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Machinery designing aided by augmented reality technology

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This paper describes results of the research concerning an augmented reality (AR) system for CAD design, developed within the framework of MSc Thesis in the Department of Fundamentals of Machinery Design. The authors present advantages resulted from utilization of AR systems allowing to combine the interactive computer-generated world with an interactive real world in such a way that they appear as one environment, especially in CAD design. The authors decided to apply the system to aid the designer of the machinery systems by choosing standard parts. The system enables the user to easily view the 3D models of standard parts from any perspective, in more natural, intuitive way than traditional one (on the computer screen). Next, the user can export the model to the modeling software and use it to model some machinery system. This paper presents possibilities of using AR technology in CAD design with the hope that maybe someday it would become an integral part of a standard design process.

Keywords: augmented reality, image processing, CAD design, visualization, marker, VRML

1. Introduction

Augmented Reality (AR) is a technology that integrates an interactive computer-generated world with an interactive real world in such a way that they appear as one environment. It originates from the well-known Virtual Reality (VR). Augmented Reality is often compared to Virtual Reality. The goal of Augmented Reality is to supplement reality rather than to replace it. In case of Virtual Reality systems some users can feel unsafe if their view is "locked" in an immersive virtual world whereas AR allows them to keep full control, to see the real world around them. It gives for AR system the advantage over VR system.

Some researchers define AR as systems that have the following three characteristics [7, 8]:

1. Combines real and virtual
2. Interactive in real time
3. Registered in 3-D

Each of AR systems must meet these three enumerated requirements.

The video images of the real world can be taken from a camera. At the same time the user can see through Head-Mounted Display (HMD) the virtual images from computer superimposed on the real world. When the user of AR system moves about the real scene the virtual objects appear as if they actually exist in the scene. Ideally, the virtual objects should interact with the user and real objects in the scene in a natural way.

A place of AR in Reality-Virtuality Continuum presents Fig. 1. This continuum was described by P. Milgram *et al.* in [6]. Augmented Reality occupies that place in the continuum where virtual objects are immersed into a predominantly real world environment.

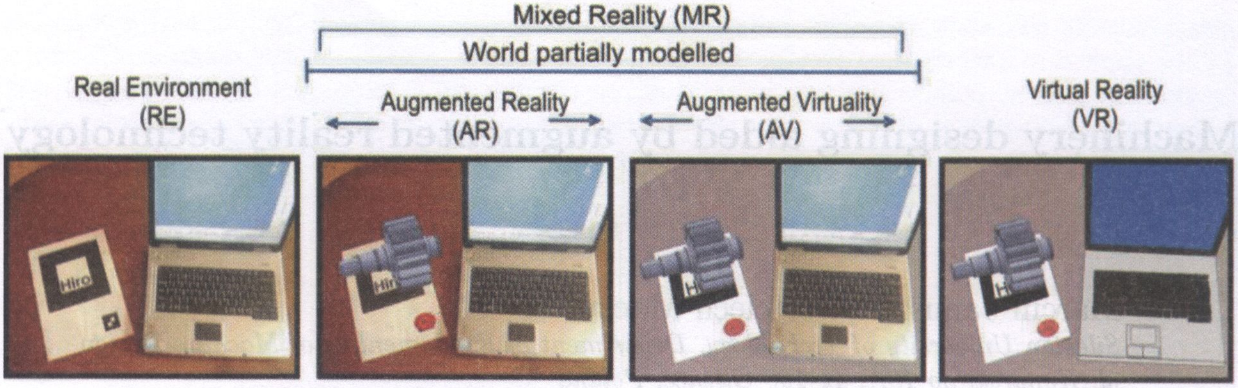

Fig. 1. Milgram's Reality-Virtuality Continuum [6]

Generally, at least six classes of potential AR applications can be specified: diagnostics, designing and manufacturing, medical, visualization, entertainment, military navigation and targeting. AR technology can be used to help surgeons see inside patients in real time without distracting one's mind from patient, using AR to help visualize and model three-dimensional objects, and using AR to help technicians in maintenance and assembly line workers by highlighting important parts of machinery and displaying instructions. At present a lot of research concerning at AR systems are conducted. Information about these systems in [8] are presented.

