INTRODUCTION
Although it may not be apparent, our ability to perceive the world is greatly dependent on the movement of our eyes; this sets biological visual systems apart from cameras. Our eyes are constantly in motion, both to stabilize the visual image on the retina and to move the fovea to objects of interest using fast saccadic eye movements. Even though much is known about oculomotor physiology [2], many aspects of the mechanics of the eye, its musculature, and how it is controlled remain poorly understood (e.g., see [1] for a taste of the current controversies). Our goal is to construct a geometrically accurate robotic eye that can serve as a platform for understanding how the human oculomotor plant works. Understanding the tight integration between how we move our eyes and what we perceive is critical to understanding how certain diseases or injuries affect vision as well as to finding potential solutions for treating these conditions. Furthermore, we hope to obtain insights from biology that may aid the future development of robotic eyes.

METHODS
Our design decisions have primarily focused on creating an eye model that incorporates aspects of the anatomy that are functionally important for understanding the oculomotor system. Thus, the eye robot has 3DOF (yaw, pitch and roll) and is driven by 6 DC motors (Amax-25, Maxon Motor AG) through low friction dyneema cables (a HMPE fibre). The DC motors represent muscle actuation while dyneema cables represent the 6 extraocular muscles. The globe’s natural orbital support is emulated by a custom designed, low friction gimbal structure that supports the eye on the anteroposterior axis at the back of the globe, where there is no tendon interference. Moreover, we have used the Buckingham II theorem (i.e., dimensional analysis) to scale the geometric and dynamic properties of the biological eye according to the model’s specified dimensions and inertia. Lastly, to confirm the functionality of the eye and to verify that the initial design requirements have been satisfied, we have implemented a controller design to drive this robot.

RESULTS
Figure 1 illustrates the final design of the robotic eye. An important aspect of gimbal design is the sequence of rotations it implements. Since a gimbal forms a serial kinematic chain, the proximal axes of rotations have larger inertia than the distal ones. Thus, since the most common eye movement is yaw, our gimbal implements pitch, followed by roll, with yaw as the final rotation. The acceptability of the eye system for emulating oculomotor behaviors was evaluated by assessing 3 main characteristics of the robotic eye.

DISCUSSION & CONCLUSIONS
We have developed a novel 3 DOF tendon-driven model of the human eye and a corresponding controller for driving this redundant system. The presented robotic eye focuses on creating a physical model that incorporates several key aspects of the anatomy that are functionally important for using this model as a testbed for evaluating oculomotor control theories. However, in addition to a geometrically correct robot, a physiologically accurate system must also incorporate a biologically-inspired control algorithm, which is left as future work.

REFERENCES