INTERACTIVE FOUR-BAR LINKAGE 3D-SIMULATION USING AUGMENTED REALITY

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Abstract

This paper presents a methodology to enhance an interactive simulation system using Augmented Reality (AR) in the field of teaching/learning dynamics. The 3D-simulation model is being developed as a first step in order to develop an interactive (AR) book for engineering students. The purpose is to illustrate the benefits of enhancing the computer-aided simulation (CAS) using augmented reality technology to improve three important factors in learning/teaching dynamics (Imagination, Thinking and Understanding). An experimental study is also performed to compare the learning experience and students' performance in using augmented reality simulation vs. Matlab simulation. The results of this study show that students can meet the given learning objectives by using both of the pervious methods. While in using the augmented reality simulation, the students' visualization and understanding in learning dynamics were improved and the outcomes of the learning process were increased.

Keyword - Augmented reality, Four-bar linkage, Mechanical engineering, Mechanisms, Computer-aided simulation.

1 INTRODUCTION

Because of the important improvements of simulation and modelling techniques in mechanisms and dynamics kinematics (MDK) some research have been conducted to overcome the problems of understanding and imagining dynamics kinematics. One of the reasons behind the lack of the understanding and imagining is the complexity of designing and modelling. This complexity arises because of the needs for defining many input parameters and/or interprets many output results. One of the important tools used for modelling and simulation is MATLAB developed by Math-Works. it used for modelling, simulating and analyzing dynamic systems. In addition we found 3D-max as one popular software which is used for modelling and simulation. It's a 3D computer graphics software for designing 3D animation models and images. It was developed and produced by Autodesk Media and Entertainment. It has modelling capabilities which can help in visualizing dynamics kinematics. 3D-max integrated with augmented reality technology to design the simulation model will be investigated in this study.

For the purpose of engineering education generally and for learning and understanding dynamics models specifically there are three important factors that must be taken into account: imagination, understanding and thinking. These factors should be improved in any teaching tool used in teaching such subjects and support them. The method in this paper merges the theory and the technology together in order to create a modelling environment. This could interpret the mating relations in assembling the linkage mechanisms. The simulation of the visible models might be assumed as the first step in improving the first two factors (Imagination, understanding) in the linkage dynamics.

However in the third factor (Thinking), the simulation should support the interactivity between the students and the visible models and the ability of controlling the equation constraints.

The simplification in developing and designing proper simulation for these mechanisms and dynamic kinematics boosted their usage in industrial maintenance, developing and understanding the machine theory. It will allow Teachers to prepare these realistic 3D mechanisms and dynamic kinematics models to explain the functioning of the complex mechanisms to be more effective in learners` achievements in this subject.

2 IMAGINATION, UNDERSTANDING AND THINKING

Imagination, Understanding and Thinking are considered as factors that affect learning dynamics subject. If you are studying engineering or geometry, sometimes you need to imagine the shapes or the objects in order to understand their behavior. So it is very important to discover the relation between these three factors, and in which way they can affect each other in one hand and how they can affect the learning outcomes in the other hand.

Imagination is the ability of creating mental images, sensations and concepts, at the moment when you are not able to perceive it through sight. Karen Hanson [1]. Defines it as “Imagination is what allows us to envision possibilities in or beyond the actualities in which we are immersed.” Imagination can be an important factor in the learning process, if we consider that the human mind is like the computer in which information is located for later processing. Egan [2]. writes: “This has been going on so long and so ubiquitously in schools that the meaning of learning that is most common is this kind of mechanical storage and retrieval." The question that must be asked here is: does the imagination help in the understanding process? Imagination helps to provide a meaning of the experience, and to understand the knowledge. Imagination gives ability to mentally visualize images and create a thing which has values. “It is a fundamental faculty through which people make sense of the world, and it also plays a key role in the learning process” [3].

