools, which are based on bi-dimensional drawings, can be useful to assess some of the above-mentioned criteria. Actually, it is possible to simply evaluate the encumbrance, the position and the orientation of each object with respect to the dimensions of the room. However, this simplified representation does not allow correctly evaluating other criteria, such as the aesthetic impact of the final layout.

3D modelling and rendering techniques, instead, give the possibility of improving the virtual representation both of the objects and of the surrounding environment, where the objects have to be arranged. The result of this virtual simulation is very effective and the visualization of the different layouts provides a high level of realism. However, making this kind of virtual simulation is a time-consuming process and requires specific skills. Furthermore, while the 3D models of objects can be imported from pre-existent databases, often, the surrounding environment has to be modelled from scratch. Consequently, the time needed for modelling the surrounding environment is a task that requires more time than that required for the arrangement of the environment [4].

By using Augmented Reality (AR) technology is possible to overcome this issue, since it allows the user to see virtual objects overlaying the real scene [1]. Therefore, AR has been already used to develop some applications for SP, in order to enable the direct rearrangement of the virtual objects in the real environment. [15] is one of the first examples and it grounds on the augmentation of a housing space by static pictures previously taken. This simple approach of working with pictures has been also used in industrial contexts to plan the disposition of machineries in a factory [5, 13].

The use of the real environment increases the comprehension of the final result as well. In fact, if the virtual objects arrangement is displayed in the real world, no abstraction activities are required to imagine the final results. In addition, the better understanding of the final result allows the user to directly interact with the environment to be planned and to be fully involved in the arrangement of the spaces. In this way, every kind of user can participate in the design process even if he/she has no skills in SP and in 3D modelling. This is the case of customers and final users for whom some solutions based on Mobile AR are under investigation [10, 16].

However, performing SP activities in an AR environment implies using systems that allow the tracking of the whole working area. In this way, it is possible to correctly place virtual objects according to the real environment. High-accuracy systems, such as the optical ones, are able to cover an entire room but require the installations of several and expensive devices. Cheaper tracking systems, instead, use Computer Vision (CV) algorithms to detect the camera. Some of these algorithms estimate the camera pose by detecting natural features in the environment [3] but they cannot work in case of completely empty spaces. Another more reliable solution is by adding known objects, such as fiducial markers, within the real scene. However, also in this case, the tracked environment requires to be structured by positioning and calibrating several markers in the working area [7, 2]. This activity is time-consuming and not versatile.

This research proposes the use of an AR system integrating marker-based tracking with the tracking ability of a commercial mobile robot. The robot can be seen as a mobile point of reference, which is automatically controlled by means of the device used to visualize the AR scene. A fiducial marker has been placed on the robot to maintain the marker always traceable. Consequently, starting from an absolute reference point, the AR system is always able to track its position in the space, by moving also the robot within the environment. Several authors have investigated the use of mobile robots in AR environment for different purposes [19, 6, 8]. However, in none of these works the tracking ability of the robot is used to extend the working area of the tracking techniques based on fiducial marker.

In order to exploit the characteristics of this AR system, the authors have developed a software application to support the SP activities. This software application enables the user to work with virtual objects located in the real scene. By means of a Graphic User Interface (GUI), the user can see the real environment and manage in real time the virtual objects that are placed within the real environment.

The paper presents also the description of some evaluation tests in order to validate the versatility and the usability of the AR system in different SP scenarios. During these evaluation tests, the users had to arrange different objects and in different environments. In particular, the scenarios, which have been analysed, concern the field of interior design, the setting up of an exhibition and for configuration of the machineries to be placed in a factory.

2 Description of the AR System

The design of the whole AR system grounds on a versatile and cost-effective architecture. The system has been developed by using not encumbrance devices, which are available on the mass market. Consequently, the AR system is quite inexpensive and can be easily transported. The versatility of the AR system allows using it in different kinds of SP contexts and its strong points relate to the ease of installation in different working environments and the ease of managing different virtual objects. The AR system mainly consists of two parts: an AR Interface and a mobile robot, as showed in Fig. 1.

The AR Interface provides all the interactive AR tools to support SP activities. It consists of a laptop and an external USB camera settled on a trolley. In this way it can be easily moved within the augmented environment, thus reducing the workload of the user.

