Augmented Reality and Artificial Intelligence for Learning Spatial Transformations

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Abstract

We use augmented reality (AR) and artificial intelligence (AI) to improve student's understanding of spatial transforms. Specifically, we use AI to generate an AR overlay for physical manipulatives (such as a LEGO® airplane) which allows students to view the associated rotation matrices and translation vectors in real time. Students can then use this real time overlay to confirm their mathematical intuition about spatial transformations.

Spatial Transformations in STEM

Spatial and mathematical thinking are closely allied. Understanding coupled spatial transformations and mathematical concepts significantly contribute to STEM learning in fields of geometric modeling, computer graphics, computer-aided design (CAD), computer vision, robotics, video games, quantum mechanics, and more. A solid understanding of these concepts have enabled developers to overcome problems such as,

- gimbal lock was a problem in NASA's Project Apollo.
- inverse perspective transformation in the visual odometry process determined the position and orientation of Mars Exploration Rovers.
- control of an object's location and orientation in a video game, or more generally, computer graphics.

Motivation for Using AR and AI in the Teaching of Spatial Transformations

It is well known that students have trouble with spatial reasoning in 3D geometry and its algebraic description. The study of spatial transformations through linear algebra provides opportunities for students to build intuition about the relation between translations and rotations of a physical object and their mathematical description using

- directions, distances traveled, and Euler angles of rotations.
- rotation matrices and translation vectors.
- quaternion transformations.

Our team's belief is that the use of haptic and proprioceptic sensation in combination with AR and associated AI will enhance the learning of geometrical transformations and their mathematical representations. Current results leave room for further exploration on the use of geometric visualization and haptic and proprioceptive feedback in teaching and learning linear algebra, so this project seeks to assess the unique potentials of AR and AI in learning linear algebra.

Overview of the Application

Using Figure 1 as a reference, we will outline the basic functions available within the application. Firstly, there are two main workshops available to students; the first workshop enables students to virtually rotate the LEGO model and view its projection on the screen. The second workshop enables students to rotate the physical model and view the associated mathematical objects for each rotation. Students have a variety of options to section from to aid in their learning,

- Axis: Users are able to choose between tracking the degrees of rotation about the X, Y, and Z axes. This angle is reflected on the screen in various places including the formula for associated rotation matrices.
- 2D and 3D: To aid younger students in learning we have found it helpful to add the 2D option for simpler rotation matrices. Planned workshops plan to utilize this feature by observing how rotation matrices change as an object follows a path on a flat surface.
- Degrees and Radians: Students are able to select how they wish to measure rotation; having physical intuition for how radians describe rotation can serve as a useful introduction to the concept for some students.
- Model and Axis: Students may choose to show or hide the wire-frame model and axis markers to provide the preferred level of visual clarity.

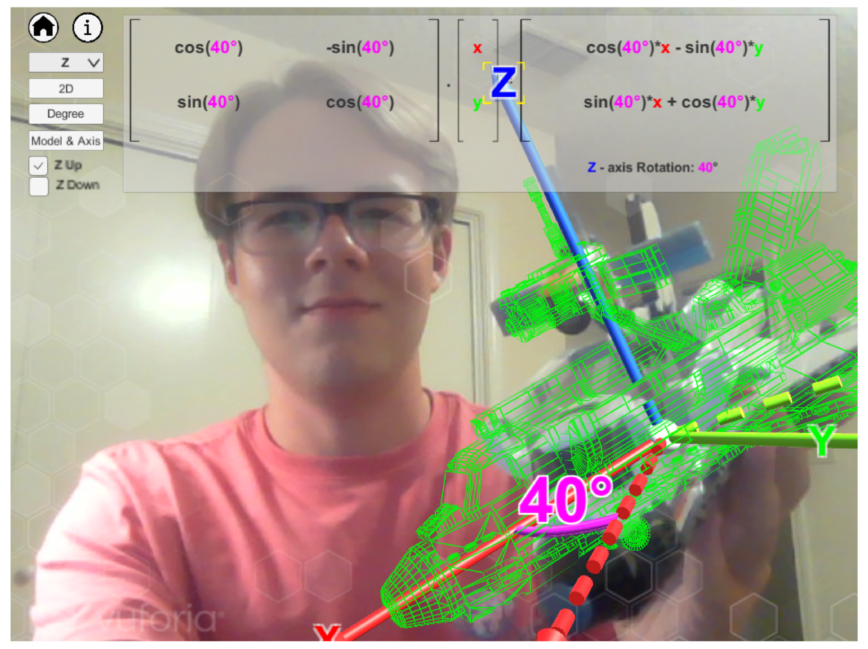

Fig. 1: Example view from within the application

The matrices corresponding to various rotations are displayed on the top of thescreen; we utilize matrix/vector notation to provide a compact visual interface, as well as introducing students to a potentially new mathematical concept. This application is built off of the AI platform Vuforia which allows the program to recognize and understand the rotations of objects through computer vision. Then, we apply an AR overlay using the data achieved through Vuforia.

