VOXOGRAM: A 3D Volumetric Hologram

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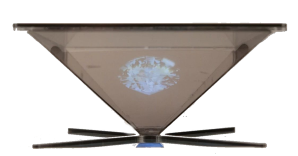
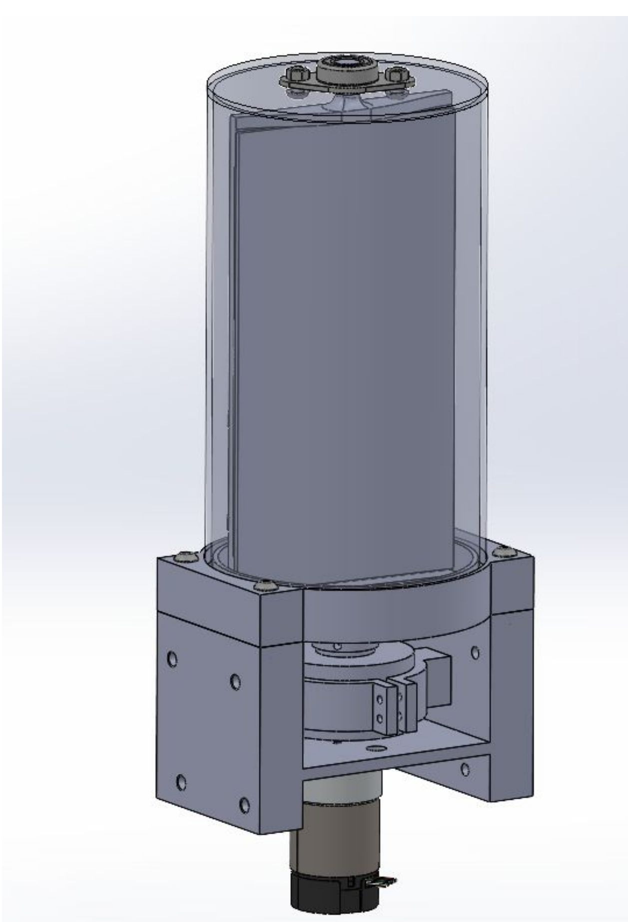
Motivation & Project Objective

Currently, many technologies exist that allow 3D content to be visualized and consumed. Existing solutions include 2D screens to view 3D content, 3D glasses and AR/VR headsets [1]. However, they do not allow for multiple observers viewing from different angles simultaneously.
The objective is to create a display technology that can output 3D content using a rapidly rotating LED display, allowing for multiple simultaneous viewers at any angle.

Existing Solutions & Our Advantage

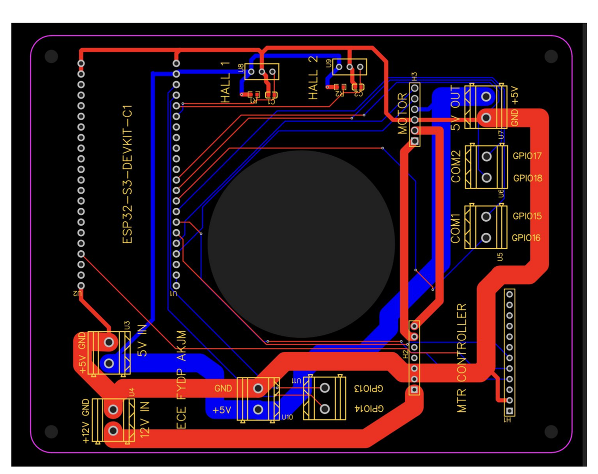
Existing Technologies	Our Advantage
Traditional AR/VR Goggles 	Voxogram's design fits on a desktop so there is no bulky, user isolating headset or wearable equipment involved. There is also no motion sickness. A single voxogram devices supports as many simultaneous viewers as can fit in view of the device, compared to needing a headset for each user
3D glasses 	Similar to the AR/VR goggles, Voxogram's design precludes the need for any wearable items while also supporting 360° simultaneous viewing angles. Additionally, these glasses require a specialized screen that can emit polarized light.
Holographic Pyramid 	Voxogram's design allows for 180° azimuthal viewing angles while not compromising on producing duplicate images. The Holographic Pyramid suffers from limited longitudinal viewing angles while also having certain spots that show duplicate images.
Holographic Fan 	Voxogram's advantage over prevailing holographic fan concepts is that holographic fans do not display in 3D, but rather give the illusion of depth by making a 2D object float in air. Voxogram truly displays in 3D, meaning there is no need to give an illusion of depth.