The mobile robot, instead, has been equipped with a fiducial marker, which is used for tracking. The robot manages the position of this marker, placed on its top, with the purpose to extend the AR working area. The mobile robot used in this research is an iRobot Roomba 560[1], which is a commercial mobile robot. The choice of this mobile robot was mainly due to its robustness, its availability on the market and the remote-control easiness. The system uses a tracking approach able to estimate the pose of the

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[1] iRobot Roomba 560 – store.irobot.com/product/index.jsp?productId=3881236.

camera in the environment by merging data coming from the mobile robot and the ones coming from the marker-based tracking. The communication between the robot and the laptop has been obtained by using two XBee[2] devices that allow a wireless bidirectional transmission of the data coming from the serial port mounted on the top of the robot to the USB port of the laptop. Thus, the robot position can be remotely controlled by the user either in a manual or in automatic way.

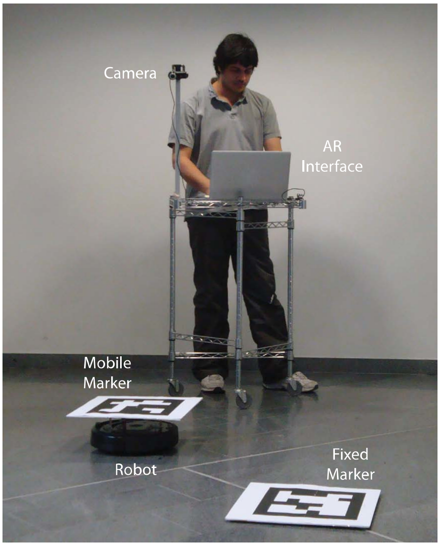

Fig. 1. The components of the AR system

2.1 Tracking Technique

The tracking technique used by the AR system relies on a particular approach that can combine two different kinds of data to estimate the camera pose [14]. These two data refer to the camera pose estimation performed by means of ARToolkit Plus [17] with two squared planar markers of 320mm size and to the position of the robot obtained by its own odometric system. One marker is fixedly placed on the floor of the room (fixed marker) and defines the position of the absolute reference system. In this way, the AR system estimates the camera pose according to the position of this marker. Moreover, the fixed marker is also used to set the initial position of the mobile robot, so as to have the robot position always coherent with the defined reference system. Every time the fixed marker is framed by the AR system, only the data obtained by tracking it by means of a standard marker-based approach are used to estimate the camera pose.

The other marker is placed on the top of the robot (mobile marker) and it can be moved, in an automatic or manual mode, every time the user moves the AR Interface to frame another part of the scene. In this way, this marker can be always visible to

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[2] Xbee – Wireless RF Modules, `www.digi.com/xbee/`

the camera. Every time only the mobile marker is in the framed scene, the AR system estimates the camera pose by exploiting also data coming from the robot. Actually, the marker tracking is performed on a mobile support, whose location is known by means of the odometric data, which the robot continuously sends to the AR Interface, to convey its position. In this way, the camera pose is calculated as a linear combination of data from the encoders and the mobile marker tracking.

In order to perform tracking, the AR system includes an initialization phase that consists in calibrating the initial position of the robot according to the reference fixed marker. Since the environment is not structured, the initialization is very fast and takes less than a minute. In order to perform this initialization, the only request is to frame both the markers by the camera. Afterwards, once the reference marker is arranged in the defined position of the working space and the robot is placed on the floor, the AR system automatically performs an auto-calibration and it can be used.

2.2 AR Visualization and Interaction Tools

The AR Interface has been designed to provide the users with two main functions, which enable supporting SP activities. These two functions are the AR visualization and the management of the virtual models directly in the AR environment. The user can see the augmented environment through the main window of the AR Interface. The visualization exploits the above-described tracking approach in order to have spatial and temporal coherence between the real environment and the virtual objects. The user can autonomously manage virtual objects in the real environment by means of a dedicated GUI, which is integrated in the AR Interface. The GUI shows all the available virtual objects, which are stored in a database, by means of a preview window. Once the user has selected and added the desired virtual object through this GUI into the real space, it is automatically placed in the scene and visualised in front of the camera point of view, to a distance of 1.80 metres. Afterwards, the user can change the object position in order to correctly place it in the desired location or in the most consistent one with the defined specifications. This operation is performed by means of six buttons, two for each axis, which enable the user to modify the position and the orientation of the virtual objects according to a step-by-step value.

