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A Data Visualization Virtual Environment Supported by Augmented Reality

Claudio Kirner, Member, IEEE; Tereza G. Kirner

***Abstract* — The increasing dissemination of information demands new techniques to represent and visualize data, so that the user can understand information sets to support decision-making in a fast and adequate way. This paper presents the DATAVIS-AR, a Virtual Environment for Data Visualization that incorporates Augmented Reality, which allows graphics to be superimposed over scenes from the real world. The main benefits of DATAVIS-AR is that the user can manipulate (put, delete, arrange and configure) graphics in the real world, enabling the detailed understanding of the considered data sets and contributing to improve the decision-making. An application example representing the traffic of vehicles in a Toll Plaza is given and the results are discussed.**

I. INTRODUCTION

Information Visualization provides an association between two very powerful information-processing systems: the human mind and the computer. Visualization refers to the process of transforming data, information and knowledge in a form of visual presentation, susceptible to be easily interpreted. Through efficient visual interfaces, people can work with large volumes of data, in a fast and effective way, aiming to discover characteristics, patterns and tendencies that, at first, would not be identified. Such interfaces are essential in the current society, in which it is necessary to manipulate increasing amounts of information, including complex data for decision-making [9], [14], [25].

Information Visualization is responsible for mapping groups of data, many times available in a text-based format (such as textual descriptions, numeric information shown in tables, etc.), representing them in a visual format, aiming to support the users in the exploration and understanding of such data [7], [10]. The presentations, in these cases, tend to be more attractive, concise, and user-friendly.

Nowadays, the quality of information visualization systems and tools has been improved substantially, due to advanced three-dimensional representations, combined with techniques for incorporating color effects, texture, light, etc. Additionally, there are several information visualization systems that use virtual reality, as those discussed in Kirner [14]. Virtual reality is considered, according to Myers [19], a very powerful tendency in the development of human-computer interfaces.

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C. Kirner and T.G. Kirner are with the Graduate Program in Computer Science at the Methodist University of Piracicaba, Rodovia do Açucar, Km 156, 13400-911 - Piracicaba – SP, Brazil (e-mail: ckirner@unimep.br; tgkirner@unimep.br).

Virtual reality allows the expansion of the visualization possibilities, breaking the barrier of the computer screen. With virtual reality, an infinite three-dimensional space is provided, in which graphics can be inserted and through where the users can navigate and interact.

The main characteristics of virtual reality environments refer to the levels of interaction, immersion and navigation propitiated to the users [15], [23]. However, navigation and interaction in virtual environments require a certain training and familiarity with nonconventional devices, which can restrict the use of information visualization systems based on virtual reality [16]. To overcome that difficulty, a virtual environment for supporting information visualization using resources of augmented reality was developed,

Augmented reality is a technology that uses virtual reality to improve and supplement the real environments with virtual, computer-generated objects [16]. According to Azuma [2], [3], an augmented reality-based application has the following characteristics: it combines real and virtual objects in a real environment; it runs interactively, in real time; and it aligns real and virtual objects with each other, through some special devices, such as head-mounted displays. A simple example is to use a web cam to capture a scene, in which the virtual objects are added, showing it in the computer screen.

The DATA VISualization virtual environment using Augmented Reality (DATAVIS-AR), here described, enables to add virtual objects (representative data graphics) to the real environment, which can be explored by the users. In this case, data that were traditionally described by tables can be modeled and shown in a very interesting, interactive way, propitiated by virtual reality and augmented reality. In a virtual environment using augmented reality, it is possible to perform actions as, for instance, to "put" an imaginary vase on a real table or "construct" a virtual bridge over a real river. Otherwise, these virtual environments can also be supplemented through the inclusion of real elements, as people or objects, configuring what it is called as "virtuality." Augmented reality and virtuality are part of an application category known by mixed reality [3], [20].

