REASONING IN MACHINERY DIAGNOSTICS AIDED BY AUGMENTED REALITY SYSTEM

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Summary

This paper[1] deals with augmented reality system that was developed within the framework of MSc Thesis in Department of Fundamentals of Machinery Design. The main idea of this thesis was to implement AR system in reasoning in machinery diagnostics. The authors decided to apply the system to aid measuring noise level of the machine in the course of its operation. Next, using graphical elements, the system informs the user about measurement results. In the first part of this paper augmented reality systems are shortly described. Afterwards the elaborated system is presented, including its concept, structure, and functioning. The paper ends with some conclusions concerning especially system operation.

Keywords: augmented reality, transformation matrix, image processing.

WNIOSKOWANIE W DIAGNOSTYCE MASZYN WSPOMAGANE SYSTEMEM ROZSZERZONEJ RZECZYWISTOŚCI

Streszczenie

Artykuł ten przedstawia system rozszerzonej rzeczywistości, który został opracowany w Katedrze Podstaw Konstrukcji Maszyn Politechniki Śląskiej w Gliwicach podczas realizacji Pracy Dyplomowej Magisterskiej. Głównym celem tej pracy było zastosowanie systemu rozszerzonej rzeczywistości we wspomaganiu procesu wnioskowania diagnostycznego. Zdecydowano się na wykorzystanie systemu jako środka wspomagającego pomiar mocy akustycznej hałasu wytwarzanego przez maszynę podczas jej działania. Następnie system ten informuje (za pomocą elementów graficznych) o wynikach pomiarów w określonych punktach znajdujących się wokół maszyny. W pierwszej części artykułu opisane są krótko systemy rozszerzonej rzeczywistości. Następnie przedstawiony jest opracowany system rozszerzonej rzeczywistości oraz wnioski, jakie nasunęły się w trakcie prac nad nim.

Słowa kluczowe: rozszerzona rzeczywistość, macierz transformacji, przetwarzanie obrazów.

1. INTRODUCTION

A term "Augmented Reality" (AR) describes systems that join virtual information with a view of real environment and present them to the user's eyes. Augmentation may take form of labels, diagrams, schematics, virtual models, shadows, etc. A characteristic feature of augmented reality systems is placing real objects and virtual data in one space. Virtual information should be accurately oriented with respect to real objects. Therefore significant task is to provide a quick, accurate registration and joining process. Usually, user of such a system wears a Head-Mounted Display (HMD) and with the help of this device can see augmented reality image.

There are many practical applications of augmented reality systems. For example in medicine, designing, manufacturing, maintenance and repair, assembling, robotics, military domain (Head-Up Displays), even in entertainment. In all mentioned applications the main goal of using an augmented reality system is to aid a user in his/her operation. Since many effort in the Department of Fundamentals of Machinery Design (DFMD) has been done for a couple of years in the domain of

[1] This paper is based on the MSc Thesis [1] and the paper [5] that was accepted for publishing in Proceedings of AI-METH Symposium in Gliwice (2005)

technical diagnostics, the authors decided to implement AR in diagnostic reasoning.

The paper is composed as follows. In the next section augmented reality systems are more precisely described, especially its functioning, structure and system types. Then the elaborated system is presented focusing on its implementation in technical diagnostics. The paper ends with placed conclusions.

2. AUGMENTED REALITY SYSTEMS

2.1. Functioning

Operation of AR systems consists of three main stages. First, system has to estimate a pose (position and orientation) of the user's head. It can be made using various position trackers such as magnetic, acoustic, optical, video, mechanical ones, GPS and their combinations. The second task is to combine information about the pose of the user's head (with respect to real objects) with information about virtual elements. At this stage an Additional Information Model (AIM) is required. Finally, the system has to present a combination of a real world and virtual data on HMD or monitor or else projector.

2.2. Structure

At present an augmented reality system usually consists of: camera(-s) which provide(-s) image of real environment; position trackers that estimate the user's pose; a computer that combines information about real world and virtual objects, and then sends combination result to a displaying device; cables that are responsible for communication between all devices; Head-Mounted Display (eventually monitor or projector); and helmet.

2.3. Types of AR systems

Taking into account displaying method there are two main kinds of devices that present augmented reality image: optical see-through devices and video see-through devices. First of them use semi-transparent glasses placed in front of the user's eyes. The user sees the real environment through these glasses and reflected additional information generated by small monitors. Such a system may use a camera, but only to estimate the pose of the user's head. Second of them, most often using two LCDs, present the user's eyes a combination of a camera's view with virtual elements in one space. Information about the pose of the head is provided by different kinds of tracking systems, including usage of view of the camera.