The system also provides the user with two further functionalities. The first one regards the designed plans of the environments, which are useful to provide a further reference for locating the virtual objects in their specific position. These plans are previously prepared by the user and, once loaded, they are visualised on the ground of the working space. The second functionality regards the virtual light configuration. A correct illumination enhances the coherency between the real and the digital worlds and the level of immersiveness of the augmented environment. In this way, the user's perception of the designed space is improved and the AR interface helps evaluating the aesthetic impact of the virtual object more deeply. The lights settings are externally designed according to the different real illumination of the working environment and the user can load them within the AR scene to assess the visual impact on the virtual objects.

Finally, the AR Interface allows saving the current solution in a file during or at the end of the Space Planning process. In this way, the user can store different configurations and quickly switch from one to another, in order to quickly show the results to other people (e.g., customers) or keep on working on a previous space plan.

3 Evaluation

The main feature of the AR system is the possibility of being used in different SP contexts and, hence, some evaluation sessions have been organized in order to evaluate and validate the usability of the AR system in various scenarios. In particular, the AR system has been tested for the interior design of an apartment, the setting up of an exhibition in a museum and the planning of machineries layout in a factory. Each of these scenarios has allowed the authors to test the AR system with different typologies of virtual objects and in different spaces.

During the evaluation session, 5 users have been involved with the purpose to qualitatively assess the usability of the system. These ones are experts in the context of interior design, exhibit organization and engineering. The evaluation has been performed through specific heuristics, which have been developed starting from the ones proposed by Nielsen [12]. Therefore, it has been asked to the user to fill in a questionnaire after using the AR system, wherein they have to express their opinions with a scale of points from 0 (bad) to 5 (excellent).

3.1 Interior Design Scenario

The interior design scenario has concerned the definition of a furnishing for an apartment about 40 square metres wide. Two users, expert in interior design, have tested the AR system in this scenario. Their tasks concerned the placing of virtual furniture in the apartment, according to a plan. The system provided the visualization of the designed plan on the floor so that the user could have reference points for the disposition of the objects. Fig. 2 shows: one of the two users during the initialization procedure (on the left), the virtual plan, in which the furniture layout is defined (centre), furnishing of a room of the apartment (on the right).

Fig. 2. Example of using the AR system for interior design purposes

3.2 Exhibition Planning Scenario

In the scenario related to the exhibition planning, the test was conducted in an empty area of a museum about 30 square meters wide and the tasks concerned the setting up of an exhibition. The users were two professional exhibits organizers, who have been involved in arranging some statues in the area of the museum. The AR system allows the user to have a preview of the final layout without moving the real statues. Moreover, it is possible to use the system to check if the pieces of art can fit in the space without any troubles or risks to be damaged. The statues are indeed valuable and, often, fragile objects that have to be moved with extremely care. In this way, all the exhibit supervisors can participate in the arrangement of the statues and change also the final configuration, without the risk of damaging the real one. Fig. 3 shows some images taken during the arranging of the statues.

Fig. 3. Example of using the system as support for exhibition planning

3.3 Factory Scenario

The factory scenario consists in defining a functional layout of industrial machineries. In this scenario, an engineer, who is expert in factory planning, has been involved with the aim of testing the system in the evaluation of the machinery layout before buying all the industrial equipment. In particular, the aim of the assessment relates to the encumbrances of the machineries within a factory area about 15 square meters wide.

In this scenario, primitive 3D shapes have been used rather than virtual models of machineries, since the encumbrance evaluation does not need a complete definition of the shape. In addition, it is important to provide the user with the working volume of the machinery that usually does not coincide with the size of the machine at rest (as in case of a robotic arm). For these reasons, during the test, the whole functional encumbrance has been represented by using simple parallelepipeds with different colours. Fig. 4 shows the user during the execution of the definition of the machinery layout.