This article focuses on the DATAVIS-AR, a tool for data representation based on three-dimensional discrete graphics. Section II introduces the data visualization, pointing out aspects of representation and interaction with the graphics. Section III gives an overview of the DATAVIS-AR. Section IV stresses the use of augmented reality, including illustrative examples. Section V explains the main implementation issues. In section VI, the use of the tool is exemplified in the data visualization of vehicle traffic in toll plazas. Finally, the concluding remarks are presented in section VII.

II. DATA VISUALIZATION AND REPRESENTATION

The fact of being easier to the people analyzing graphic representations than manipulate data in text-format reinforces the impact of visualization in cognitive subjects. Consequently, the cognition, associated to the acquisition and use of knowledge, has its focus more oriented to the objective than to the meaning of visualization [5]. Thus, the objective of visualization is the perception and understanding of the contents that enable the discovery, decision-making, and explanation of data shown in a visual format.

A. Data Visualization

Visualization is normally based on physical data and, since it deals with abstractions, they are related to physical spaces. Nonphysical information, as, for example, financial data, can get benefits from visual representations, although they do not present an obvious mapping of space. The usefulness for the cognition results from a good visual representation of the problem and from its interactive manipulation, which lead people to use their inherent capacities of visual perception.

Information visualization can be defined, in general terms, as "the use of visual and interactive representations of abstract data, supported by computer, aiming to amplify the cognition" [13].

The type of visualization more adequate for each situation is related to the data representation. Schneiderman [22] defines a taxonomy composed of seven types of information visualizations: one-dimensional, two-dimensional, three-dimensional, multidimensional, temporal, hierarchical and networked. The proposed taxonomy is adopted in several studies (see [5], [13], for instance) and assumes that users are viewing collections of items, which have multiple attributes. In all seven data types, the items have attributes and a basic search task is to select all items that satisfy values of a set of attributes. The first four types are characterized as spatial types and the other three ones are the structural types. The spatial types are especially interesting for data visualization supported by virtual and augmented reality, as focused on this paper.

B. Data Representation

Data representation aims to present the information to the user, in a simple and synthetic way. A very common example of achieving that is through three-dimensional discrete graphics with multiple attributes, such as bars charts disposed in the space and complemented with visual elements and animations.

The visual elements include forms, dimension (width, depth and height), color, shade, transparency, color pulsation (frequency), etc. The animation elements show the variations of the graphics (or of part of them), in a certain time interval and with a pre-defined speed or timing variation rate.

Visual elements give a static notion of the data situation, but they can also incorporate a vision of the recent history and tendencies, when they are associated to some Mathematics dynamic functions. Sound resources are more used as warning, or to call the attention for special or non typical occurrences, so that the user can notice the fact that is occurring, even if he is analyzing another section of the graphics [8]. Sound is particularly useful in virtual reality applications, since the warning event can be out of the user's field of view. Sound can suggest the user to inspect the critical data.

The animated elements allow the data evaluation in a dynamic way, enabling to visualize the behavior of its data into periods of time [21].

Although most information visualization systems focuses exclusively on the visualization itself, in windows or through three-dimensional navigation, the interaction with the representation of the data is becoming important, once it can improve the applications, optimizing the analysis and the decision making by the user. In this way, graphics can be mapped in certain areas, subject to the interaction with the user, supplying additional information or executing specific actions. Visual limits with minimum, maximum, error-prone regions, etc., can be inserted or modified graphically by the user.

Those interaction characteristics can be incorporated to systems implemented as traditional applications (two-dimensional environments) or three-dimensional applications, used in virtual reality and augmented reality [3], [4], [10].

III. VIRTUAL ENVIRONMENT FOR DATA VISUALIZATION

The DATAVIS-AR is an interactive data visualization tool, which was developed as a virtual environment and incorporates virtual reality and augmented reality. Its purpose is to support the data analysis, by providing graphical representations of large amounts of data from specific applications. One of its outstanding features is the interactivity, that is, the user can configure the system so that it can work automatically, under the monitoring and even the intervention by the user.

