Evaluation of Cognitive Effort in the Perception of Engineering Drawings as 3D Models

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***Abstract*—In this paper, an experiment aiming at estimating the cognitive complexity of engineering drawings by measuring the reaction time and the accuracy of mentally reconstructing 3D objects from engineering drawings is presented. The performed experiment emphasizes the complexity that the engineer is facing in the product development process, shown by increased reaction time and reduced accuracy of 3D reconstructed objects. The precision and the reaction time were not considerably improved by using 3D stereoscopic viewing. Based on the results obtained from the experiment, a new class of technical drawings called Augmented Reality Technical Drawings (ARTD) is proposed. This solution enhances the visual perception by co-locating the 3D virtual object with the corresponding engineering drawing and offers the quick recognition of the object with less perceptive ambiguities.**

Keywords-computer aided design; product development; engineering drawings; mental reconstruction.

I. Introduction

Since the industrial age, engineering design has become an extremely demanding activity. New instruments and tools have been continuously invented in order to aid the engineer during this activity and this increase their productivity. One of the most important technologies from the last century that significantly increased the productivity in design is Computer Aided Design (CAD). Nowadays, CAD is a mature technology, without which the industrial design cannot be conceived. CAD systems have been proved to reduce the design time, costs and improve the design quality [6].

Engineering design requires sketches as well as drawings, commonly referred to as engineering drawings, taught in most engineering colleges [10]. Engineering drawings store geometrical data relating to mechanical components and assemblies, in the form of 2D planar views, either on paper or computer files. CAD systems are the main tools that help the engineer create accurately and correctly 2D drawings. CAD tools improve the productivity and the cognitive complexity by using comprehensive databases and intuitive (real-like) 3D graphic representations. Although CAD systems use 3D representation, the actual technical drawings are based just on 2D planar representations of the product. These techniques require the perception and understanding of spatial information from 2D planar representation of a 3D object. The reconstruction problem is difficult because the 3D perception is determined from 2D planar projections and sections of the part. The user has to create a 3D image in the brain, by using 2D projections, which than is used in the manufacturing process of the respective product. In the case of a product with a high complexity, the mental effort can have a negative effect on the reaction time and the accuracy of the mentally reconstructed 3D image of the product.

Our research activities are focused on reducing the cognitive complexity that the engineer is facing. This paper presents an experimental study conducted with the purpose of analyzing the cognitive effort of using 2D engineering drawings for mentally reconstruction of 3D objects. The role of 3D stereoscopic visualization is also investigated. The paper is organized as follows: Section 2 reviews prior work, Section 3 describes the conducted experiment, Section 4 points up the results, and Section 5 presents conclusion and sketches possible directions for future work.

II. Research Background

The investigation of perceiving 3D object has been carried out for many years [1], [5], [9]. There is, however, a shortage of reported work that qualifies the cognitive effort of using 2D engineering drawing for mental reconstruction of 3D parts.

Hoffmann et al. [7] evaluate the perception of 3D surfaces that have been rendered by a set of lines drawn on the surface and the role of binocular disparity as a depth cue. Their results indicate that binocular and monocular mechanisms for 3D shape reconstruction from contours involve similar mechanisms.

More recently, in [8], the reaction time and the accuracy of creating brain images of 2D or 3D figures are explored. The set-up consists of performing four types of tasks: simple 2D, selective 2D, 2D-3D and 3D tasks. Their results indicate that the task of constructing the image of 3D objects in the brain has the longest reaction time. In the study were used simple and basic figures but in engineering drawings are used complex shapes.

With this in mind the objective of this research was to carry out the human factors evaluation related to mentally reconstruction of 3D parts from 2D engineering drawing via the use of a comparative assessment of monoscopic visual perception with 3D stereoscopic visual perception.

ISBN: 978-1-61208-177-9

III. Experimental Protocol

This study tries to answer to the following research questions:

1) What is the accuracy and the reaction time needed to mentally reconstruct a 3D model from 2D engineering drawing?