2. MOTIVATIONS

One motivation for AR is to enhance the user's perception. Representations of machinery systems might be easier to understand if they were available, not in the form of manuals with text, tables and pictures, but as 3D models and drawings superimposed upon the real world. The goal of our research is to provide a solution for the interactive AR system aiding the user in the design process.

Our AR system was inspired by the work of P. Dunston, M. Bilinghurst, Y. Luo, and B. Hampson. Their experimental prototype of ARCAD system allows designing some CAD model pipe layout for a new building with the ability to visualize the CAD design in augmented reality modes [1, 2]. Our system like the ARCAD system allows integrating CAD and AR systems, but in different domain namely machinery design.

Augmented Reality is a relatively new field where most of the research have occurred in academic and industrial research laboratories. In spite of there are still some technological problems to solve in AR technology, we do hope that someday AR will be integral part of our everyday life. We see prospects for AR in many aspects of our everyday lives. By this reason development of AR technology especially in CAD domain arouses our interest.

3. CONCEPTION OF AR SYSTEM AIDING THE DESIGNER OF THE MACHINERY SYSTEMS

Our prototype system called AR-CATIA enables the user to easily view the model from any perspective. AR mode for changing views of the model allows the user to understand the prospective system in a more comprehensive way, thus making design process more efficient than the one supported by conventional present-day CAD systems

The final effect of the research is an elaborated AR system (see Fig. 2) aiding the designer of the machinery systems in choosing of standard parts. In the presented conception of AR system the user with HMD on head sits in front of a computer. The user looks over the cards from a special catalog with markers through HMD and a virtual objects are seen onto this cards. The user by changing pages can preview all the standard parts (for example couplings) from the catalog. When the user

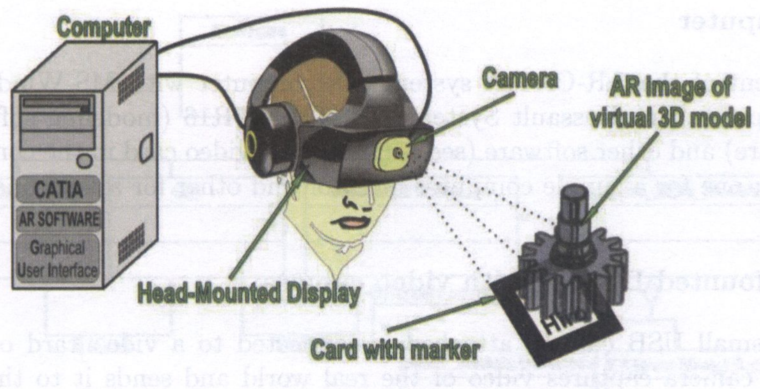

Fig. 2. Conception of AR system aiding the designer of the machinery systems

chooses the best fitting part, she/he can export this part to the modeling software CATIA V5R16. The designer in the CATIA's workplane can see the imported part. After this the user can go back to the modeling in CATIA or repeat the procedure for another part. When the design process is accomplished the user can export the finished 3D model back to AR software and preview results of her/his work on the first page from the catalog. A designer can pick up the catalog and manually manipulate the model for an inspection.

4. Hardware components of proposed AR system

Our AR system consists of the following hardware components (see Fig. 3):

- a computer running particular software,
- a video Head-Mounted Display (HMD) integrated with a camera,
- a printed catalog with special markers.