In the version with virtual reality, the user should use special visualization and interaction devices (data glove, head-mounted display, joystick, etc.) to take him/her into the computer generated virtual environment. For this, the user normally needs some training with the devices and, since with this training, he user can have difficulties during the navigation through the system. The necessity of devices and the navigation and interaction difficulties impose limitations on the successful use of the system.

The version with augmented reality intends to overcome the problems of the virtual reality, by means of a kind of tangible multimodal interfaces. In this case, the virtual environment is projected in the physical environment of the user, where he/she can work without the special devices and does not need training for that. These interfaces can be implemented by means of computer vision, using cameras and mixing real and virtual scenes in the computer monitor or head-mounted display. In some cases, it is necessary to put a small marker in the user hand, to make the tracking easier.

Although the user work space is more limited with augmented reality than with virtual reality, the advantages provided by a more natural interface is very interesting and prevail over the application using virtual reality.

The DATAVIS-AR is structured into the modules of Configuration, Database, Control, and Rendering. These modules are interrelated to an Acquisition System and to Application Tasks from a specific domain, and the results are sent to a Display. The user interacts with the tool and receives the displayed results. Figure 1 gives an overview of the tool.

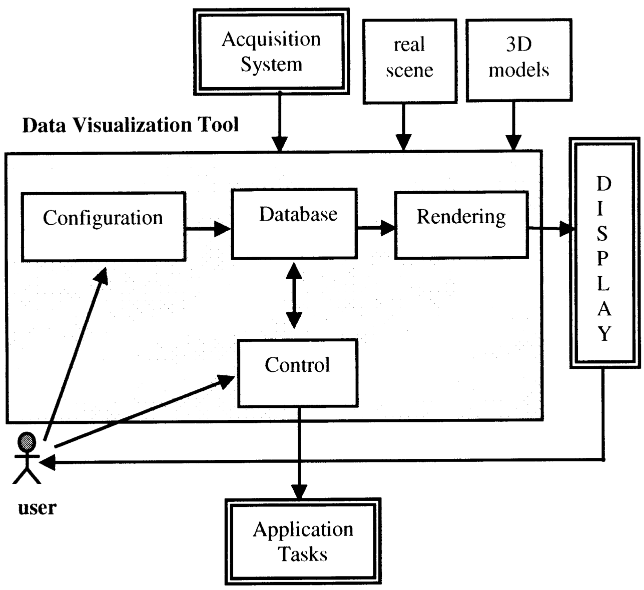


Fig. 1. Overview of the DATAVIS-AR

The functioning of the DATAVIS-AR é summarized as follows.

- An Acquisition System sends continuously data to the Database, which is able to update and maintain the received data.
- While the Database receives the data, it is also tracked by the Control module, which analyses the data concerning to constraints and decision factors, and also triggers the required action commands.
- In a similar way, the Rendering module tracks the Database, to prepare the images that will be displayed.
- Aiming to adjust the Database, the user interacts with the Configuration module, which enables the definition of constraints and the upgrading of decision factors. In this way, the user is able to adjust parameters related to the visualized graphics.
- Additionally, the user can interact with the dynamic images that he visualizes, by means of special operations. These operations actuate on the Control module and trigger action commands to the Application Tasks module. In this case, the user can select some graphics and click on them to generate an action. An interesting alternative is to use the hands tracked by a web cam to select the graphics and commands, aiming to generate actions on the selected elements, using gesture, voice and devices.
- Besides the values received from the Acquisition System, the Database also receives parameters sent by the user (through the Configuration module) and other important data sent by the Control module. This occurs, for example, with parameters such as values of minimum and maximum established by the Configuration module, as well as with the variation rate of the historic data (obtained with basis on the derivate) generated by the Control module. As a result, the graphic is shown using colors, shadows, pulses, sound, etc.