Thinking is an important part of the educational process and is increasingly spreading as student’s progress goes through learning in schools, universities and graduate studies. Thinking can occur whenever learners need to solve a problem in general, or when they need to figure out what to believe or what to do. Thinking is "a way of taking up the problems of life." [4].

Imagination, understanding and Thinking again are three important factors in any learning process and there is no doubt that the deep impact of these factors in the outcomes of the learning process. In this research we believe that they have the greatest impact in learning the dynamics subject.

3 AUGMENTED REALITY (AR)

The basic goal of AR is to enhance the user’s perception of interaction with the real world. This achieved by supplementing the three-dimensional virtual object into the real world as shown in Fig. 3.1, This will give an effect as the real world is coexisting with the virtual world in the same space.

AR will truly change the way we view the world. Instead of putting the real object into the virtual environment, AR is pulling out the virtual object and integrates them into the real world environment. This action will further blur the line between what is real and what is computer generated object. This kind of technology will create countless applications ranging from the tourism application to the military application. The advantages of the AR capability will enhance the user perception of the real world [5].

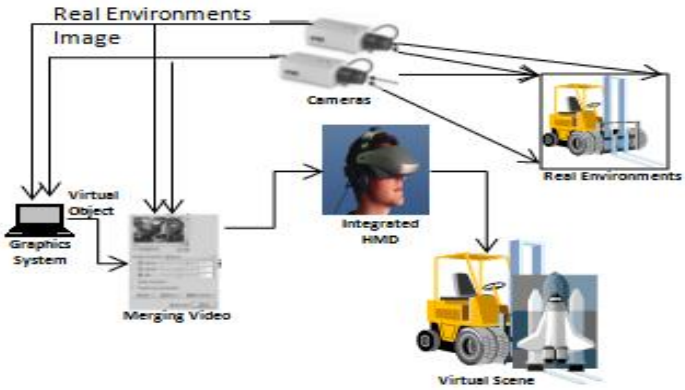

Figure 3:1 video see-through system

Augmented Reality as a tool or a supporting technology has been used in many scientific fields such as medicine, surgery, military, maintenance, robotics, and architecture. Also, there is an increasing interest in developing augmented reality applications for education purposes. One of the most recent projects in learning mathematics is CyberMath [6]. It's considered as avatar-based shared virtual environment aimed at improving mathematics education. the CyberMath project is suitable for exploring and teaching mathematics in situations where both the teacher and the students are co present and physically separated. For engineering education some research have been done to develop an augmented reality applications and tools that assist the engineering learning. F. Liarokapis presented an approach to enhance students' learning and understanding of digital design [7]. The system designed was based on augmented reality and XML metadata, and an XML integrated database system. Ildar developed an application for automotive engineering learning to teach students how to assemble and disassemble automatic vehicle transmission[8]. In addition to that and for the purpose of maintenance an augmented reality application to support military mechanics conducting routine maintenance tasks inside an armored vehicle turret were shown [9]. In another project, an efficient approach to robot grasping of randomly positioned and oriented objects by using a single camera was presented [10]. A merge between Matlab software in implementing the overall control scheme and ARtoolkit library was used for object location and orientation estimation.

For the purpose of multi body systems simulations Valentini used augmented reality technology to simulate a multi body system [11]. The project was used to illustrate how recent developments in computer-aided design and augmented reality can improve the realism and interactivity when simulating the movement of digital mock-ups

4 LINKAGE MECHANISMS

4.1 Definition.

Mechanical linkages can be defined as a series of rigid links connected with joints to form a closed chain, or a series of closed chains. Each link has two or more joints, and the joints have various degrees of freedom (DOF) to allow motion between the links as shown in Fig 4.1.

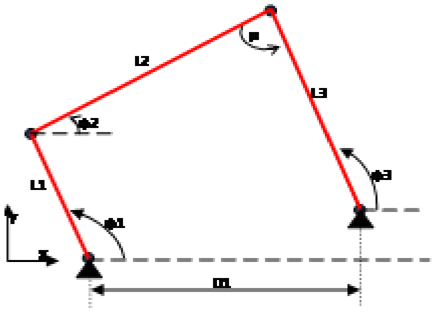

Figure 4:1 Four-Bar-Linkage Diagram.