Physical Design

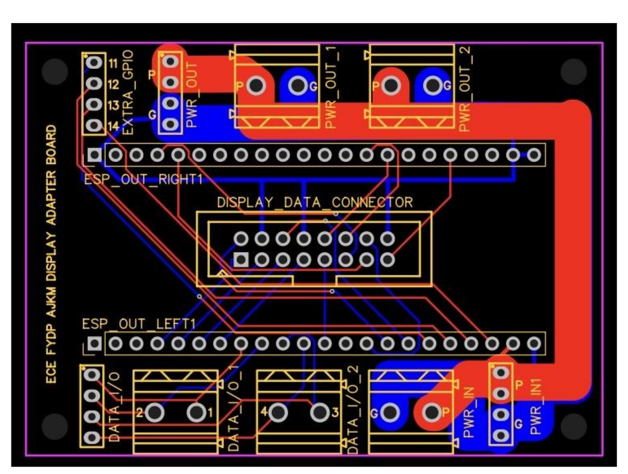


Assembly CAD Design

Image of Physical Assembly



Bottom Circuit Board

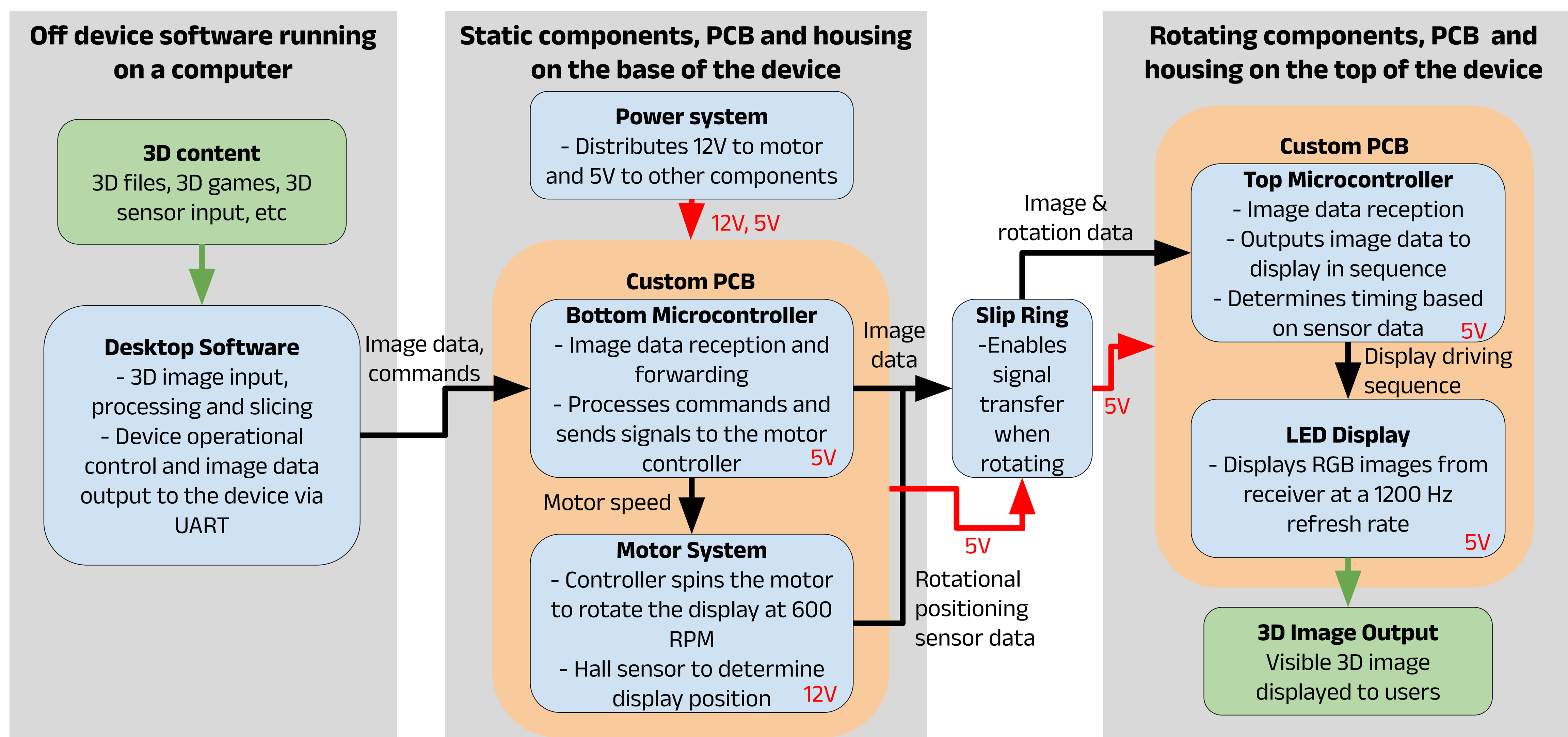


Top Circuit Board

Major Design Alternatives

Component	Selected Option	Primary Alternative(s)	Rationale
Display	64 x 32 RGB LED Matrix	Transparent OLED Display	The RGB matrix can be refreshed at over 2000 Hz, which enables 10 FPS live 3D content. It is also brighter than a transparent OLED so viewing is more clear. Additionally, when being rotated at a high speed, the solid LED display effectively disappears, so transparency is not beneficial.
Power System	AC Wall Power Adapter	Battery powered LiPo system	To achieve a desirable amount of continuous operation time, we decided on an AC wall adapter system that allows for theoretical unlimited operation time. Additionally, the device is specced to function as a desktop device, and therefore portability is not required.
Communication Protocol	UART	Wifi, SPI	A data transfer rate of 1.2 Mbps is required to support RGB live image data with our protocol. UART at a high baud rate supports this speed. UART allows for the device to work with any computer that can run the desktop software and has a USB COM port. Avoids the computer connecting to the device via Wifi.

System Design



Engineering Theory

Concept

The device takes advantage of the persistence of vision phenomenon to display 3D content. By rapidly rotating a display and illuminating specific pixels in a precise manner, a voxel (3D pixel) can be drawn. Doing this in rapid succession allows for a 3D image to be perceived by the brain.

Requirements for Success

There are several critical factors that contribute to creating a 3D image based on the principle of persistence of vision.

- **Rate of rotation of the display** - A desirable frame rate to play a 3D video is 10 frames per second. Since one 3D image corresponds to one complete revolution of the display, the motor should spin the display at 10 rotations per second.