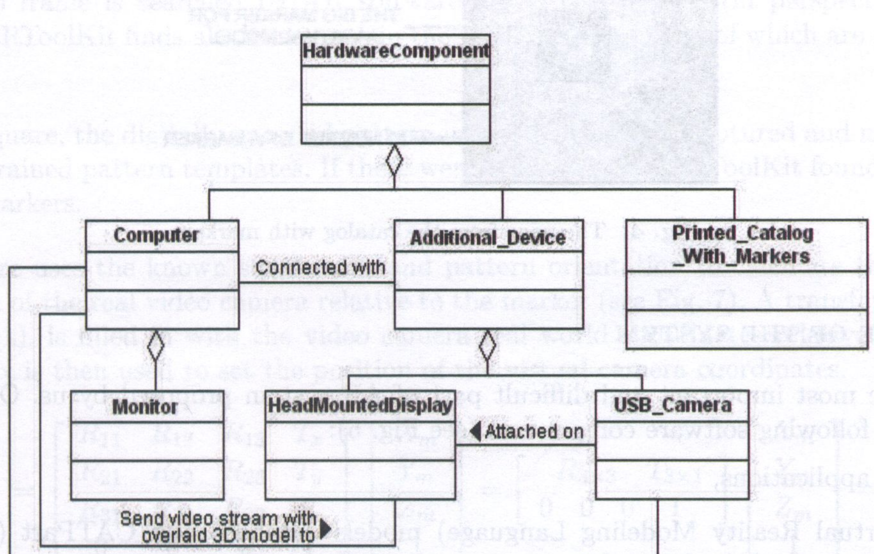

Fig. 3. UML Class diagram of all hardware components [3]

4.1. The PC computer

The basic component of the AR-CATIA system is a computer with MS-Windows$^{(R)}$ XP system installed. The computer runs Dassault Systemes CATIA V5R16 (modeling software), ARToolKit (AR viewing software) and other software (see Section 5). A video card in the computer should have two D-SUB sockets: one for a simple computer monitor and other for a head-mounted display.

4.2. The Head Mounted Display with video camera

The HMD with a small USB camera attached is connected to a video card of the computer by a cable. The video camera captures video of the real world and sends it to the computer. HMD allows to see 3D models in real environment surrounding the user. The user wears the HMD with the video camera attached, so that when she/he looks at the tracking card through the HMD a virtual object is seen on the card.

4.3. The catalog with markers

The AR software uses computer vision techniques to precisely overlay 3D models onto the real world. For that purpose software uses markers. Each marker shows a different digitally-encoded pattern on it, so that unique identification of each marker is possible. In our conception the markers are printed on the cards of the catalog. We can compute the user's head location as soon as the given marker is tracked by the optical tracking system.

Each page from the catalog contains two markers. On the bigger marker position and orientation a 3D model of a standard part is displayed. On the smaller marker position and orientation a virtual description of the given standard part is displayed. Each page from the catalog contains also a ID number (see Fig. 4) used during export process of the displayed models to the computer (to the modeling software).

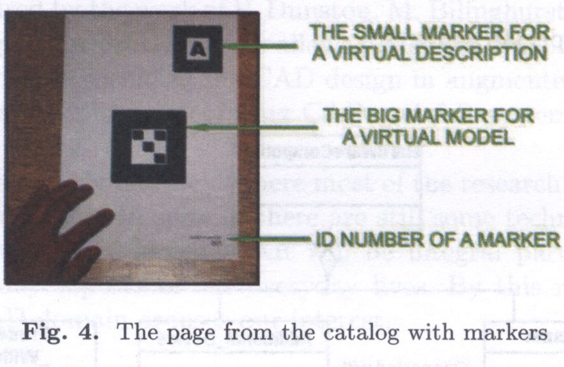

Fig. 4. The page from the catalog with markers

5. Software of the system

Software is the most important and difficult part of AR system proposed by us. Our AR system consists of the following software components (see Fig. 5):

- ARToolKit applications,
- VRML (Virtual Reality Modeling Language) models database and CATPart (3D models in CATIA environment) models database,
- Dassault Systemes CATIA V5R16 (modeling software),
- a special application to realize system functions.