A linkage is called a mechanism if two or more links are movable with respect to a fixed link. Mechanical linkages are usually designed to take an input and produce a different output. In the Four-Bar Linkage this input changes the behavior of the mechanism. According to Grashofs' Law [12]. We can determine whether there is a link that can rotate 360 degree or not. See Fig 4.2.

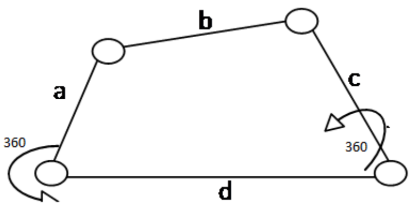

Figure 4:2 Graphical Representation of Grashof's Law

Grashof's Law: - "*If the sum of lengths of the longest and shortest links is less than the sum of lengths of the other two links, there must be a link that can rotate 360 degrees*".

When Grashofs' law is applied then four types of linkages as shown in Fig. 4.3. can satisfy Grashof's (Drag-Link, Crank-Rocker, Double- Rocker, and Parallelogram-Linkage) which they defined as Four Bar Linkages [13].

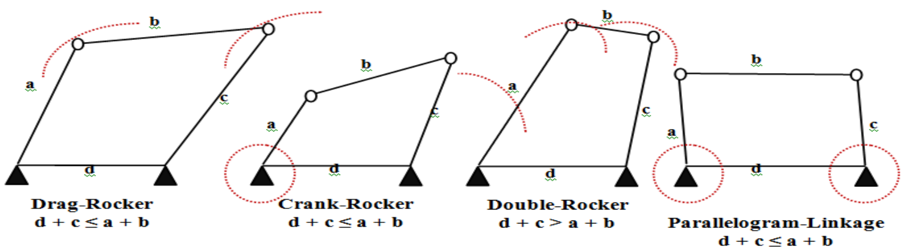

Figure 4:3 Mechanisms Type according to Grashof's Law

4.2 Algebraic Analysis

In Fig. 4.4. (a, b, c and d) represent the Linkages. (A and B) represent the Joint points. R1, R2, R3 and R4 represent the Vector loop. This mechanism satisfies the first condition of the Law where (a + d ≤ c + d) and the linkage (a) rotates 360 degree.

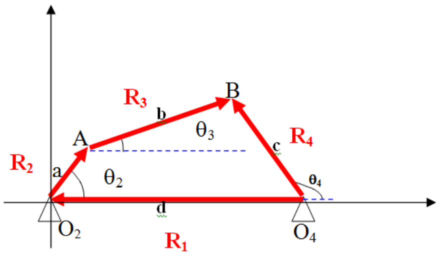

Figure 4:4 Linkages & Joints Graph.

By applying Grashof's law, we recognize that (a, b, c, d and θ2) are known variables, and based on the complex number theory [14]. we have :

$$\vec{R}_2 + \vec{R}_3 - \vec{R}_4 + \vec{R}_1 = 0$$

$$ae^{j\theta_2} + be^{j\theta_3} - ce^{j\theta_4} + de^{j\pi} = 0$$

The task now is to find the possible values of (θ3 , θ4). Back again to the definition of Grashof's mechanism theory, we have:

The Rule of Open and Crossed Grashof's mechanism: "*If $0 < \theta \leq \pi/2$ then the two links adjacent to the shortest link (crank) do not cross each other***".**

Now we can calculate the values of (θ4 and θ3) from the following equations see Fig. 4.5. The same equations will be used again in the MATLAB program in order to simulate the four bar linkage.