- **Voxel size** - A desirable voxel size is 3 x 3 x 3 mm^3. This requires the pixel size of the rotating display to be 3 x 3 mm^2 and that the display be refreshed 120 times per revolution. This corresponds to a voxel with an arc of 3 degrees, which for the pixels at the edge of the display, end up being an arc length of 3mm. Therefore the target display refresh rate is 120 slices/image * 10 images/sec = 1200 Hz

Implementation

Voxogram leverages several techniques from a variety of disciplines, such as linear algebra, computer hardware and communication. Notable techniques are explained below.

Image Processing

The object processing software takes each 3D image and transforms it to a point cloud (a list of points in 3D space with colours). It then computes the central axis and intersects virtual planes through the point cloud and classifies points to specific slices of the 3D image. These selected points are flattened with the use of transformation matrices, and then downsampled to fit the provided screen resolution.

Communication

The communication protocol is built on UART and is responsible for sending operational commands and image data between entities of the Voxogram system using a custom message format. Additionally, lossless compression in the form of Run-Length Encoding (RLE) is used to reduce the size of data transmitted and lower the communication latency.

Synchronization

A static, 'non-drifting', image requires synchronization between the displaying of slices and the rotation of the screen. To do this, a homing signal, driven by a hall sensor, triggers a display sequence that is dynamically updated based on triggering delays implemented in a feedback control system.

Analysis and Results

The Voxogram design depends on the low latency pipeline of several processing steps in order to produce not only a convincing 3D image, but also 3D videos.
The critical conditions to successfully display a 3D image are ensuring that the following rates are sufficiently high:

- The rate of rotation of the display
- The slicing throughput of the desktop software
- The frame rate of the display
- The data transmission rate

We see the respective rate constants corresponding to each critical stage of the Voxogram pipeline.