Figure 2 shows a virtual environment representing a toll plaza. In the illustration 2c, each row corresponds to an approach lane of the toll plaza, including a non-stop lane. The lines indicate the period of time in which the traffic has been measured.

IV. Use of Augmented Reality

The DATAVIS-AR was experimented by putting virtual graphics in the real world, that is, on a plate in the user's hand. This was implemented by the ARTOOLKIT [1] and the use of a web cam. The ARToolkit, developed at the University of Washington, comprises a set of libraries for the development of Augmented Reality applications. It provides computer vision techniques to calculate the camera position and orientation relative to marked cards, so that virtual three-dimensional objects can be overlaid precisely on the markers.

In the DATAVIS-AR, the objects overlaid are toll plaza 3D models and the bar charts represent application data sets, which are taken from the virtual environment. Thus, when putting the plates, with the marker in the field of vision of the web cam, the system puts the toll plaza models and the graphics on the plates, that can be inspected by the user. Besides, the user can interact with the graphics in the screen, selecting each one and defining their limits.

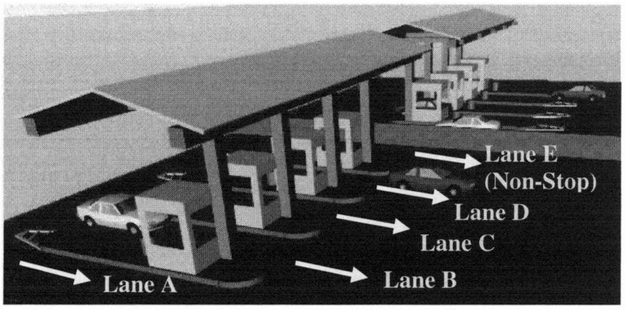
As the system recognizes several different marks simultaneously, it was possible to build a board to contain several plates, so that each plate contains a portion the whole graphic. Like this, the user can see the group, catch a part of the graphic and move it, change the place of graphic portions, and substitute, eliminate or include new portions of the graphic. Such functionality is illustrated in the Figure 4.

The characteristics of the DATAVIS-AR are useful in the execution of several classes of interactive applications from the real world, such as:

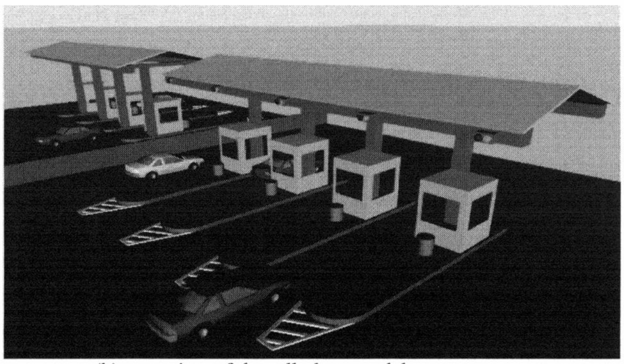
- Monitoring of pollution elements that can exist in the water of rivers and lakes.
- Monitoring of temperature, volume, pressure, and other parameters in industrial process-control systems.

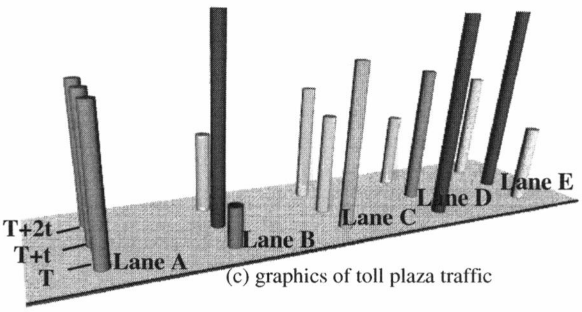
In such applications, it is possible to visualize the real world scenes, captured by video cameras and, after that, in the virtual environment, overlap the graphics showing specific parameters from the application that are useful for the users. In this way, the user can detect exception situations and actuate on the items of the graphic, by using some interaction procedures, and including the triggering of necessary actions. Those actions can involve the capture of historic or updated data, the activation of actuators, the visualization of details of some portion of the graphic, the execution of tasks related to the application, etc.