$\boldsymbol{\Theta}_4 = 2 * \tan^{-1}(\boldsymbol{\Theta}_2) * \left(\frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \right)$	$\boldsymbol{\Theta}_3 = 2 * \tan^{-1}(\boldsymbol{\Theta}_2) * \left(\frac{-E \pm \sqrt{E^2 - 4DF}}{2D} \right)$
$B = -2 * \sin(\boldsymbol{\Theta}_2)$	$F = K_1 + (K_4 - 1) * \cos(\boldsymbol{\Theta}_2) + K_5$
$C = K_1 + (K_4 + 1) * \sin(\boldsymbol{\Theta}_2) + K_3$	$D = \cos(\boldsymbol{\Theta}_2) + K_1 + K_4 * \cos(\boldsymbol{\Theta}_2) + K_5$
$K_1 = \frac{d}{a}$	$E = -2 * \sin(\boldsymbol{\Theta}_2)$
$K_2 = \frac{d}{c}$	$K_4 = \frac{d}{b}$
$K_3 = \frac{a^2 + b^2 + c^2 + d^2}{2ac}$	$K_5 = \frac{c^2 - d^2 - a^2 - b^2}{2ab}$

Figure 4:5 Equations of movable angles (θ3 and θ4).

5 SIMULATION OF FOUR-BAR LINKAGE MECHANISMS USING MATLAB AND AUGMENTED REALITY

This section explains the technique used in simulation of the elementary of 4BL using both Matlab and Augmented Reality. The model is simulated in 2D using Matlab and in 3D using Augmented Reality.

5.1 Matlab Simulation.

The final result of the crank Rocker motion using Matlab simulation is shown in Figure 5:1.

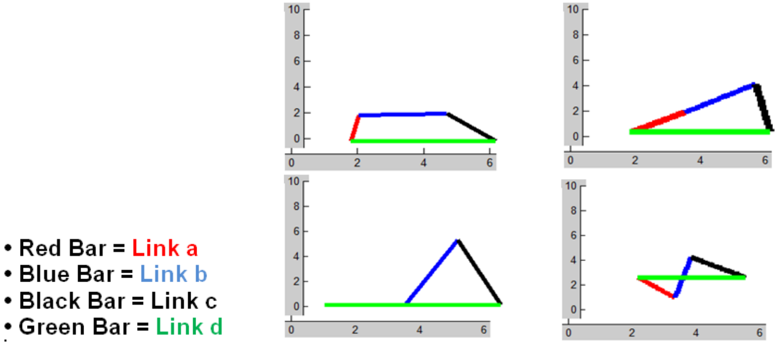

Figure 5:1 motion simulation of the Crank Rocker using Matlab

5.2 3D-Max Modelling

This section deals with simulating the dynamics of the Four Bar mechanism. The aim of this simulation is to show the construction and the dynamics of the four bar linkages mechanism. It allows learners to visualize the four types of the mechanism (Crank-Rocker, Double Rocker, Drag-Link and parallelogram-Linkage). Learners, can also select, rotate, move and scale any of these above listed types. A 3D model for each type was constructed by 3D-max modelling software as shown in Fig. 5.2. The reason of choosing it is the capability of this 3D-max in modelling and designing 3D-models. Furthermore it allows direct manipulation of one or more primitives at their given pivot point. The following Figures show the types of the four bar linkage designed by 3Dmax.