3. ELABORATED SYSTEM

Because the Department of Fundamentals of Machinery Design deals with diagnostics, the authors decided to apply the AR system in this domain. Results of this implementation are described in the MSc Thesis [1]. Below are presented some details of this implementation .

3.1. Concept

A concept of a project consisted in elaborating a system, whose functioning principle was based on video see-through devices, but HMD was replaced by a monitor. A square marker (Fig. 1a), printed on a rigid piece of paper, was used for tracking. Its structure allows estimating correctly the camera pose.

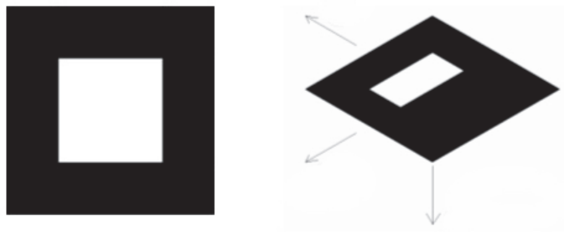


Fig. 1. a) basic marker, b) marker used in elaborated system[1]

The marker has two areas: inner white area and outer black area with an additional black element. The inner area enables recognition of the marker in the camera view (if the black region in the camera view has the area greater than assumed and has four corners, it is considered as a potential marker view). The additional element present in the inner area allows to determine one of four possible marker orientations. The simpler is the additional element, the better results of recognition are. A square or circle are not used in the centre of the marker, because they would not allow finding the right orientation of the marker. The authors decided to use a rectangular element in one side of the inner area (Fig.1b).

Operation of the system consists of a few steps (Fig. 2). Firstly, the camera registers an image of the real world and next sends the image to computational software. Further on, basing on the marker size and shape in the image, program estimates the pose of the camera – generates a Transformation Matrix between co-ordinate systems of the camera and the marker. Dimensions and shape of the marker must be known. Supplementing virtual information to the image of the real world takes place next. Finally, a combination result is sent to the monitor.

3.2. Transformation Matrix

One of the most important features of AR systems is the registration process of real environment and accurate location of objects that are present in this environment. If we want to put virtual information in the right place, we have to know how the camera is located relatively to these objects. Marker as a tracking element is located in some way to objects. So that to determine camera position in real world, there is the need to know its pose relatively to the marker co-ordinate system.

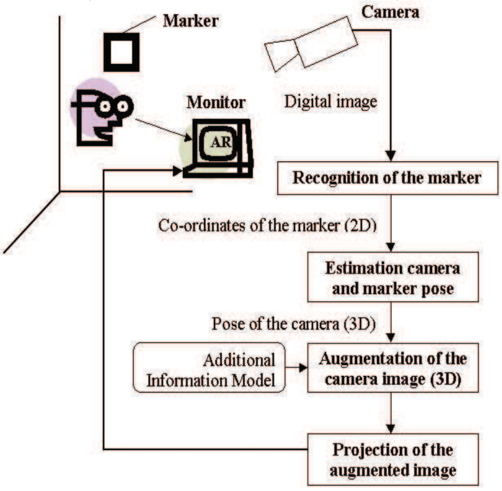
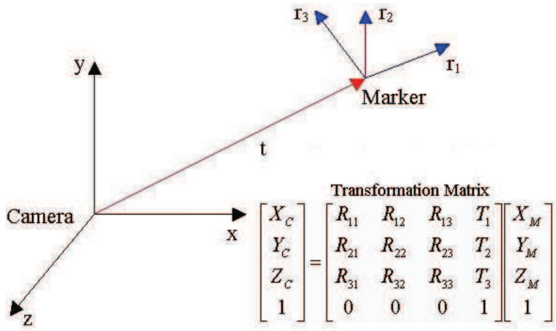


Fig. 2. Concept of the AR system [1]

To determine the pose of the camera two elements are required: translation vector and orientation matrix between the marker and the camera co-ordinate systems. Heart of AR systems, that use markers to estimate the camera (i.e. the user's head) pose, is the Transformation Matrix (Fig. 3). This matrix contains a translation vector and an orientation matrix.