	Rate Constant	Absolute Time per image
Motor spin rate	7 revolutions / s	140 ms
Display Refresh Rate	$3.6 * 10^3$ slices / s	33 ms
Slice Processing Rate	$1.2 * 10^3$ slices / s	100 ms
Data Transmission Rate	11.52 kilobytes / s	860 ms

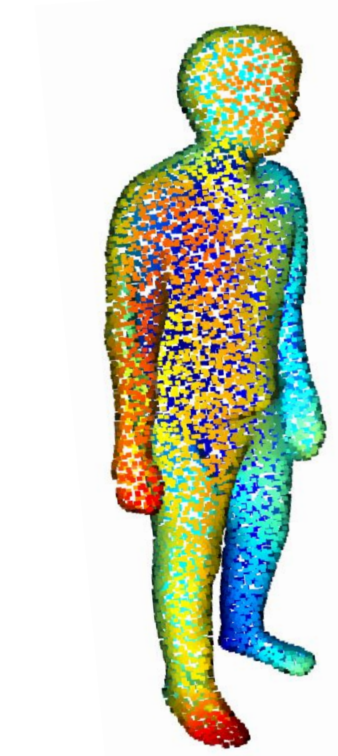
From the above table, we can see that the the data transmission rate is the bottleneck factor. To compensate for this, a Run-Length Encoding (RLE) scheme is implemented which compresses the transmission data in a lossless manner which encodes sums of similar data with a data value and a count. This encoding scheme allows for a 10x increase in the data transmission rate, which allows us to display 1 image per second.

Results

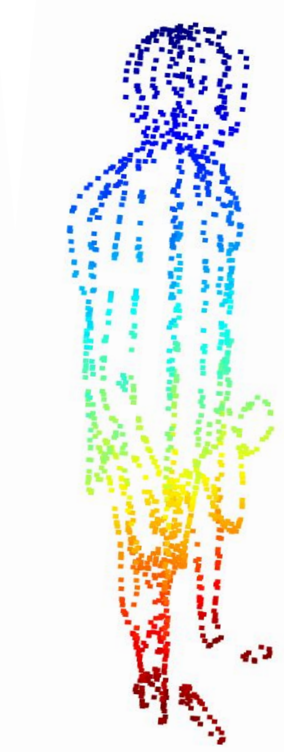
Voxogram has demonstrated the ability to process and display static images and videos of 3D object files in a holographic format. The immediate advantage of Voxogram is twofold:

- The design allows for observers to view the display with 360° viewing angles simultaneously
- The independence from relying on wearable hardware allows for seamless transitions between multiple users

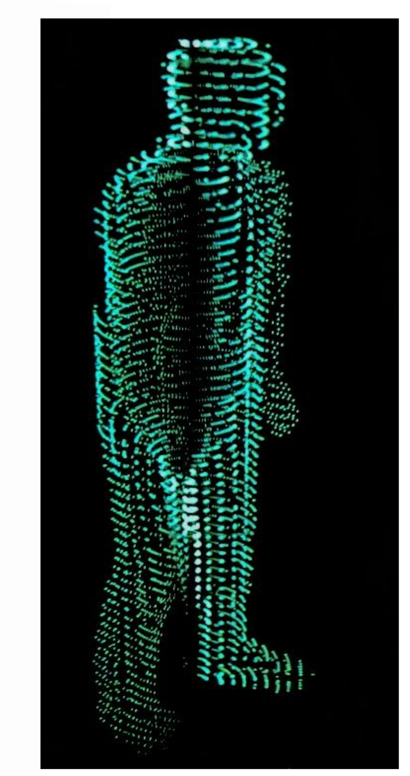
1) Physical Object Scan



2) Point Cloud



3) Slicing



4) Hologram displayed

These images represent the series of processing steps that occur to transform a scanned object into a hologram displayed on the Voxogram hardware.

Acknowledgements

Thank you to Professor Dan Davison for advising this project.

References

[1] J. Wong, "Visualizing the future: Holograms will soon have us all going places," LinkedIn, https://www.linkedin.com/pulse/visualizing-future-holograms-soon-have-us-all-going-places-jeff-wong/#:~:text=1%3A%20Right%20now%2C%20holograms%20are%20more%20screen%20than%20beam.&text=Those%20fluorescent%20blue%20light%20fields,screens%20rather%20than%20light%20beams.