Figure 3 shows: (a) a marker, (b) an object being visualized, and (c) a plate in the user hand with a graphic on it.



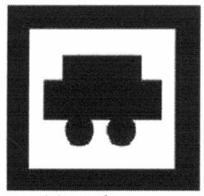
(a) overview of the toll plaza model with annotations

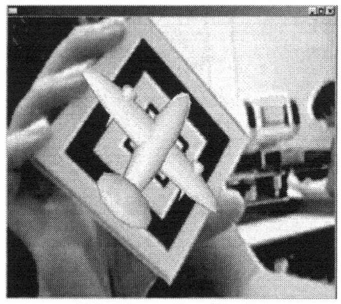

(b) overview of the toll plaza model



(c) graphics of toll plaza traffic

Fig. 2. Visualization in virtual reality of the toll plaza


(a) marker


(b) object visualization

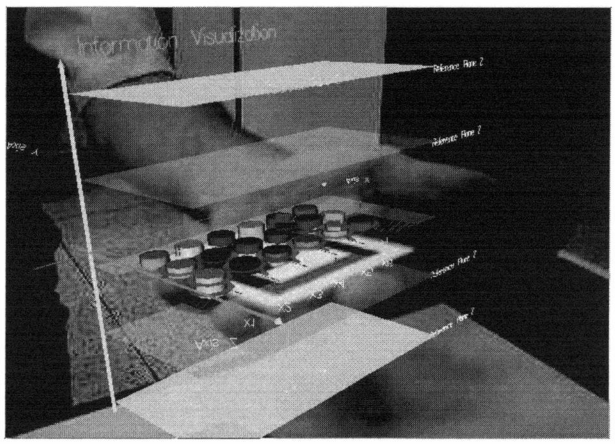

(c) graphic visualization

Fig. 3. Visualization in the DATAVIS-AR

V. IMPLEMENTATION ISSUES

The virtual environment was implemented in VRML - Virtual Reality Modeling Language [6], [12], [18], including three-dimensional toll plaza models and bar charts that can be explored by interaction, immersion, and navigation. The manipulation interface was developed in HTML - Hyper Text Markup Language [11], and Java Applets and JavaScript [17], which make possible the system to work on the Internet. The integration between Java and VRML was implemented by the EAI - External Authoring Interface [24].

The DATAVIS-AR provides the dynamic visualization of data sets in the user space, as is shown in Figure 4. This is due to the augmented reality facilities that permit the three-dimensional visualization of the bar charts of 3D objects from the toll plaza in real space, captured by the web cam. In this case, the bar charts are also updated through consults to the database and the real-time rendering of the graphical images over objects of the real scene, like a plate.

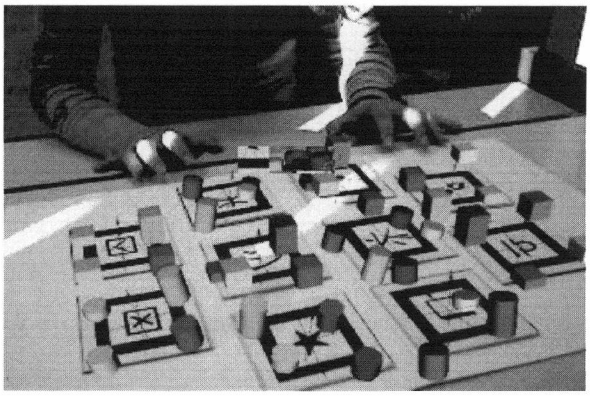
To achieve the intended functioning of the DATAVIS-AR, it was necessary to make some alterations in the ARToolKit and also to develop a VRML code editor.