The translation vector informs about the distance between origins of the marker and the camera co-ordinate systems. The orientation matrix informs about this, how each axis of the marker co-ordinate system is rotated relatively to each axis of the camera co-ordinate system.



$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_1 \\ R_{21} & R_{22} & R_{23} & T_2 \\ R_{31} & R_{32} & R_{33} & T_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_M \\ Y_M \\ Z_M \\ 1 \end{bmatrix}$$

Fig. 3. Transformation Matrix [2]

3.3. Structure

The elaborated system (Fig.4) consists of an USB camera, display monitor, PC computer with software, cables and the marker. As a computational software Matlab and ARToolKit for Matlab [2] are used. The ARToolKit, basing on the view of the marker in the image of the camera, determines the camera pose (by calculating the Transformation Matrix) using various methods of image processing such as thresholding, labelling, edge and corner recognition. Next the ARToolKit superimposes virtual information appropriately oriented to objects in the image of the real environment and sends the augmented image to the monitor.

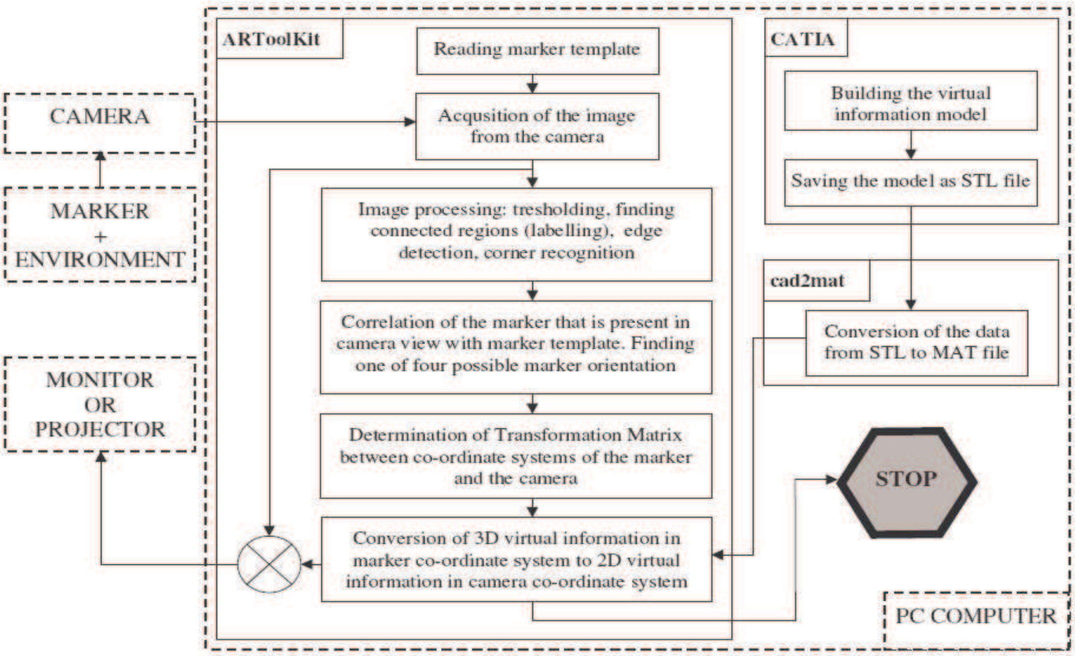


Fig. 4. The structure of the elaborated system [1]

3.4. Additional Information Model

It was decided to build a model of virtual information in a CAD system. To perform this task the CATIA V5 was used. Once a solid in CATIA is built, a very important thing is to remember about co-ordinate systems of the camera and the marker. The model of virtual information in the augmented image is oriented in the co-ordinate system of the marker, the same as the solid in co-ordinate system of the CATIA is.

The CATIA model is saved in a STL file format. The stereolithographic format that is used in *Rapid Prototyping,* is a surface one. It describes a model using a net of triangles. Having the STL model of virtual information the final step to get AIM is converting data from STL file into MAT file that is understandable for MATLAB. The authors used the modified *cad2mat[3]* (for Matlab) program that enabled them to obtain information about the model of virtual information.

4. IMPLEMENTATION OF ELABORATED SYSTEM IN MACHINERY DIAGNOSTICS

The authors decided to implement a system that is adjusted to the standard PN-84/N-01332 – "Noise. Survey method for determination of sound power level of machines" and to the classes to be carried out basing on this standard in DFMD laboratory. The classes consist in measuring noise in 21 points placed on virtual half-sphere (Fig.5) around the machine. Measurement points are located in places where six planes intersect with the half-sphere. Particular requirements concerning a way of measuring and dimensions of the half-sphere (its radius, distances between the reflecting plane and other planes) are not described in this paper. They are presented in the standard PN-84/N-01332.