2) What is the advantage of using 3D visualization for the recognition of mentally reconstructed 3D CAD models?

3) How engineering drawings can be improved in order to reduce the cognitive complexity?

Thus, we have devised and conducted an experiment to record and measure the reaction time and the accuracy in the brain images from several 2D engineering drawings. The results of this experiment allow us to answer the three research questions and to assess the relative impact of VR technologies on the users' performance.

A. Subjects

In the experiment, eleven volunteered subjects with healthy sense of vision were tested. One subject was familiar with the stimuli and with the research. The other subjects never used VR immersive stereoscopic 3D visualization for the perception of 3D CAD models until the experiment. Instead, they had extensive experience in using 2D engineering drawings and good computer skills.

B. Stimuli

In the conducted experiment was needed a set of sixty 3D CAD parts with medium complexity. The test parts were selected from a mechanical engineering drawing handbook and had different topology. In the first phase, each part was modeled using the legacy CATIA CAD software. In the second phase, 2D engineering drawings corresponding to CAD models were created via the drafting module of CATIA CAD software. The engineering drawings include orthographic views and for some parts sections and detailed features (Fig. 1).

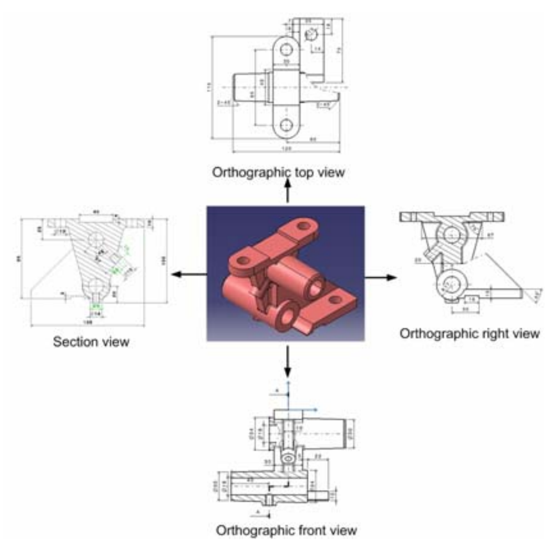

Figure 1. Components of an engineering drawing

Orthographic projections are a collection of 2D drawings that represent projections from different directions of a 3D object. Usually front, side and plan views are drawn so that a person, looking at the drawing, can reconstruct the 3D object. The sectional view is applicable to objects where the interior details are difficult to understand through the usage of dotted lines on an orthographic projection. The sectional view is obtained by cutting the object by a plane so that the hidden details are visible. Because we want to investigate the influence of stereoscopic binocular 3D vision, the parts where exported in Virtual Reality Modeling Language (VRML) neutral format and then imported in a custom developed software application.

C. Display technology

The 3D models were visualized using two type of devices: a universal 2D LCD display with the diagonal of 19" for desktop interface and an active stereoscopic system for 3D perception (fig. 2). For perceiving the 3D stereoscopic images, a standard solution based on desktop CRT monitors with wireless Crystal Eyes shutter glasses was used. The display renders the images at 120 Hz. For rendering the 3D environment was used the BSContact Stereo VRML visualization player integrated with a dedicated software C++ application (fig. 2).

Figure 2. The subject selecting a 3D model using 3D display active stereoscopic visualization system

D. Tests set-up

Before conducting the experiment, each participant had the opportunity to become familiar with the system. The users had ten minutes prior the experiment, for practicing the navigation interaction modalities in a 3D testing environment. After that they pressed the "Start" button. A random 2D drawing is initially presented and the subjects imagine a 3D model in the brain. In order to evaluate the cognitive effort of the mental reconstruction and the reaction time, for the first five parts of the experiment, the 2D drawing were presented for maxim 20 seconds. If the subjects clearly constructed in the brain the 3D model before the time passed, they click the "OK" button and step forward to the 3D environment.