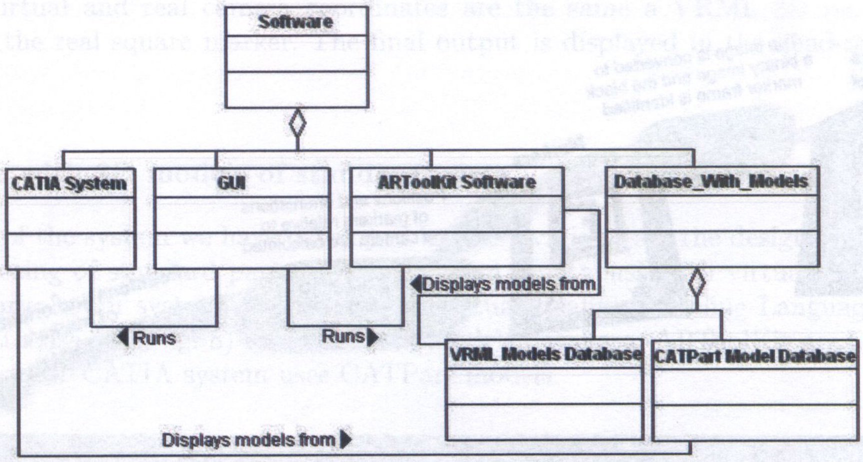

Fig. 5. UML Class diagram of all software components [3]

5.1. ARToolKit applications

We base on the public-domain augmented reality tracking library called ARToolKit (from HIT Lab [7]) with LibVRML97 parser for reading and viewing VRML files. ARToolKit is a software library that uses computer vision techniques to precisely overlay VRML models onto the real world. For that purpose software uses markers. Finally the ARToolKit application allows to display 3D VRML models of standard parts superimposed on the real world (exactly on the card with marker position and orientation).

The process of video-based marker detection and overlay of virtual objects by ARToolKit software proceeds as follows (see Fig. 6) [4]:

1. The video camera captures video of the real world and sends it to the computer.

2. The live video image is converted into a binary image based on a lighting threshold value.

3. Each video frame is searched by AR software for square regions (in perspective quadrangle regions). ARToolKit finds all the squares in the binary image, many of which are not the tracked markers.

4. For each square, the digitally encoded pattern inside the square is captured and matched against some pre-trained pattern templates. If there were a match, then ARToolKit found one of the AR tracking markers.

5. AR software uses the known square size and pattern orientation to calculate the position and orientation of the real video camera relative to the marker (see Fig. 7). A transformation matrix T_{cm}, Eq. (1), is filled in with the video camera real world coordinates relative to the marker. This matrix is then used to set the position of the virtual camera coordinates.

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_x \\ R_{21} & R_{22} & R_{23} & T_y \\ R_{31} & R_{32} & R_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} = \begin{bmatrix} R_{3\times3} & T_{3\times1} \\ 0\ 0\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} = T_{cm} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} \tag{1}$$

where: X_m, Y_m, Z_m – marker coordinates, X_c, Y_c, Z_c – camera coordinates, $R_{3\times3}$ – orientation matrix, $T_{3\times1}$ – translation vector.

