Visualization Tools for Robotics Education

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Abstract:

Robotics typically involves several objects interacting in motions that are sometimes hard to visualize without having a well-equipped robotics laboratory. Computer graphics display rendering of objects in motion an inexpensive, safe, and interactive visualization tools to assist in Robotics education. In recent years software and hardware tools have been developed in connection with the rise and development of the Internet, including several programming tools that allow easy visualization, 3-dimensional rendering of objects in motion, and virtual reality scenes. It is now possible to develop low cost, realistic-looking, virtual robots and observe their motions on a computer display from a variety of different view points. This article presents and discusses the implementation of interactive computer visualization tools for robotics analysis, design, and education.

Keywords: Visualization, Robotics, Education, Virtual

Introduction

Visualization techniques have proven to be of great educational value and help reduce analysis and study time while allowing deeper understanding of the material under study. Advances in computer technology, hardware and software, and especially in computer graphics and modeling, now allow easy development of visual tools to assist in the learning process, the analysis of systems, and in the understanding of complex processes.

The National Geographic web site, for example, offers an interactive Virtual Reality Solar System [1] where users can navigate to any point in the solar system and examine every planet, moon, and their orbits, and even the asteroids all at a click of a computer mouse button.

In robotics, virtual reality scenes and computer graphics techniques help illustrate robot manipulator modeling, kinematics, end-effector trajectories, robotic collisions, and in general, provide invaluable assistance in robotics education. RobotDraw, a robot manipulator modeling software, developed by the author and his students is available on the internet [2]. RobotDraw generates a virtual reality 3D model of a robot manipulator using only a Denavit-Hartenberg model [3] description entered by the user. The RobotDraw software and its uses in engineering education are also presented and discussed in [4].

Current robotics textbooks include only drawings and pictures of robots and robotic tasks and trajectories [5][6][7] in their description of robotic motions and processes. This article, some elements of which were discussed in [8], presents interactive visualization tools that can be used alone or in support of a textbook for effective robotics education. Besides education, the tools described here are also useful in the design and analysis of robotic systems.

Virtual Reality Modeling Language (VRML)

VRML [9][10] is an efficient programming language for generating virtual reality objects and scenes. It allows programmers to generate 3D objects that can be animated and viewed on any computer using an internet browser equipped with a VRML viewer plug-in. Graphical VRML programming tools are also available that greatly facilitate the synthesis of virtual reality scenes. One such tool used by the author is Spazz3D [11]. VRML viewers [12][13] are available free of charge and work well with Internet-Explorer[TM] or Netscape[TM] browsers. The ability of browsers to display VRML programs is particularly useful feature since no additional software is required. A VRML viewer typically presents a scene on a computer display along with viewing tools that allow the user to rotate, pan, move, or animate objects at the touch of a button.

**Developing Visualization tools for Robotics**

The interactive visualization tools operate by accepting input values from users through a graphical user interface developed using a visual language such as Visual Basic, Visual C++, or any other object and graphics oriented language. The main program then creates a VRML file description of the visualization tool and inserts the user supplied values where necessary to create the desired virtual reality display and interactive animation which is then passed to the internet browser for viewing.

Visualizing Robot Motion: Virtual Puma560 Robot

As an example of visualization tools for robotics, a Virtual PUMA560 interactive animation allows users to examine the individual joint motions and the overall end-effector trajectory in space on their computer displays. This animation was developed to assist students in the understanding of robot modeling, direct and inverse kinematics, joint motions, trajectories, and workspace limitations.

Figure 1 shows the virtual Puma560 robot in its home position where all the joint variables are zero. Figure 2 shows one possible graphical user interface for using the Virtual PUMA560 arm. In this interface, users can enter a starting joint configuration and an ending joint configuration. The visualization program then generates a VRML program that displays the virtual PUMA560 robotic arm and allows the user to activate any individual joint separately by clicking on its link, or animate the whole robot at once by mouse-clicking on the robot base. The animation will move the robot from its initial to its final configuration. On the Virtual Reality Puma, each link serves as a trigger for the joint that immediately precedes it. For example, a mouse click on the robot gripper will animate the rotation of the last joint $\theta 6$ from the de4sired initial value (0 in Figure 2) to its final value (60° in Figure 2). The robot base serves as a trigger for all the joints and a click on the robot base will move the robot from its initial configuration to its final configuration as entered by the user in the GUI of Figure 2.

In an illustration of inverse kinematics, users can enter inverse kinematics solutions and verify that they do indeed provide a desired end-effector pose. The virtual PUMA560 will also readily show which joint configurations are physically realizable and why some theoretical inverse kinematics solutions cannot be achieved, for example, when they result in robot links colliding with each other.