The ARToolKit loads and allocates the VRML code (the scene graphs) in the system, showing the virtual object when the respective marker appears in the view space of the web cam. As the graphic is dynamic (it is continuously updated by the database), it was necessary to modify the VRML code and load it again.

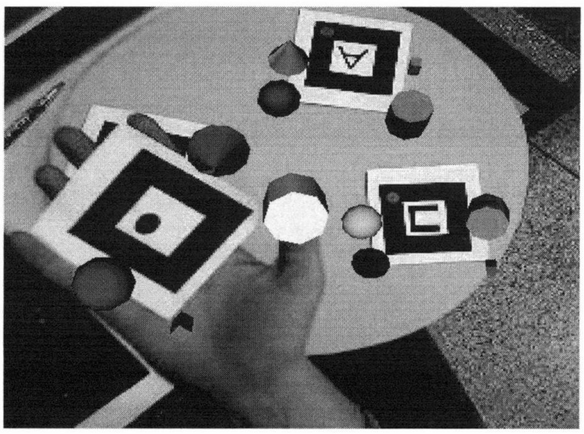
To modify the code, the user inserts comments preceded by index (##1, ##2, etc.) in the VRML code, indicating the lines that could be changed with new parameters (see Figure 5). The commented index ##r*i* indicates the code line with parameters that must be updated and replaces the code line by the respective commented index ##*i*. When the data arrive from the database to the text editor, it identifies the lines to be modified, updates the parameters, changes the VRML code and saves it.

To make possible the graphic alteration in the system, some modifications in the library *arvrml.lib* were performed. The *reload* function of the VRML code was created, and some alterations in the *simplevrml.cpp* were implemented, in order to activate the *reload*. In this sense, the system is able to receive data, modify the VRML code, and activate a new rendering on the marker plate.

As the editor can modify every line on the VRML code, any graphic characteristic can be modified, such as position, dimension, color, animation, etc.



(a) graphics assembled with parts



(b) graphics over a plate

Fig. 4. Graphics visualization with augmented reality

```
#VRML V2.0 utf8
# This is an excerpt of the graphic VRML code
# ...
   DEF dad_Group5 Transform {
##1 This marker point indicates that the position below
##   will be changed by external data
    translation -10 0 0
    children [
# …
# Lines to be changed with new values (v) replacing
# the originals
##r1
#    translation v1 v2 v3
# …
```

Fig. 5. Portion of VRML code with alteration indexes

VI. Example of Data Visualization in a Toll Plaza

The main goal of the DATAVIS-AR is to enable the user to interact with the visualization process, through the manipulation of the marker of the ARToolKit, using the hands in front of a web cam. This makes possible to any people to choose what he/she is interested to show and also to interact with the visualization without have to act directly in the computer.

Toll plazas elsewhere produce delays, waste energy, pollute the environment, reduce roadway capacity, and degrade safety of traffic operations. These potential problems lead to the development of the data visualization application described as follows.

The application is concerned with the data visualization of vehicles traffic in toll plazas, located in roads of São Paulo State, Brazil. For this, the following objects and sceneries were modeled through the DATAVIS-AR and associated to markers: (a) Map of São Paulo State and of its main roads; (b) Toll plaza; (c) Visualization graphics related to the traffic of vehicles, in periods of time, on the lines of the toll plaza, including the visualization of previous periods of measurement.

The user can configure the visualization, by selecting markers and putting them on the table in front of the view area of the web cam, as is shown in Figure 6. First, the user put the marker of the State map, which does not become visible in the visualization because it remains covered by the three dimensional state map. Then, the user adjusts the marker of the road map to put it correctly over the state map. After that, the user chooses the toll plaza he wants to visualize, putting it in the adequate position. Finally, the user selects the marker of the traffic of vehicles, adjusting it so that the graphic appears on the toll plaza. It is important to point out that all the objects associated to the markers were previously allocated in appropriate positions, to avoid superimposition.