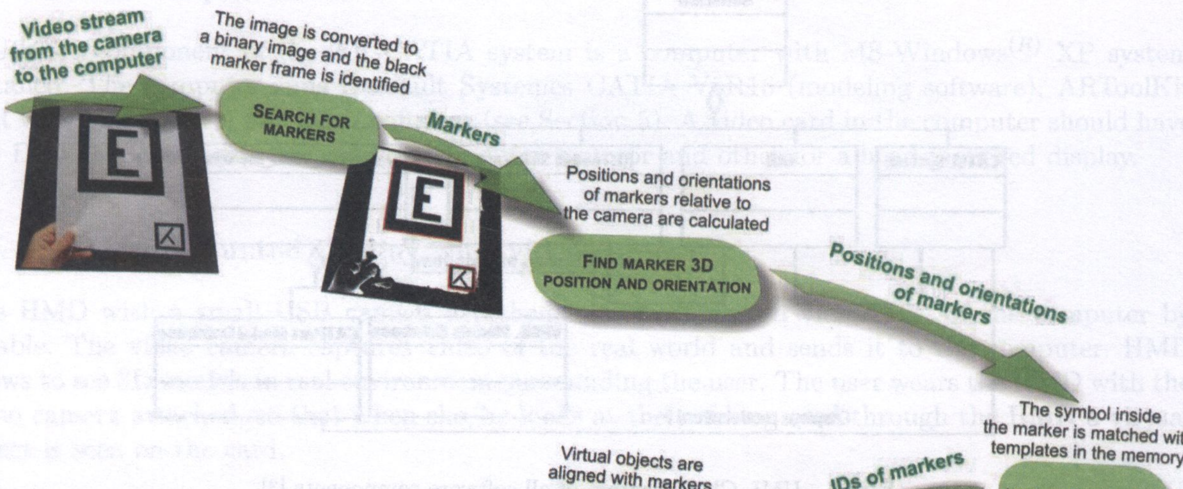

Fig. 6. The process of video-based marker detection and overlay of virtual objects [4, 7]

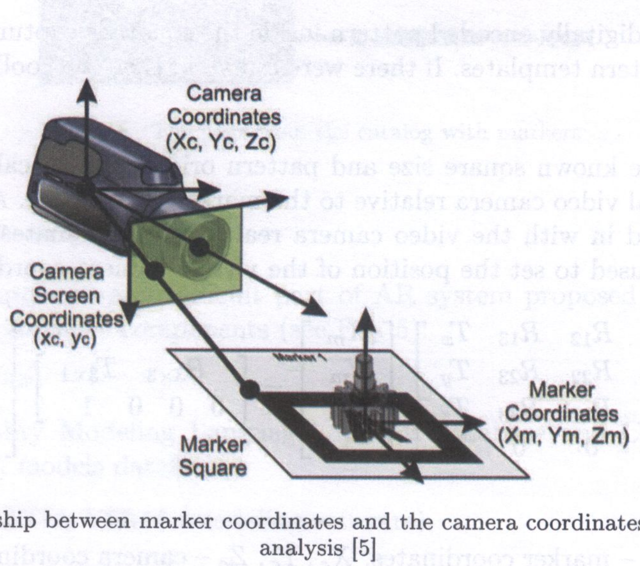

Fig. 7. The relationship between marker coordinates and the camera coordinates, estimated by image analysis [5]

6. Since the virtual and real camera coordinates are the same a VRML 3D model is precisely overlaid on the real square marker. The final output is displayed in the head-mounted display (HMD).

5.2. Database with 3D models of standard parts

The main goal of the system we have developed by our own is to aid the designer of the machinery systems in choosing of standard parts. For this reason a database with virtual model of standard parts is necessary. In our system we use VRML (Virtual Reality Modeling Language) models with descriptions database (see Fig. 8) and CATPart models database. ARToolKit applications use the VRML models while CATIA system uses CATPart models.

