THE TESSERACT: A MODULAR, NETWORK-BASED PORTABLE HIGH-DENSITY LOUDSPEAKER ARRAY

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ABSTRACT

To manage the abundance of data that is produced and tracked in the digital world, organizations are developing and implementing information systems that monitor, analyze, and give access to information. However, it is becoming increasingly difficult to manage the immense complexity of some systems and the data which they present due to high-dimensionality and competing streams of information. The Tesseract addresses some facets of this problem as a multichannel auditory display for presenting sonifications of data. The system is a modular and portable high-density loudspeaker array, originally designed to spatially display cybersecurity data. The following report describes the design of the system, current applications, and plans for future work.

1. INTRODUCTION

Multi-loudspeaker spatial audio systems exist primarily in research, academic, and entertainment settings. These systems are typically standardized in both physical architecture and content production environments for fixed-media playback. Arbitrary and nontraditional loudspeaker arrays that deliver real-time spatial audio could offer distinct advantages in several industrial domains, such as process control [1]. As organizations seek to find new ways to monitor and interact with big data, the high-density loudspeaker array (HDLA) format offers unique solutions for current and emerging problems.

Permanent HDLAs are found in a handful of universities around the world. Large-scale facilities like EMPAC at Rensselaer Institute of Technology demonstrate modular loudspeaker arrays of over 500 discrete speakers used for a variety of experimental acoustics studies [2]. The AlloSphere located at the University of California Santa Barbara can house over 54 speakers arranged in hemispherical rings behind large curved display [3, 4]. The Cube is a similar large-scale facility at Virginia Tech that houses 140 speakers in a black-box theater [5]. These academic facilities are state-of-the-art, however it's difficult to replicate the experience they can achieve elsewhere.

Casali and Lee [6] developed an auditory situation awareness test battery that inspired the development of a portable speaker array [7]. This important work demonstrated the power of incorporating a portable HDLA in a real-world situation. While this system demonstrates the benefits of an HDLA which can be rapidly deployed in many types of non-permanent settings, it is limited in that it only routes audio to one loudspeaker at a time for specific research use cases. More research is needed exploring multi-stream audio output and their effects on perception and task efficiency.

The desire to easily assemble and disassemble a modular speaker array is appealing for maneuverability and layout flexibility. In addition, if a system can self-calibrate, it would serve as a robust and dynamic tool that can be transported and adjusted to fit a wide range of environments. The current research is supported by the Commonwealth Cyber Initiative (CCI) and seeks to explore the development and use of a multichannel spatial audio displays for sonification of cybersecurity data. This report covers the development of a system that can be utilized as an adaptable experimental apparatus and an immersive audio interface (with the option of visual displays and tracking systems for multimodal presentation) to explore how data can be presented in unique formats and configurations.

2. SYSTEM OVERVIEW

The current report describes The Tesseract, a portable, modular HDLA that utilizes network protocols both for audio transmission and powering loudspeakers with one connector [8, 9, 10]. The Tesseract was developed as a flexible HDLA design to be used for a variety of applications, but with cybersecurity data sonification as the primary objective. Through future research and development, self-calibration procedures will be completed which significantly decrease setup time and allow for a lab-grade auditory display.

2.1. Design

The Tesseract is built around off-the-shelf modular box truss, which can be mixed and matched with standard theatrical truss and pipe elements. Between truss members, aluminum pipes act as support arms for speakers that are attached by clamps. Figure 1 shows The Tesseract assembled with 32 loudspeakers. The common structural parts afford predictable designs for most locations, are easy to source, and offer structural flexibility for additional display components.

MiniDSP SPK-4P and SPK-4 loudspeakers were selected for this system due to their relatively low cost, two channel amplifier, AVB data input, onboard SHARC digital signal processors, and Power over Ethernet (PoE) power distribution. Each SPK-4P

https://doi.org/10.21785/icad2022.037

Figure 1: The Tesseract with 32 loudspeakers

only needs one ethernet cable for both data and power, and can drive a passive companion SPK-4. Ethernet cables are grouped and pre-labled to ensure consistent setup when routing, but the network-based approach allows an arbitrary setup. Analog loudspeaker HDLAs necessitate more planning in regards to cabling and loudspeaker locations, whereas network protocol enables arbitrary arrays which can be defined by software. An AVB enabled Extreme Network switch connects all the loudspeakers to a Mac Mini computer which has a small form factor in transport. MacOS was originally selected due to the built-in AVB architecture, but channel limitations and routing challenges necessitated the addition of RME Digiface AVB for signal routing.

The network-based approach permits variability in the number of speakers needed to achieve a desired result and for arbitrary speaker layouts. The Tesseract has been assembled and disassembled several times with a team of three or four people taking 30 minutes to 2 hours to assemble depending on the use case. The Tesseract has also been deployed using different truss systems and dimensions to fit specific venues as shown in figure 2 which demonstrates its portability and robustness.

2.2. Software

AVB software and hardware are used to deliver audio over Ethernet to each speaker. This method allows for uncompressed 48kHz multi-channel audio to be routed with extremely low-latency. Cycling '74 Max and PureData are the most common signal generating software suites used with The Tesseract. However, any other software platform is possible on the host computer or an external input, expanding the tools available to researchers, artists, or engineers using the system.