Figure 1. Virtual Puma 560 home position
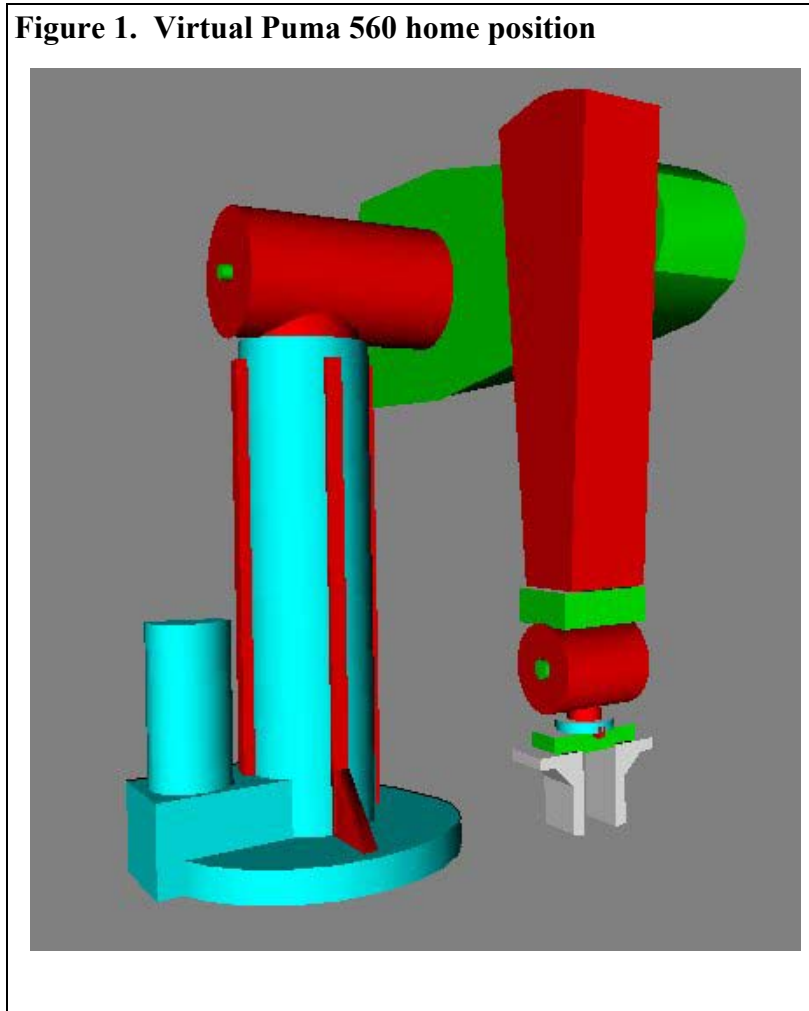
Understanding Robot Modeling

In robotics education, students must learn to mathematically model robots. When introduced to Denavit-Hartenberg modeling techniques, it is useful to visually assess the effect of each DH-parameter. The first interactive computer visualization tool described here offers students the ability to enter and modify DH-parameters and immediately visualize the effect on a Virtual Reality scene. Interested readers can download the DH-Animation visualization tool from [12].

