DATALEV: Acoustophoretic Data Physicalisation

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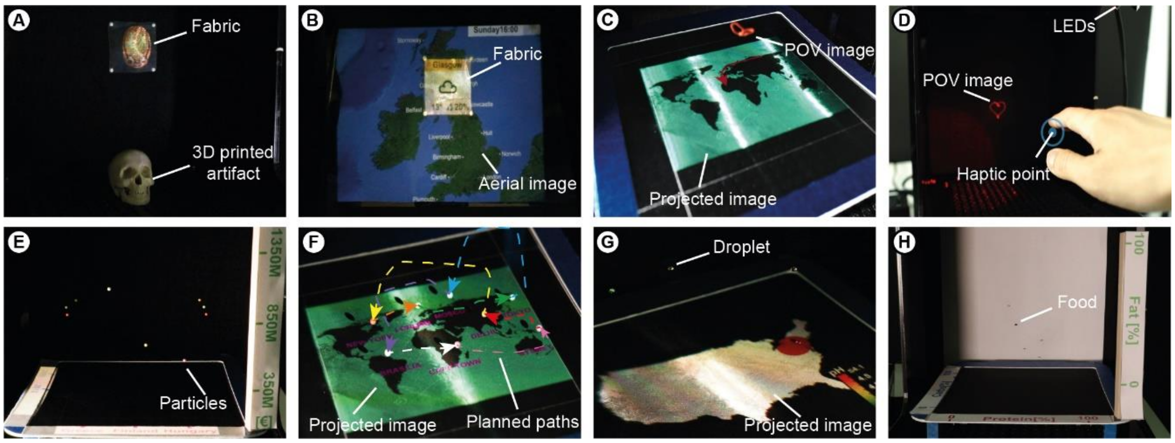

Figure 1: New types of data physicalisations allowed by DataLev. (A) Scientific data visualization (cross sections of a human head). (B) Interactive weather forecast. (C) 3D arc diagram (bird migration). (D) Multi-sensory physicalisation of heart rates. (E) Interactive 3D scatter plot using 9 particles. (F) Network diagram (airport connections). (G) Droplet map chart representing pH levels in acid rain. (H) Edible 3D scatter plot presenting nutrition data.

Here, we demonstrate DataLev, a data physicalisation platform with a physical assembly pipeline that allows us to computationally assemble 3D physical charts using acoustically levitated contents. DataLev consists of several enhancement props that allow us to incorporate high-resolution projection, different 3D printed artifacts and multi-modal interaction. DataLev supports reconfigurable and dynamic physicalisations that we animate and illustrate for different chart types. Our work opens up new opportunities for data storytelling using acoustic levitation.

CCS CONCEPTS • Human-centered computing • Interactive systems and tools

Additional Keywords and Phrases: Data physicalisation, Acoustic levitation, Physical assembly

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1 INTRODUCTION

Acoustophoresis is a method of suspending and manipulating matter in a medium using acoustic radiation pressure. Sound waves can exert radiation forces and form acoustic traps at points where these forces converge. Recent advances in acoustophoresis have enabled us to create visual, tactile and audio content simultaneously to create multi-modal displays using a single levitated particle [2] and even create volumetric displays using the persistence of vision (POV) effect with multiple levitated particles [5]. Acoustophoresis opens immense opportunities to build and explore data physicalisations by creating richer physical displays and multi-sensory interaction capabilities. Despite being a natural conceptual fit between acoustophoresis and data physicalisations, there are few demonstrations or mappings from data to such a form of data physicalisations. Early attempts to use acoustophoresis to levitate small physical particles to show data points in mid-air (e.g., FloatingCharts [4]) only provide primitive examples that do not leverage the recent advances in acoustophoresis thus limiting such demonstrations and capabilities.

Here, we demonstrate DataLev, a physicalisation platform that allows computational assembly of physical charts using acoustophoresis. By tightly incorporating the recent advances in acoustophoresis with novel hardware and software components (e.g., aerial imagery and path planning), DataLev allows diverse data physicalizations in mid-air (see Figure 1), such as network diagrams, scatter plots and geospatial maps, all of which are firstly demonstrated in a single physicalisation platform.

2 DATALEV OVERVIEW

The platform combines novel hardware and software components with an acoustophoretic system enabling us to explore new types of data physicalizations, which have never been demonstrated.

2.1 Hardware components

The main hardware component of DataLev is the acoustophoretic system consisting of any arrangement of single/multiple ultrasound transducer arrays (e.g., 16×16 array of 40-kHz transducers), for example, the top-bottom setup with two opposed arrays (see Fig. 2A). The system can levitate and manipulate different types of materials such as expanded polystyrene (EPS) particles with diameters of 1-3 mm, fabric [3], droplets and edible food items [6]. This material-independency in acoustophoresis provides enhanced storytelling and materiality in data physicalizations. The system can also provide multi-sensory stimulations and create volumetric 3D images with persistence of vision (POV) effect by quickly scanning particles. Additionally, it provides haptics by directing the sound pressure on the user’s hand and directional audio sound by using amplitude modulation [2, 5].

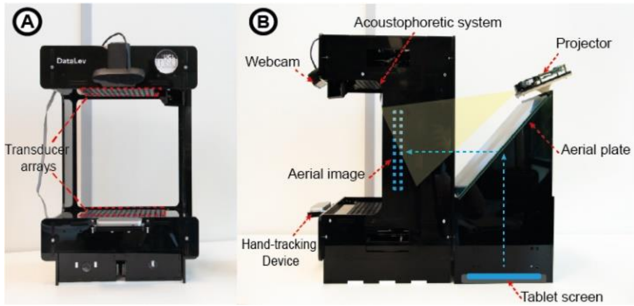

Figure 2: The DataLev setup. (A) The acoustophoretic system consists of two transducer arrays. (B) The acoustophoretic system with other components (e.g., the aerial plate and the projector).