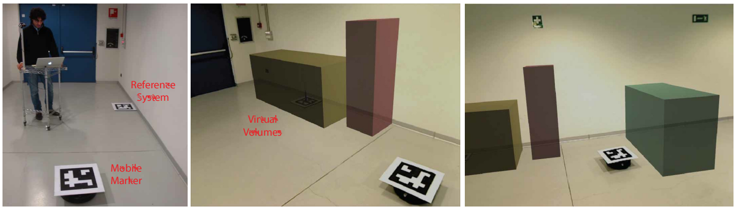

Fig. 4. Example of using the system for encumbrance evaluation in a factory

4 Discussion

The proposed evaluation scenarios have demonstrated that the AR system can be effectively used in different fields of SP. In particular, the system enables the user to overcome some issues regarding the tracking. The tracking solution adopted turned out to be advantageous in terms of ease of installation and usability. This solution has allowed the user to avoid the typical time-consuming phase of initialization and setup of the traditional tracking methods. In addition, the precision of the tracking solution adopted is reasonably acceptable for SP planning purposes and it represents a good compromise between precision and costs.

Moreover, the AR system resulted to be an effective interactive device for SP in the different scenarios analysed without any distinction. Actually all its functionalities worked well in all of the three environments analysed without any problem concerning the typologies of objects involved and their visualization.

The heuristics elaborated to assess the usability of the AR system show positive results, as shown in Tab.1. The AR Interface designed to visualize and manage the virtual objects turned out to be effective for the designers and engineers that tested the application (Q2, Q7 and Q8). Concerning the visualization, the AR Interface provides a good level of integration of the virtual objects with the real environment (Q1 and Q3). Moreover, it comes up with an easy method to manage the objects, which is also easy to learn (Q5). As a matter of fact, each user was able to autonomously use the AR system after few minutes (Q4 and Q6).

However, some users noticed the lack of some common tools that are present in the traditional VR systems for modelling. The first one is the possibility of selecting and moving different objects together. This is particularly evident in the case of interior design, where the designer has to deal with objects that are grouped for function (as for instance, the chairs and the table in a living room or the night table and the bed in a bedroom). The second one is related to the possibility of having a snap tool to help the user placing the virtual object in the space. In this way, it would be easier to attach to objects together, as in the case of the modules of which a kitchen is made up.

Table 1. Result of the questionnaires for the three scenarios

Questions	Interior Design	Exhibition	Factory
Q1. Level of integration of the virtual objects	4	3.5	4
Q2. Effectiveness for layout evaluation	3.5	4	5
Q3. Effectiveness of the whole AR visualization	4	3.5	4
Q4. Easiness and intuitiveness	3.5	4	4
Q5. Effectiveness for managing of the virtual objects	4	4.5	4
Q6. Learnability of the positioning methodology	4.5	4	5
Q7. Overall comfort	4	4.5	4
Q8. Satisfaction in using the AR system	4	4.5	4

5 Conclusion

AR can be a useful tool for Space Planning, since it allows the user to visualize in the real environment the final layout before buying or installing the objects inside. This kind of approach provides an easier comprehension of how the space will appear by using a traditional designed plan. The user, in fact, has to perform a minor abstraction effort to understand the result. In addition, an AR system provides a better interaction solution compared with the VR systems since the objects are located in real time in the real world.

The AR system proposed in this research provides a user-friendly tracking solution for the end user, who is able to cover a wide working area by using a mobile robot, avoiding the time-consuming procedure to structure the environment. Moreover, the system provides interactive software to easily manage virtual objects to effectively arrange them in the space. In this way, the designed system turned out to be versatile since it is able to provide an AR support, which is easy to install in various Space Planning scenarios and it can deal with different typologies of working environments and objects.

Therefore, some evaluation sessions with expert users have been carried out in order to validate the system. In particular, the AR system has been validated in three different scenarios: the interior design of an apartment, the configuration of the layout of machineries in a factory and the design of the arrangement of statues for an exhibition. The system was easy to install and it worked well in all the three scenarios. Thanks to the feedbacks provided by the users through a questionnaire, it is possible to state that the AR system provides an easy interactive approach with different typologies of virtual object in an effective manner.

The authors intend to continue investigating this field of research and, in particular, they will study how to improve the interactivity of the system, in order to make it more suitable for users in the space design sector and common users as well. For this reason, new techniques to manage the virtual objects will be developed, in particular by proposing new interactive metaphors. Finally, some quantitative tests with users will be carried out in order to assess the usability and interactive performances of the proposed system in different Space Planning scenarios.

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