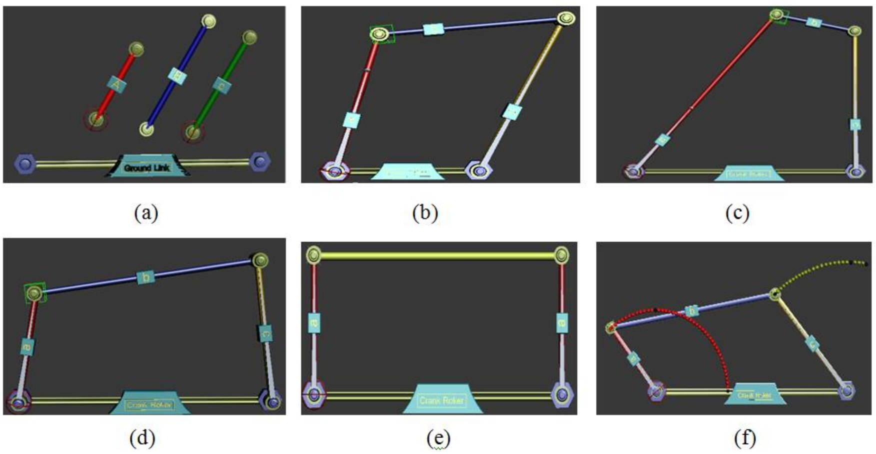

Figure 5:2 (a) Linkage Parts; (b) Drag-Link; (c) Double-Rocker; (d) Crank-Rocker; (e) parallelogram-Linkage; (f) Dynamics of the Crank-Rocker.

5.3 Creating the AR Scenes Using ARmedia

This section shows the process used in creating the Augmented Reality Scenes for each type of the four bar linkage mechanism, for this purpose AR-media™ Plug-in is used [15]. With AR-media™ Plug-in users can experiment the power of Augmented Reality. AR-media™ Plug-in allows users to visualize their 3D creations directly in the real physical space which surrounds them. The 3D models can be visualized out of the digital workspace directly on users' desktop or in any physical location by connecting a simple webcam and by printing a suitable code.

For the simulation interface a normal book used as the main interface objects. Learners can turn the pages of the book, look at the pictures, and read the text without any additional technology as shown Fig. 5.3.a. However, if they look at the pages through an Augmented Reality display or by holding the printed marker in front of the PC-Camera, they see three -dimensional virtual models appearing out of the pages as shown in Fig. 5.3.b. The models appear attached to the real page so users can see the AR scene from any side simply by rotating the book in any direction. The model can be resized, scaled and rotated in 360 degrees. Animation can be paused or replayed in any time as shown in (Fig. 5.3.c and Fig. 5.3.d). The analysis of the dynamics could be done as shown in Fig. 5.3.e. The AR view enhances learners with the scenes by the interactivity with the three-dimensional objects popped up over the book. By turning the pages of the book learners can view and interact with the different types of the linkage Mechanisms as shown in Fig. 5.3.f.

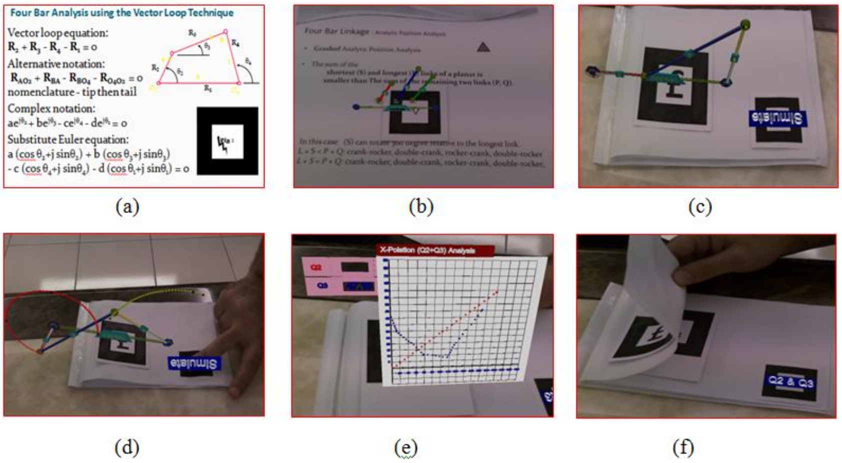

Figure 5:3 (a) Book Pages; (b) AR scenes; (c) view one; (d) view two; (e) dynamics Analysis; (f) changing the page.