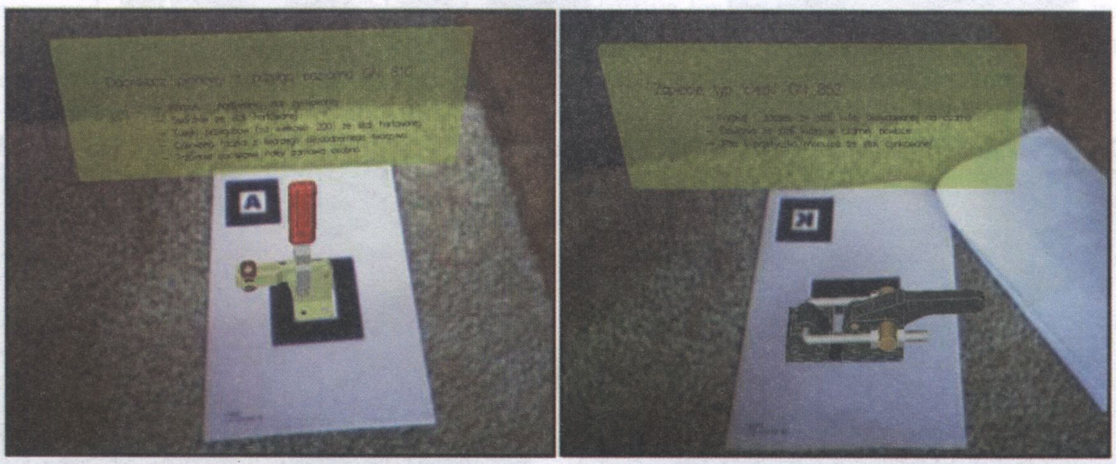

Fig. 8. VRML models with descriptions seen through HMD [3]

5.3. Modeling software CATIA V5R16

The system CATIA is used by a designer in modeling machinery systems. The designer of machinery systems can export chosen models of standard parts to the system CATIA. It is possible to use these models in modeling some complex machinery system.

5.4. Application realizing system functions

To realize tasks with the help of AR-CATIA system a special application was elaborated. This application allows to run CATIA system and ARToolKit application with proper 3D models database. It is possible also to export 3D models displayed in AR mode to the CATIA system and import the finished 3D model from CATIA to the AR software (see Fig. 9). The imported model of a complex machinery system could be also displayed in AR mode and results of designer's work previewed in an efficient way.

The graphical user interface (GUI) as part of the application was designed and elaborated in Visual Basic programming language. GUI composes some laps (see Fig. 9). Each lap corresponds to one catalog of standard parts. When we select the optimal catalog with standard parts we can run ARToolKit application and preview 3D models. Next, with the help of GUI we can export optimal 3D model to the CATIA. For that purpose the user must enter the ID number of a proper marker into a special text box. The last lap from GUI allows to import the ready 3D model of complex machinery system with the purpose of previewing results of her/his work.