The database is continuously updated with the data collected in the toll plaza through the data acquisition system. During the rendering, the graphics that are visible (which markers are in the view area of the web cam) are updated every time that any updating occurs in the database. To achieve this functionality, two resources were implemented: an automatic VRML code editor, commanded by the database, and an alteration in the ARToolKit software, aiming to provide the redraw every time there is an updating.

Figure 6 illustrates the data visualization in a toll plaza.

The data visualization of vehicles traffic in toll plazas, above described, is indicated for engineers, planners, and supervisors involved. Several benefits can result from this application, such as: (a) improvement of the process of data visualization, by the use of a very interactive process, involving the users; (b) analysis of delays, throughput, and interference of traffic conditions; (c) identification of impacts to changes in the configuration of a toll plaza; (d) evaluate plans for repaving or other construction activities so that plans may be identified which minimize the disruption to traffic during construction; (f) assistance in the design of better toll plazas, including toll collection schemes; etc.

Besides, the resulting reduction in traffic overload will provide energy and environmental benefits, as well as economic benefits achieved from probable lower costs for transportation of goods and services.

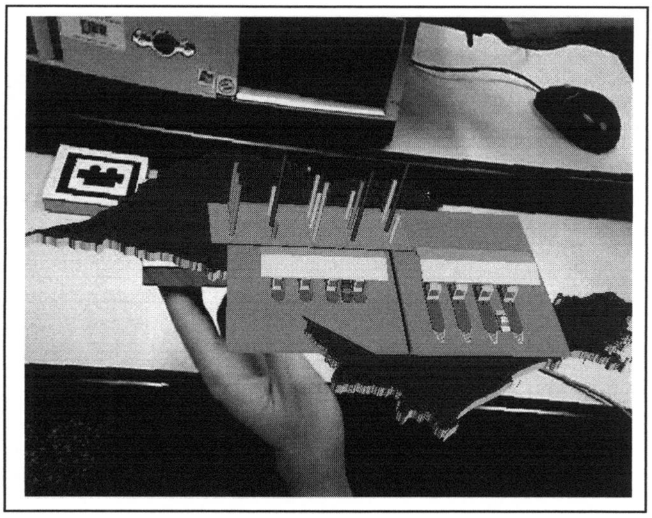


Fig. 6. Data visualization in a toll plaza

VII. Conclusion

Virtual reality offers many resources for information visualization, particularly for visualization of great volumes of data, because it does not impose space limits for the exploration of the represented data.

However, the interaction with virtual reality requires familiarization and training for navigating through the virtual worlds and using the special devices.

Augmented reality contributes significantly to the establishment of a user-friendly and natural interaction with the visualization environments. That allows the overlapping of images captured by video cameras with images generated by computer, making easy the analysis and the interaction with the graphics and exploring the cognitive aspects, related with the understanding of the information.

This article focused on the information visualization, presenting a data visualization tool, in virtual reality and supported by augmented reality. The incorporation of augmented reality to the system was explained, as a form of optimizing the interaction with the data graphics.

The data visualization tool here presented can be useful to a broad range of applications, whenever it is necessary to obtain and analyze great volumes of complex data, to support decision-making. Particularly, the data visualization of traffic of vehicles in the Toll Plaza, presented in section 6, has several potential advantages, which can result in environmental and economic benefits.

As foreseen extensions, there are ongoing studies that seek new interaction techniques controlled by the user's hands and by voice, which will make the interaction with the system more natural. Besides, new effective uses of the DATAVIS-AR in real applications have been prioritized.

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References

[1] ARToolKit – Augmented Reality Tool Kit. HITLab, University of Washington. <http://www.hitl.washington.edu>

[2] Azuma, R. A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments. V.6, N.4, Aug. 1997, pp. 355-385.