6 METHODOLOGY, RESULTS AND DISCUSSIONS

The main objective of this research is to compare the effectiveness of the use of augmented reality 3D-simulation against the use of Matlab simulation in terms of (imagination, Understanding and Thinking) in the subject of teaching/learning dynamics, and how it can affect on the learning outcomes. The simulation of the four bar linkage has been done using both augmented reality and Matlab. A sample set of 30 mechanical engineering students were chosen from Tenaga National University, Malaysia, interviews and a survey was conducted with mechanical engineering students and teachers from the same college. The experimental study was carried out randomly as the selected students were divided into two groups; one group was exposed to use Matlab simulation, while the other group was aided with 3D-simulation using augmented reality.

Hypothesis 1 (H_1) - There is no significant difference in using 3D simulation using augmented reality against Matlab simulation in terms of Understanding the subject of learning dynamics between the first group (X1) and the second group (X2).

Table 1 Understanding Analysis

Variable	Mean	SD[a]	Sig. (2 tailed)[b]

[a] Standard deviation is a widely used measure of variability or diversity. It shows how much variation or "dispersion" exists from the average (mean, or expected value).

[b] The two-tailed test is a statistical test used in the process of drawing conclusions from data subject to random variation.

X1	**1.2333**	**1.00630**	**0.58**
X2	**1.3000**	**1.11880**	**0.58**

In general, the understanding test indicates that students from both groups are at the same level of understanding the dynamics subject whereby the mean score difference between X1 and X2 is just 0.0667. The significant (2 tailed) value (P) is 0.58 which is greater than α = 0.05. This indicates that there is no difference in the mean scores of understanding the dynamics subject for both groups, and the null hypothesis for Hypothesis 1 (H1) is therefore accepted.

Hypothesis 2 (H_2) - There is no significant difference in using 3D simulation using augmented reality against Matlab simulation in terms of Imagination of the subject of learning dynamics between the first group (X1) and the second group (X2).

Table 2 . Imagination Analysis

Variable	Mean	SD	Sig. (2 tailed)
X1	**6.8000**	**1.91905**	**0.00**
X2	**8.8333**	**1.23409**	**0.00**

The above table shows the results of imagination test. X1 group of students scored comparatively lower as compared to the X2 students result in the Imagination of the dynamics test with the mean score of 6.8000 and 8.8333, respectively. The differences in performance between both groups are statistically proven as the significant (2 tailed) value of p=0.00 which is lesser than α = 0.05. The null hypothesis H2 is rejected. This indirectly indicates that there is a significant difference in students' performance in term of Imagination the dynamics between X1 and X2 groups. Based on that statistical finding, it can be concluded that there are some improvements in average students mark after using the 3D-simulation using augmented reality. This indirectly supports what we need to prove from this research.

Hypothesis 3 (H_3) - There is no significant difference in using 3D simulation using augmented reality against Matlab simulation in terms of Thinking of the subject of learning dynamics between the first group (X1) and the second group (X2).

Table 3 Thinking Analysis.

Variable	Mean	SD	Sig. (2 tailed)
X1	5.5000	2.08029	0.00
X2	7.6000	0.89443	0.00

The above table shows the results of the thinking test. The student's score in X1 group is lower than the student's score in X2 group, the mean score is 5.5000 and 7.6000 respectively. The different in performance between both groups are statistically proven as the significant (2 tailed) value of p=0.00 which is lesser than α = 0.05. As in the previous hypothesis. H3 hypothesis also will be rejected which indirectly indicates that there is a significant difference of students' performance in term of Thinking about dynamics. As a conclusion there are some improvements after using the 3D-simulation using augmented reality. which again indirectly may supports what we need to prove from this research.

7 CONCLUSIONS AND FUTURE WORKS

The usage of new technologies could provide the students with better ways to solve engineering – related problems which sometimes may be difficult to be understood from the textbook. The four bar mechanisms discussed in section four are difficult to be explained to some engineering learners. Alternatives methods such as 3D-Simulation needed to help in the (imagination, understanding and thinking) process.