Usability Testing

While developing the application we have let students interact with many development builds to improve the interface and usability of the application. In the figures below (Fig. 2, 3) we have photos of our most recent usability test with middle school aged students.

Fig. 2: A View of the Classroom Setup with Students

Fig. 3: The Added Game Feature for Students

On the left (Fig. 2), we have a photo of the typical classroom setup. And on the right (Fig. 3) we have a photo of one of the students working with one of the more recent features; one of the workshops we have added is a game which has students point their manipulative towards a certain rotation matrix. Upon pointing in this direction with sufficient precision, an animation plays. The goal of this is to keep students engaged in learning through more game-like elements.

Geogebra Applets

In addition to the work in augmented reality, we have developed some Geogebra applets to assist in the process of learning rotations. Additionally, the techniques learned in developing these applets are being used to integrate Geogebra with the AR program.

$$T(\vec{x}) = \begin{pmatrix} -\sqrt{2}/2 & -\sqrt{2}/2 & 0 \\ \sqrt{2}/2 & -\sqrt{2}/2 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \sqrt{2}/2 & 0 & \sqrt{2}/2 \\ 0 & 1 & 0 \\ -\sqrt{2}/2 & 0 & \sqrt{2}/2 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \sqrt{2}/2 & -\sqrt{2}/2 \\ 0 & \sqrt{2}/2 & \sqrt{2}/2 \end{pmatrix} \vec{x} + \begin{pmatrix} 2 \\ 1 \\ 1 \end{pmatrix}$$

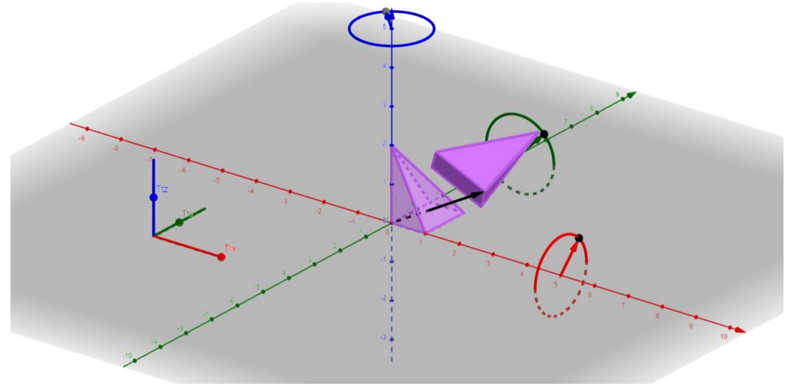

Fig. 4: Geogebra applet to learn rotation and translation matrices in 3D with example transformation

In the figure above (Fig. 4), students are able to rotate a pyramid in X-Y-Z order and impose a translation on the shape. Because the restriction on the order of rotation about the axes is somewhat counter-intuitive for many students, there is also a version which allows for any arbitrary number of rotation about any axis in any order.

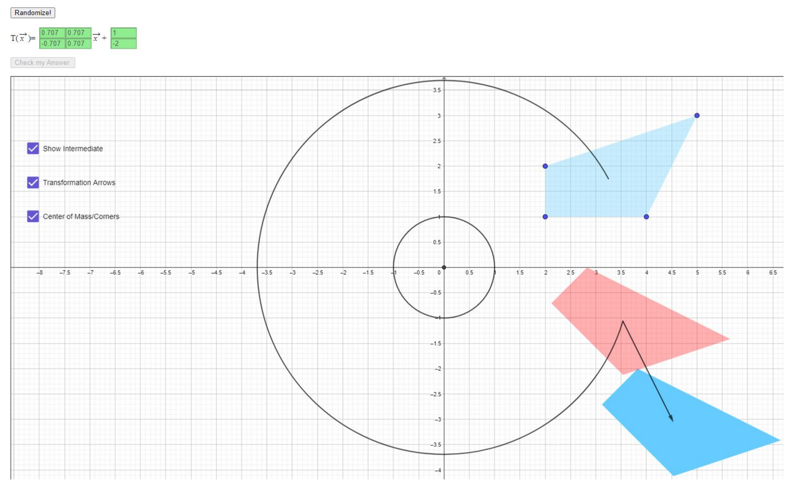

Fig. 5: Geogebra applet to quiz students on their understanding of rotation and translation matrices in 2D

In the figure above (Fig. 5), students are able to view a random rotation and transformation and then work backwards to obtain the original matrix. This allows students to gain hands-on insight into fundamental theorems regarding matrix transformations; namely, the action on the plane is uniquely determined by the action on the basis vectors.

All of these applets are available here:

`http://people.tamu.edu/~prestontranbarger/1/geogebra/`

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2119549.