[3] Azuma, R. et al. "Recent Advances in Augmented Reality." *IEEE Computer Graphics and Applications, v .21,* n.6, 2001, p. 34-47.

[4] Belcher, et al. "Using Augmented Reality for Visualizing Complex Graphs in Three Dimensions." Proceedings of the Second IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'03), Tokyo, Japan, Oct. 2003, p. 84-92.

[5] Card, S.K., Mackinlay, J.D., Schneiderman, B. Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann Pub., 1999.

[6] Carey, R., Bell, G. The Annotated VRML 97 Reference Manual." Addison Wesley Longman, 1997.

[7] Carlis, J.V, Konstans, J.A. "Interactive Visualization of Serial Periodic Data." Proceedings of the IEEE Symposium on Information Visualization, 1999, p. 29-38.

[8] Franklin, K.N., Roberts, J. "Pie Chart Sonification." Proceedings of the Seventh International Conference on Information Visualization (IV'03), London, England, July 2003, p. 4-9.

[9] Gershon, N.D., Eick, S.G. "Information Visualization Applications in the Real World." IEEE Computer Graphics and Applications, July/August 1997, p. 66-70.

[10] Gershon, N.D., Eick, S.G., Card, S. "New Visions of Human-Computer Interaction." ACM Interactions, March 1998, p.8-15.

[11] *Graham, I The HTML Sourcebook: A Complete Guide to HTML. 2nd Edition ,* John Wiley & Sons, 1996.

[12] Hartman, J., Wernecke, J. The VRML 2.0 Handbook, Addison-Wesley, 1996.

[13] Keim, D., Hao, M.C., Dayal, U. "Hierarchical Pixel Bar Charts." IEEE Transactions on Visualization and Computer Graphics, v.8, N.3, July/Sep. 2002. p.255-269.

[14] Kirner, T.G., Martins, V. F. "Development of an Information Visualization Tool Using Virtual Reality." Proceedings of the 15th ACM Symposium on Applyed Computing - SAC'2000, Como, Italy, March 2000, p. 604-607.

[15] Kirner, C., Pinho, M.S. "Introduction to Virtual Reality." Short Course, JAI/SBC, Recife, PE, 1996 (in Portuguese).

[16] Kirner, C., Calonego Jr, Buk, C., Kirner, T.G. "Data Visualization in Augmented Reality Environments." Proceedings of the 1st Workshop on Augmented Reality, Piracicaba, SP, Brazil, May 2004, p. 45-48 (in Portuguese).

[17] Lea, R.; Matsuda, K.; Miyashita, K. Java for 3D and VRML Worlds. New Riders, Indianapolis, 1996.

[18] Morcrette, C. VRML Generation Tools for Visualization of Database Content in Three Dimensions. Master Dissertation, Massachusetts Institute of Technology, 1998.

[19] Myers, B.A., Hollan, J., Cruz, I. "Strategic Directions in Human-Computer Interaction." ACM Computing Surveys. v. 28, n. 4, p. 794-809, December 1996.

[20] Milgram, P. et. al. "Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum." Telemanipulator and Telepresence Technologies, SPIE, V.2351, 1997, p. 282-292.

[21] Nakakoji, K., Takashima, Yamamoto, Y. "Cognitive Effects of Animated Visualization in Exploratory Visual Data Analysis." Proceedings of the Fifth International Conference on Infomation Visualization (IV'01), London, England, July 2001, p. 77-84.

[22] Shneiderman, B. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. Technical Report CS-TR-3665, University of Maryland College Park, 1996.

[23] Vince, J. "Introduction to Virtual Reality." Springer-Verlag, 2nd edition, 2004.

[24] VRML – Proposal for a VRML 2.0 Informative Annex – External Authoring Interface Reference. <www.vrml.org/WorkingGroups/vrml-eai/ExternalInterface.html>.

[25] Warwick, K., Gray, J., Roberts, D. "Virtual Reality in Engineering." London, IEE, 1998.