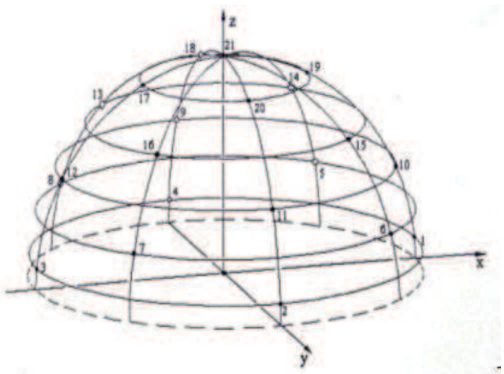


Fig. 5. Model of a half-sphere [4]

Noise level measurements are mainly performed to determine an influence of the noise generated by machine on a human organism and its operation. These measurements make also possible reasoning about technical state of the machine.

4.1. Preparation of a virtual model of a half-sphere

It was mentioned above that the model of virtual information was prepared in CATIA system. Measurements should be performed in right order. To achieve this goal a few steps were made:

- Building a solid model of the half-sphere in CATIA. Doing this by a simple revolution of a cross-section of a half-sphere does not provide information about location of measurement points. So that the authors proposed a method that enables to do this task. This method consists in: preparing seven sketches of octagons, each of them being an approximation of circle being a result of intersection of planes with the half-sphere; doing multi-loft operation with usage following sketches. Such a solid model is only an approximation of the half-sphere, but it is sufficient enough to the intentional implementation;
- Extracting information about model from STL file to MAT file (with the help of *cad2mat*);
- It was observed that in STL file two triangles create one rectangular element. So it was built a Matlab function that perform this task;
- Writing a function *selpunkty*. Its functioning consist in selecting measuring points from all points of the half-sphere, placing them in right order and determining their projections on the base of the half-sphere.

4.2. Operation of the system

The system performs two main functions: shows measurement points in right order (Fig.6) and next using measurement results informs about noise level in every measurement point (Fig.7).

The system during its functioning shows the user the current location of the measurement point, its projection on the ground and its identifier according to fig.6. The user has to put the microphone on a projection point, and then, if possible vertically, move it towards the measuring point. This task is quite difficult, because 3D model of virtual information is projected as 2D image. The user does not know if the microphone is exactly in the respective measurement point.

Once measurement results have been collected, system presents them to the user using a coloured circles. A colour shade of circles depends on measurement results. In the figure above is a screenshot of an image generated by the system under operation.

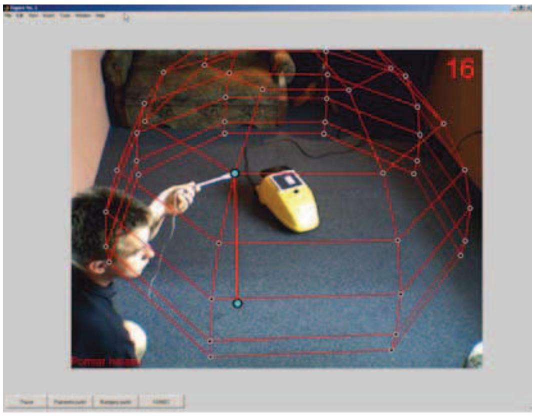


Fig. 6. Example of implementation – measuring noise level [1]

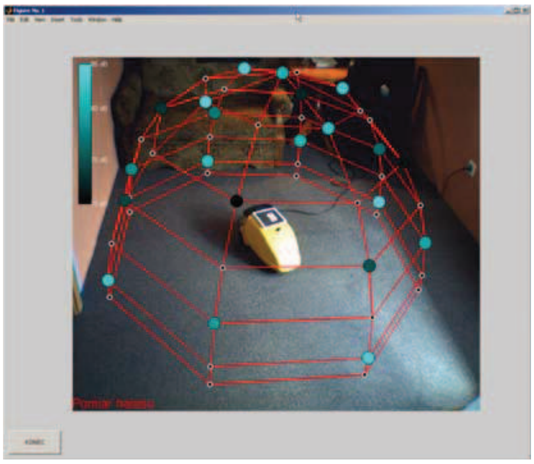


Fig. 7. Example of implementation – measuring results [1]

5. CONCLUSIONS

In the course of elaborating the AR system described above it was observed a huge influence of many factors on functioning of the system. In this section are presented some of them. They are segregated depending on an element being their source. The biggest influence have elements such as camera, marker, Additional Information Model, STL format, lighting conditions. At the end of this section are presented conclusions concerning operation of the system.