 ISBN: 978-1-61208-177-9

Immediately after that, the subjects chose between the imaged 3D model and the other three slightly different 3D models (Fig. 3). To create a difference between the presented 3D models some features where added or removed from the part displayed in the 2D drawing (for example adding a slot to the part, or removing the ribs features). Subjects where instructed to pick with the mouse the 3D model considered to be the correct one. Each of the first five versions of 3D models was presented for maxim 25 seconds. If the user didn't make a selection, the trial is considered to be a failure. For the other five model used in the experiment, the 2D drawing was presented for maxim one minute and the 3D parts were presented for maxim 20 seconds. Half of the users first took the test using the traditional desktop system, then after a break of 10 minutes, they were asked to take the test using stereoscopic visualization system. Simultaneously, the other half of subjects first selected the correct 3D models by using stereoscopic system and then using monoscopic desktop system. There were used for the test different sets of CAD models. Each subject accomplished 20 trials. Log files recorded time stamps for the selected 3D part. This provided a task completion time (TCT) in milliseconds for each subject. The log files where used afterward for the assessment of the results. Before accomplishing the test, each participant becomes familiar with the system.

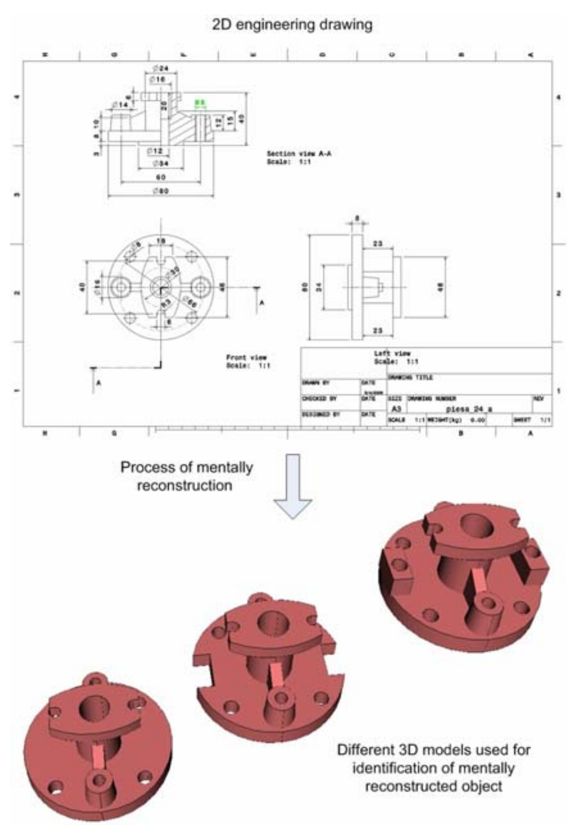

Figure 3. The process of mentally reconstruction and identification of a 3D model from a engineering drawing

IV. Results Evaluation

In Table 1, the mean of the correct answers from all the subjects that participated to the experiment is presented. The main reason of the significantly decreased accuracy might be the limited short term memory capacity of humans, which makes it difficult to choose between the three different 3D models, considering the 3D model that they constructed in the brain. There might occurs the situation when the mentally reconstructed 3d model is not the same with the visualized one. In this case, the used does not recognize the 3D object independently on the type of visualization (2D or 3D). When the time for visualizing the 2D drawing is increased to maximum 60 seconds, the accuracy is superior because the model could be comprehended better with the use of external working memory. Another significant result is that the stereoscopic 3D visualization does not considerable increase the recognition accuracy of imaged 3D models.

TABLE I. MEAN REACTION TIME OF SUBJECTS

Maxim time (s)	Accuracy monoscopic viewing	Accuracy stereoscopic viewing
25	43,20%	46,60%
60	56,60%	63,20%

Figure 4 presents the mean of the reaction time measured in the experiment. The analysis of these data indicates that monoscopic and stereoscopic 3D shape reconstruction involve similar methods and do not have major influence on the reaction time. The increased reaction time shows the complexity the engineer facing in the process of developing the product. The main cause might be due to the mentally manage of a large amount of information.