Figure 2. Graphical User Interface
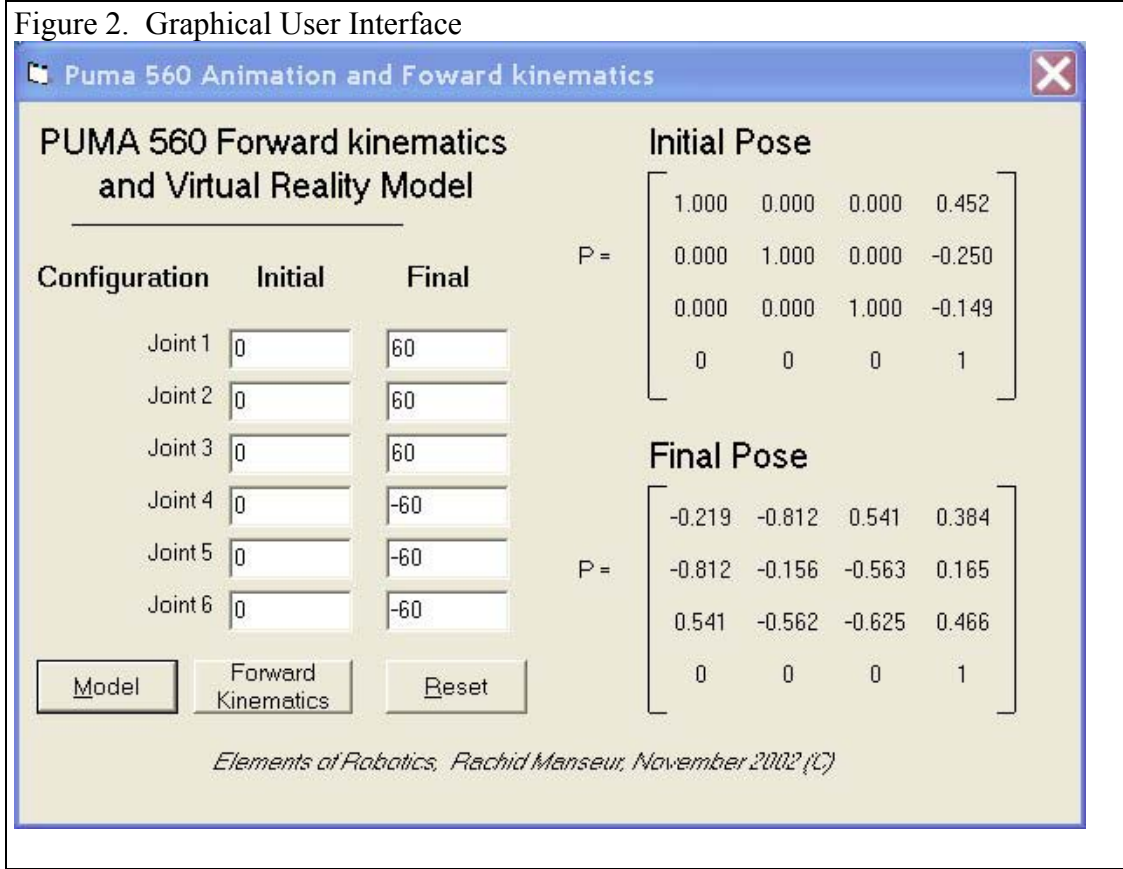
The DH-parameters, well explained in [2][5][6][7], are routinely noted d_i, a_i, α_i, and θ_i and they describe the location of a robot link-frame F_i from a preceding link-frame F_{i-1} though the sequence of translations and rotations

$$F_{i-1}: \xrightarrow{Trans(z,d_i)} \xrightarrow{Rot(z,\theta_i)} \xrightarrow{Trans(x,a_i)} \xrightarrow{Rot(x,\alpha_i)} F_i \qquad (1)$$

which leads to the homogeneous frame transform $^{i-1}A_i$ given by:

$$^{i-1}A_i = Trans(z,d_i)\ Rot(z,\theta_i)\ Trans(x,a_i)\ Rot(x,\alpha_i) = \begin{bmatrix} c_i & -\gamma_i s_i & \sigma_i s_i & a_i c_i \\ s_i & \gamma_i c_i & -\sigma_i c_i & a_i s_i \\ 0 & \sigma_i & \gamma_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

where the short-hand notation $c_i = \cos(\theta_i)$, $s_i = \sin(\theta_i)$, $\gamma_i = \cos(\alpha_i)$, and $\sigma_i = \sin(\alpha_i)$ is used.

Figure 4 shows a series of images of the computer displays generated by this interactive animation tool.

A click on the button labeled Start_VR computes the elements of the homogeneous transform matrix according to Eq. (2) and generates a VRML scene for the visualization of the four transformations that form the basis of DH-modeling as listed in Eq. (1). The VRML simulation starts with a red (fixed reference frame) and four control objects associated with the four

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transformations corresponding to each of the four DH-parameters. Rectangular boxes always represent triggers for translations and cylinders always trigger rotations.

The following sequence of events will generate the series of transformations of Eq. (1):

1. A mouse click on the blue control box activates a translation of distance d along the z-axis. A green (mobile) frame will be translated from the original red (fixed frame) as shown in Figure 2-b where a value d=1.5 was used.

2. A click on the blue cylinder causes the green frame to rotate by an angle θ about the z-axis as shown in Figure 2-c for an angle θ=60°

3. Clicking on the green box translates the green frame a distance a along its own x-axis. In Figure 2-d, the value a=1 was used.

4. A mouse click on the green cylinder then rotates the green frame by an angle α about its x-axis. Figure 2-e was obtained for α=90° and shows the green frame in its final location as described by the DH-parameters d, θ, a, and α entered by the user.