5.1. Camera

The resolution of the camera has a considerable influence on the speed of the system operation. The Creative WebCam Live! Pro camera provides image of 640x480 pixels. Using lower resolution the speed of the system operation would be increased, but the accuracy of the pose determination would be decreased and size of the image would not be sufficient enough for the user.

An area covered by the camera depends on its angle of view and its distance from the object located in environment. The usage of the camera with too wide angle of view may produce big distortions of an image (*"fish eye effect"*). The area of view could be enlarged by increasing the distance between the camera and real objects, but it decreases an accuracy of pose determination – the marker in the image becomes smaller.

Fast moving of the camera is a reason of image blurring. In this case the marker in the image from the camera may not be detected. Hence, the pose of the camera might be undetected. There was observed too long time of registration and processing of every single frame. For this reason was used a tripod for the camera. If there was a necessity to observe object from the other side, the camera with the tripod was moved.

5.2. Marker

The marker used as a tracking element is easy to make. The best way to make the marker is printing it on a lustreless (camera will not be blinded), rigid piece of paper. It was observed that the size of the marker has significant influence on the accuracy of pose determination. Another thing is that, if the element in the inner area of the marker is too small, the right orientation will not be determined. The usage of the marker as a tracking element has a one big disadvantage. If the marker is covered by real objects, the tracking is lost.

5.3. Additional Information Model and STL format

The usage of STL format for building the model of the virtual half-sphere is sufficient enough for presented implementation. It was noticed that complexity of the AIM decreased very much the speed of system functioning. For example, for the model of the half-sphere (432 triangle elements, file size – 29 kB) it was 0,8s./frame, for a model of the connecting rod (2670 triangle elements, file size – 728 kB) it was 2,9s./frame. This is why during preparing a solid model of virtual information it is recommended to use simple and as least as possible rounded elements – the number of triangle elements will be lower.

5.4. Lighting conditions

During elaborating the system it was observed that pose determination process depends very strongly on lighting conditions in place where measurements are made. Too large intensity of light causes that the white background of the marker is a reason of the camera blinding. So that the marker is not recognisable. The biggest problems are with the use of a halogen light.

The most advantageous results provides the following configuration: *marker – camera – source of light.* The configuration *source of light – marker – camera* causes blinding of the camera. Good effects could be achieved using soft light.

5.5. Operation of the system implemented for measuring sound power level

The operation of the system enables to put easily the microphone on a projection of the measurement point – the end of the microphone has two degrees of freedom (except rotation). Two-dimensional projection of the three-dimensional model of virtual information causes that the end of the microphone during lifting it to the measurement point has three degrees of freedom. The user has to lift the microphone vertically as precisely as he/she can. So there is the need to track the microphone. An essential fault of 2D projection of 3D additional information model is a perdition of the depth of the image. Sometimes virtual information should be covered by real objects.

6. SUMMARY

The main idea of the MSc Thesis briefly described in this paper was to elaborate AR system that should aid the user in the process of reasoning in machinery diagnostics.

The authors decided to implement the system in one specific application, but there are many domains in diagnostics where augmented reality can be used. It is easy to imagine the AR system that aids the user in diagnostics tests, for example, as a medium showing on displaying device (HMD, monitor) some invisible parts (shafts, gear wheel) of the machine. Also as additional graphical elements can be used some text objects that inform the user about sources (elements of the machine) of vibration, potential failures, etc.

Taking into account some sub-domains of machinery diagnostics there are three areas where AR can be used. Here are presented some examples. In the process of preparation of the object to tests an AR system could inform about location of sensors, the way of connecting measuring equipment, etc. During the test the system could show location of measurement points in right order, warn against some dangers (high temperature, rotating elements of the machine), incomming damage of the machine. In diagnostic reasoning the AR system could present some measurement results, could inform about elements of the machine or phenomena that may be reasons of any inefficiency. These issues will be addressed in the further research that is supposed to be carried out in DFMD.

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