The other hardware components include an aerial plate (ASKA3D), a video projector and 3D printed artifacts, as shown in Fig. 2B. The aerial plate is an optical element, allowing the formation of an aerial image of a 2D screen or even 3D physical objects, and the levitated materials can be spatially overlapped on such aerial images with correct 3D perspectives. By integrating aerial images within DataLev, we can provide a balance between the true-3D levitated materials, which have low resolution, with high-resolution perspective correct aerial images, which can present 2D digital images or 3D objects. The projector can be used for projecting underlying digital information on a screen inside the system and even on the levitated materials as a "digital shadow". In addition, DataLev adopts a recently proposed technique [1] to account for sound-scattering effects so that any objects such as 3D printed artifacts can be placed in the system to enhance the data representation.

The acoustophoretic system is used with a (2D or 3D) camera to detect particles' positions for initialization and a hand-tracking device such as LeapMotion for supporting user-interactions. The device footprint of DataLev in total is 30 × 45 × 42 cm^3.

2.2 Software components

The physical assembly pipeline in DataLev consists of 3 main steps – *initialization, planning and control*. We follow the pipeline to manipulate a group of physical objects and arrange their positions and movements to obtain the desired physical charts.

Initialization: when we use EPS particles or fabric (on which some EPS particles are attached and used as levitation anchors), we use the image-based particle detector (e.g., webcam) to detect particle positions and start levitating the detected particles from the flat stage. As food items are usually heavier than EPS particles or fabric and not spherical, we manually put food items at initial positions using tweezers. For liquid droplets, we use a liquid dispenser to put the droplets at their initial positions.

Planning: Once we initialize the levitated objects in mid-air, the next step is to plan the trajectory of the objects to their desired locations in 3D for physical assembly. This step involves assigning specific target locations to each object and then planning the path for each object to move them all simultaneously from their initial positions to target positions. Prior to that, we characterize the bounding volume (i.e., safe horizontal and vertical distance) of levitated contents to avoid physical collisions. Once the bounding volume for each object is defined, we can use it in path planning algorithms to make every object find its own feasible assembly path.

Control: After getting the assembly paths, we control the entire hardware system to physically assemble desired physical charts. This includes the acoustophoretic system to control the levitated objects along the assembly paths using an acoustophoretic algorithm (e.g., GS-PAT [5]). Also, the projector, the aerial images and the LED lighting need to be controlled synchronously with the acoustophoretic system.

The physical assembly pattern is updated according to pre-defined animations or inputs from the hand-tracking device. The pipeline repeats the planning and the control steps for every update while the initialization step does not usually need to be repeated unless any additional objects are required to be levitated in the system.

3 PHYSICALISATION EXAMPLES

Using the DataLev platform we assemble many unique data physicalsiations using different combinations of levitated particles and other enhancement props. Our physicalisation examples include network diagrams, scatter plots, and geospatial maps.

Example 1: Scientific data visualization

Fig. 1A shows an example of scientific data visualisation, using the fabric and a 3D printed artifact. A cross-sectional image of a human head is projected onto the fabric according to the fabric's position, and the 3D printed skull visually helps the user understand which part of the head is presented.

Example 2: Interactive weather report

The example in Fig. 1B demonstrates an interactive weather forecast combining the levitated fabric with the aerial plate. The aerial imagery of the UK map is presented, and the user can manipulate the levitated fabric, on which weather information is projected, as interactive annotation.

Example 3: Bird migration (POV)

In Fig. 1C, we demonstrate a 3D version of arc diagram using a POV image, which was created by scanning a single particle. A POV image of a bird physicalises its migration route.

Example 4: Heart-rate physicalisation (POV + Haptics)

As shown in Fig. 1D, DataLev can simultaneously create a visual image (i.e., a POV image of a heart shape) and tactile sensation representing the heart rate, and these multiple sensations can be integrated as a data physicalisation.

Example 5: Interactive 3D scatter plot

In the example of Fig. 1E, 9 EPS particles are levitated, presenting the total investment in networks in three different countries over different years. DataLev allows the presented data to be filtered, sorted and updated according to the user's gesture input.

Example 6: Network diagram

Figure 1F shows a network diagram presenting airport connections. DataLev uses a path planning algorithm to avoid collisions between the 8 EPS particles.

Example 7: Droplet map chart

The material-independency of DataLev enhances storytelling and materiality in data physicalisations. In Fig. 1G, the water droplets that are levitated and illuminated by different colors represent raindrops with different pH level. These droplets fall onto the specific locations on the US map.

Example 8: Food scatter plot

In the example of Fig. 1H, DataLev presents a 3D scatter plot of nutrient data using actual food items (e.g., bread, mushroom). The user can grab the data and even taste it to see what the food tastes like.

4 CONCLUSION

In this paper, we presented the DataLev, a physicalisation platform using recent advances in acoustophoresis. Our computational assembly pipeline integrated novel hardware and software components that embodied diverse acoustically levitated contents. We demonstrated DataLev's capability by showcasing novel mid-air physical charts that have sufficient dynamics and reconfigurability. We believe our platform makes an important step toward acoustophoretic data physicalisation and brings immense possibilities for general data storytelling in the physical world.

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