Figure 3: GUI for DH-Visualization
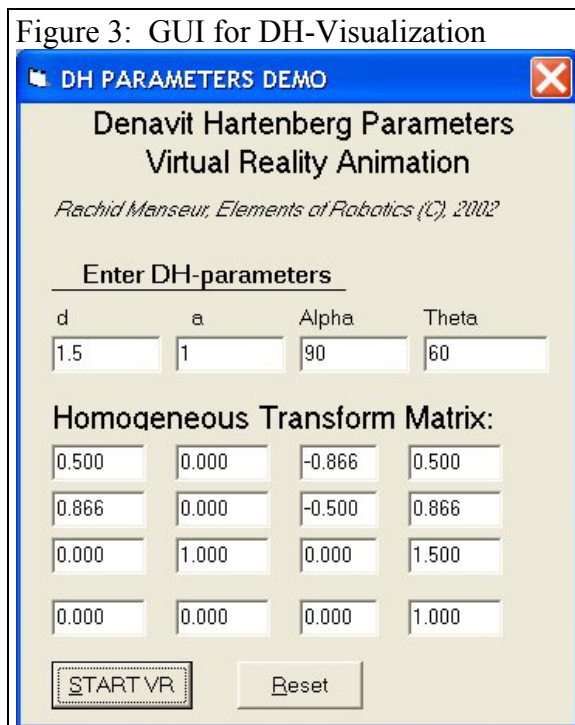
Users can run this interactive visualization software several times and with different DH-parameter values to understand how each DH-parameter affects the location of the green frame.

Conclusion

Recent advances in computer graphics hardware and software tools associated with the rise and establishment of the Internet make it possible to easily develop 3D graphics, visualization, and interactive animation tools that can be viewed and interacted with on any personal computer. This article presents visualization tools for robotics developed using the Virtual Reality Modeling Language (VRML) to illustrate robotics concepts and help students achieve a better understanding of robotics, 3D motions, and processes. An interactive virtual reality visualization tool for DH-parameters and robot modeling is presented as an example of such tools. The creation of 3D models permits also more involved visualization tools and possibly the development of virtual robotics laboratories. A Virtual Reality PUMA 560 Robotic arm that can be animated from an initial joint configuration to a final one as entered by the user is presented as another example of the effectiveness of visualization tools in robotics. These tools represent a technological advance in engineering

education and, in robotics, offer the ability to visualize 3D motions at will on a computer display. It is hoped that more educators and researchers in all fields of human knowledge will develop similar tools in the future.

Figure 4. Visualization of DH Frame transformations
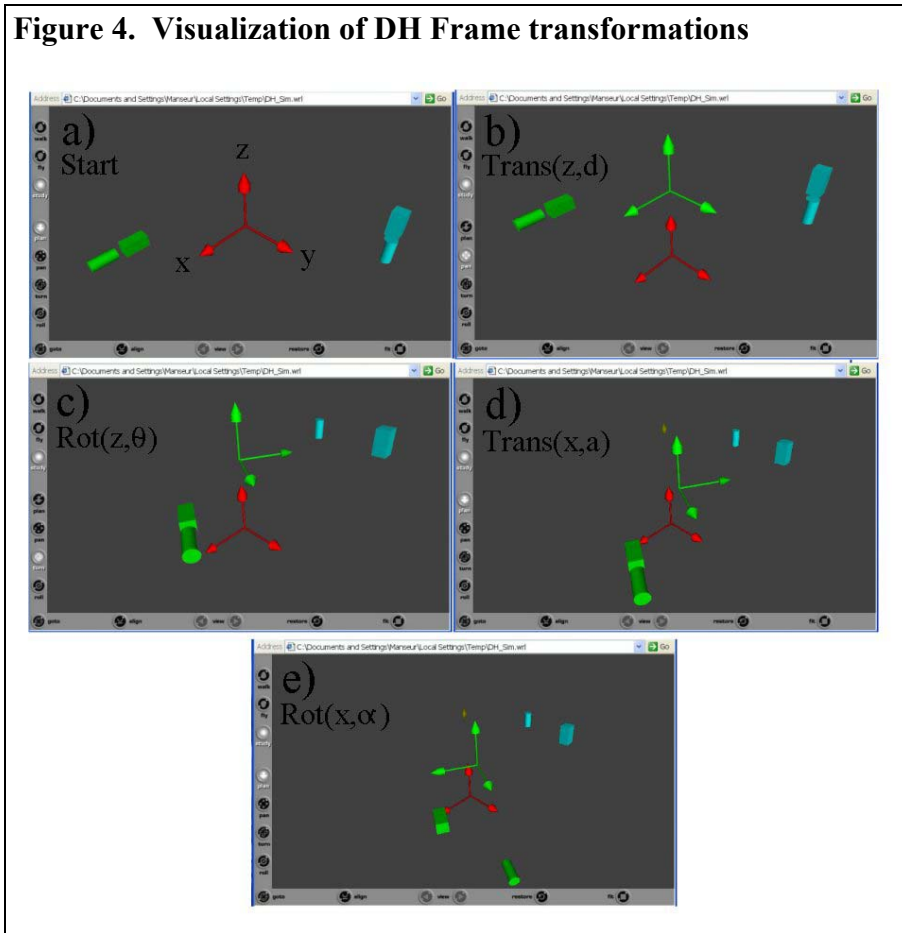
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