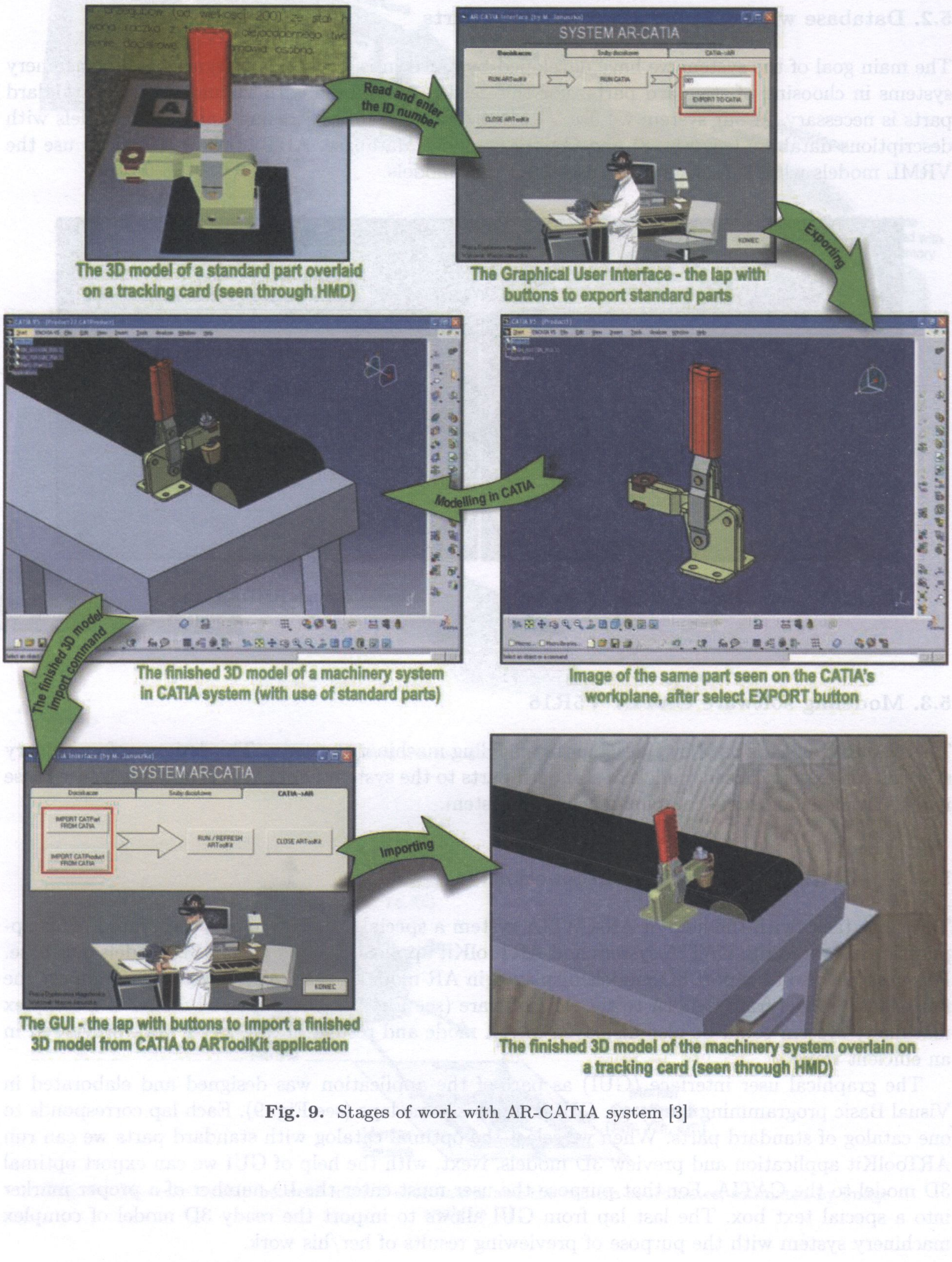

Fig. 9. Stages of work with AR-CATIA system [3]

6. Development status and deployment vision

The AR-CATIA system is in a late stage of development, however some mechanisms require improvement. We are able to:

- view models of standard parts and finished 3D models from CATIA in AR mode, from any perspective and also in 1:1 scale,
- import end export models between ARToolKit applications and CATIA system,
- have simple interaction with these models by picking up the card with the marker and manipulating the marker.

In the future the interaction with virtual models and a model export process to the CATIA can be improved. The export process should be more intuitive for example by voice command instead of keyboard command. The user should also have the possibility of more advanced interaction, for example possibility of hiding, adding, deleting some parts from displayed models.

In the future one of potential applications for the AR system proposed by us can be its application in the design session (for example in brainstorming). In the design session of the future several designers sit around a table examining projects they are about to design. Through the HMD displays they can see each other and in the midst of the table they can see a three-dimensional virtual image of their CAD models. The image is exactly aligned over the real world so the designers are free to move around the table and examine it from any viewpoint. Each person has their own viewpoint to the model. They are also free to interact with the model in real time. This is only one of many applications for our AR system and AR technology. There are also many other potential applications for AR.

7. Conclusions and summary

As a result of functional verification advantages resulted from the utilization of elaborated AR system to aid the designer of the machinery systems were confirmed. An experiment was conducted to functionally verify the system by providing meaningful scenarios to check that the system performs according to the specification. As a result of verification we acknowledge that the elaborated system allows visualizing the design in a modern way: more natural, intuitive and efficient way than traditional one on the computer screen. We can indicate other potential advantages of the elaborated system such as: shortened development time of a new product, reduced development cost of this product and improved utilization of existing constructional solutions.

There are still some technological problems to solve, but for industrial partners to be interested in investing into this technology its possible benefit and its integration with design procedures used in the whole company has to be visible.

In this paper we described the vision of how the final AR-CATIA system for CAD design will be used. We showed possibilities of using Augmented Reality technology in CAD design with the hope that maybe someday it would become an integral part of a standard design process. Future work will pursue confirmation of AR benefits for design model perception for users.

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