The result of the experimental study shows that the students who used the 3D-simulation using augmented reality scored significantly higher than the students who learned the topic by conventional teaching method. The result also indirectly reflects the effectiveness of the use of 3D-simulation to improve the (imagination, understanding and thinking) of the students when studying dynamics. In addition, the experimental study also indicates positive acceptance from the students for using 3D-simulation in learning dynamics.

For the future work. There are still rooms for improvement before gaining maximum learning outcomes in the subject of learning\teaching dynamics. More work should be done on the interactivity between the learners and the simulated model. The improvements of the Interactions can concern with both; the (boundary conditions and initial parameters) and control real time simulation. The solution of the dynamics equations has to be computed in real time in order to enable communication between the user and the scene.

REFERENCES.

[1] Hanson, Karen. (1988). “Prospects for the Good Life: Education and Perceptive Imagination”. In K. Egan and D. Nadaner (Eds.), Imagination and Education. New York: Teachers College Press.

[2] Egan, K. (1992). “Imagination in Teaching and Learning”. Chicago: University of Chicago Press.

[3] Jossey-Bass, San Francisco, 2005. “An Imaginative Approach to Teaching”, CA. ISBN 0-7879-7157-X.

[4] Sumner, William (1906). Folkways: “A Study of the Sociological Importance of Usages”, Manners, Customs, Mores, and Morals. New York: Ginn and Co.. p. 633.

[5] Azuma R.T., 1997, “ A survey of augmented reality”, Teleoperators and Virtual Environments”, 6, 4, 355-385.

[6] G. Taxén and A. Naeve, "CyberMath: Exploring Open Issues in VR-based learning”, SIGGRAPH 001 Educators Program, vol. SIGGRAPH 2001 Conference Abstracts and Applications, pp. 49-51, 2001.

[7] F. Liarokapis, N. Mourkoussis, P. Petridis, S. Rumsey, P. F. Lister, M. White, “An Interactive Augmented Reality System for Engineering Education”. 3rd Global Congress on Engineering Education Glasgow, Scotland, UK, 30 June - 5 July, 2002.

[8] Ildar Farkhatdinov, Jee-Hwan Ryu, “Development of Educational System for Automotive Engineering based on Augmented Reality”, School of Mechanical Engineering, Korea University of Technology and Education, Cheonan, Korea. 2006.

[9] Steven J. Henderson Steven Feiner, “Evaluating the Benefits of Augmented Reality for Task Localization in Maintenance of an Armored Personnel Carrier Turret”. IEEE International Symposium on Mixed and Augmented Reality 2009 Science and Technology Proceedings 19 - 22 October, Orlando, Florida, USA 978-1-4244-5419-8/09/$25.00.

[10] Bojan Nemec , “Robot Grasping Using an ArToolKit Library”. Electrotechnical Review, Ljubljana, Slovenija. Elektrotehniˇski vestnik 77(1): 69–74, 2010.

[11] Pier Paolo Valentini and Eugenio Pezzuti, “INTERACTIVE MULTIBODY SIMULATION IN AUGMENTED REALITY”. JOURNAL OF THEORETICAL AND APPLIED MECHANICS 48, 3, pp. 733-750, Warsaw 2010.

[12] F. C. Moon, “History of the Dynamics of Machines and Mechanisms from Leonardo to Timoshenko”, International Symposium on History of Machines and Mechanisms, (H. S. Yan and M. Ceccarelli, eds.), 2009. doi: 10.1007/978-1-4020-9485-9.

[13] B. Kempe, “On a general method of describing plane curves of the nth degree by linkwork”, Proceedings of the London Mathematical Society, VII:213-216, 1876.

[14] Hartenberg, R.S. & J. Denavit (1964), “Kinematic synthesis of linkages”, New York: McGraw-Hill, online link from Cornell University.

[15] http://www.inglobetechnologies.com/en/new_products/arplugin_max/info.php. last update July 2011.