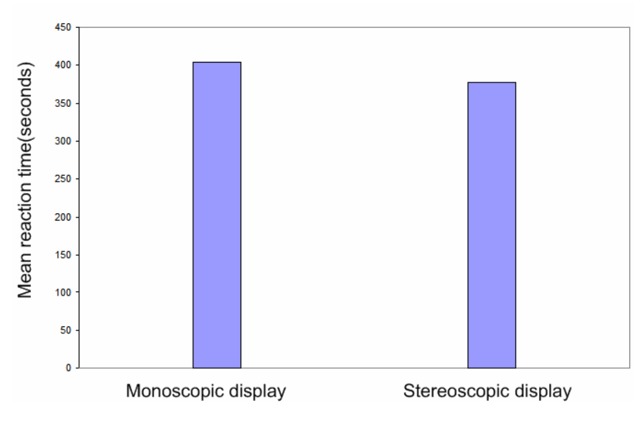

Figure 4. Mean reaction time of the subjects

V. Conclusion and Future Work

In the process of developing the product the engineer must mentally manage a large amount of important information which leads to high cognitive complexity. Available engineering drawings do not reduce the complexity that the engineer is facing or help him handle it. The 2D engineering drawings should be easy to use and should help the engineer manage the design-related complexity. The cognitive complexity can lead to a situation in which important design factors are not taken into consideration and this leads to failure.

From the conducted experiment, because of the reduced accuracy and the high reaction time, we can conclude that the user should visualize a three dimensional model of the part co-located with the 2D drawing.

Realistic perception of the 3D models from 2D engineering drawings plays an important role in decision making of design engineers. Recent studies [3], [4], [11] show that a system with a three dimensional representation of the model increases the performances of the users carrying out tasks which require the perception and understanding of spatial information. Unlike Virtual Reality (VR) systems, in which users are completely immersed in the virtual environment, AR users see the virtual objects and the real world co-existing in the same space (co-located). The co-location of the 3D CAD models in the real environment provides the possibility of a realist perception of the physical engineering drawing. Further work is focuses on the development of a new class of engineering drawings based on AR technologies. In Figure 5, a prototype of a developed Augmented Reality Engineering Drawing (ARTD) is shown. ARTD enhances the visual perception by co-locating the 3D virtual object with the corresponding engineering drawing and offers the quick recognition of the object with less perceptive ambiguities. This is an improvement for engineering applications where users must have a precise and direct appreciation of product shape.

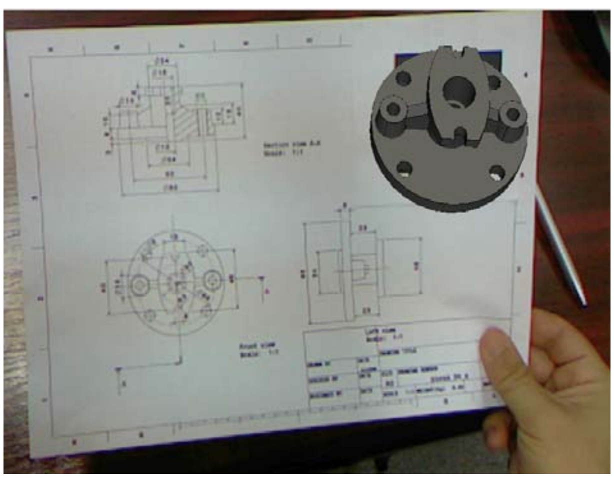

Figure 5. Augmented Reality Engineering Drawing prototype

ACKNOWLEDGMENT

The research activities where supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/89/1.5/S/59323.

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 ISBN: 978-1-61208-177-9