Figure 2: The Tesseract with a different speaker configuration

2.3. Applications

The Tesseract was built with modularity as a core feature so that the system could be used for a variety of applications. The system was initially envisioned to map data values to audio signal parameters to sonify important events. However, The Tesseract can be employed for psychoacoustic research, audio-visual installations, and audio localization training.

2.3.1. Data Sonification

In the field of cybersecurity, it has been noted that professionals are greatly fatigued by the sheer amount of data being encountered daily [11]. Large-format screens are used to display data that has been formatted graphically, however, long-term exposure can cause eye-strain and other related issues [12]. In addition, vision is limited in the number of streams of information that can be monitored at a single time, whereas the auditory system is omnidirectional. Auditory pathways allow a listener to monitor and switch between up to 30 streams of information [13].

Sonifcation techniques can be used to present multimodal data for monitoring complex network systems. However, The Tesseract could also be used for threat protection by spatially alerting the location of the attacker or by sonifying the type of threat. The researchers utilized The Tesseract to explore these ideas by sonifying static cybersecurity datasets. Example DDoS datasets were mapped to sonic parameters and displayed via the HDLA and exhibit at the venue shown in figure 2.

2.3.2. Arts and Design

The Tesseract was integrated into an audio-visual exhibit at the ACCelerate festival in Washington, DC. Shown in Figure 3, the system included 16-loudspeakers that were attached internally within each balloon. This layout suggests the flexibility afforded by the design-approach taken by the researchers.

Members of the research team are also assisting in the development of Liminal Spaces, a new composition by Dr. Ben Knapp and Dr. Eric Lyon at Virginia Tech, which situates The Tesseract as a near-field format within the Cube HDLA as shown in Figure

Figure 3: Celestial Garden exhibit at the ACCelerate Festival

4. This setup uses distance-based layers of sound by positioning an audience equipped with open-ear and bone-conduction headphones inside the Tesseract for four dimensions of sound. This system allows for exploration of layered audio systems, pushing forward the cutting edge of spatial audio displays.

3. FUTURE WORK

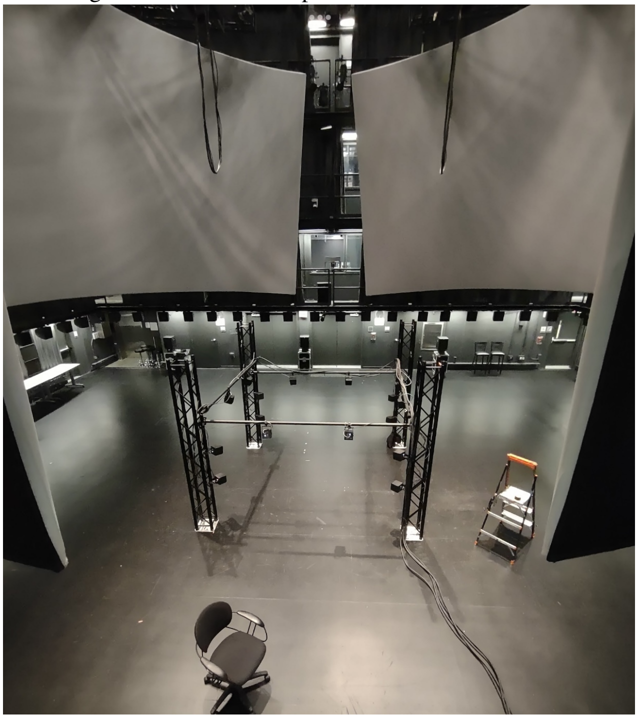
With The Tesseract developed, the next steps involve analyzing the system to ensure that it is fit for use in the aforementioned domain areas. The team is interested in developing software tools to enable self-calibration after the speakers have been configured. This process would theoretically eliminate time needed for individually calibrating each speaker to one another, which can be time consuming for HDLA configurations. The onboard SHARC DSPs are programmable and the team seeks to to push real-time calibration information to each loudspeaker pair. Progress has been made in creating a 3-D map of loudspeaker arrays using a soundfield microphone to determine an estimated location on a Hammer-Aitoff mapping with 426 possible locations. Digital signal processing techniques developed by members of the research team will be used to assist with localization of sound sources.

Moreover, The Tesseract is intended to be used as an experimental immersive auditory display for various research endeavors. For example, loudspeakers can be packed into dense, linear arrays, enabling a portable, hybrid Wave Field Synthesis and sparse loudspeaker array. The Tesseract could also be paired with an augmented or virtual reality head-worn display which will also open the door to new research possibilities for building simulations for research or training. The researchers hope systems like The Tesseract will develop the fundamental research that pushes the limits of immersive audio displays.

4. ACKNOWLEDGEMENT

The authors would like to thank the Commonwealth Cyber Initiative, the Institute for Creativity, Arts, and Technology, and Dr. Michael Roan for supporting and assisting with this work.

Figure 4: The Tesseract positioned within The Cube



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