Spaxels, Pixels in Space
A Novel Mode of Spatial Display

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Abstract: We introduce a novel visual display paradigm through the use of controllable moving visible objects in physical space. Spaxels is a conjugation of "space" and "pixels". It takes the notion of a pixel, and frees it from the confines of a static two-dimensional matrix of a screen or projection surface to move three dimensionally in space. Spaxels extend the notion of Voxels, volumetric pixels, in that a Spaxel can physically move, as well as transition in colour and shape. Our current applied research is based on the control of a swarm of unmanned aerial vehicles equipped with RGB lighting and a positioning system that can be coordinated in three dimensions to create a morphing floating display. This paper introduces Spaxels as a novel concept and paradigm as a new kind of spatial display.

1 INTRODUCTION

Visual media has undergone countless evolutionary transformations through innovations in technology, from the first primitive though enduring methods of aboriginal cave paintings, to oil painting, still photography, celluloid film, video, holography, to current day large LED displays, transparent displays, and stereoscopic displays. Some collective factors that define these modes of display are: two dimensional matrices of image elements, fixed planes of display, and the static nature of the display elements such as fixed position pixels or chemical compounds like paint or silver gelatine. The break from the fixed two dimensional image plane has been a much anticipated jump. MIT Media Lab's Hiroshi Ishii predicts the next phase of human computer interaction with his notion of Radical Atoms (Ishii et al., 2012).

Though the vision of Radical Atoms is more connected to the physicality of computational media at a smaller atomic scale, the notion of Spaxels falls neatly into this idea of a transformable, kinetic, computable environment into which visual media can be expressed. Where each visual element can be positioned at a required location, relocating as required, allowing the expansion of the image to fill a field of view, allowing changes in Spaxel density/luminosity, rotation, and scale in space.

2 RELATED WORK

A significant exception to the 2D confinement of the image plane is True 3D (Kimura et al., 2011) a system by Burton Inc and Keio University employs laser-plasma to generate dots of plasma, like pixels, in mid-air. Their 2011 paper cited a jump from 300 points/sec to 50,000 points/sec from their 2006 model, to a volume of 20x20x20cm. The researchers encouragingly promise that their next version will include red, green and blue plasma, overcoming the limitation of the monochromatic image. The excitation of air or water particles is an important leap in 3D imaging. An artwork by Art+Com *Kinetic Sculpture* (Sauter et al., 2011) for BMW uses 715 metal spheres suspended on a kinetic vertical cable system. The cables locate the spheres vertically in space to create images of BMW vehicles and waves. *Ocean of Light* ("ocean of light : home," n.d.) by Squidsoup is a volumetric array of RGB LEDs arranged vertically on hanging strips, it also generates wave forms as light sculpture from audience interactions. Several other works, such as *The Source* at the London Stock Exchange, have addressed the idea of kinetic sculpture as a mode of transformable image display.

Additionally the use of unmanned aerial vehicles for various manipulations in physical space recently became a prospering research field. Among many other research labs the GRASP Lab at the

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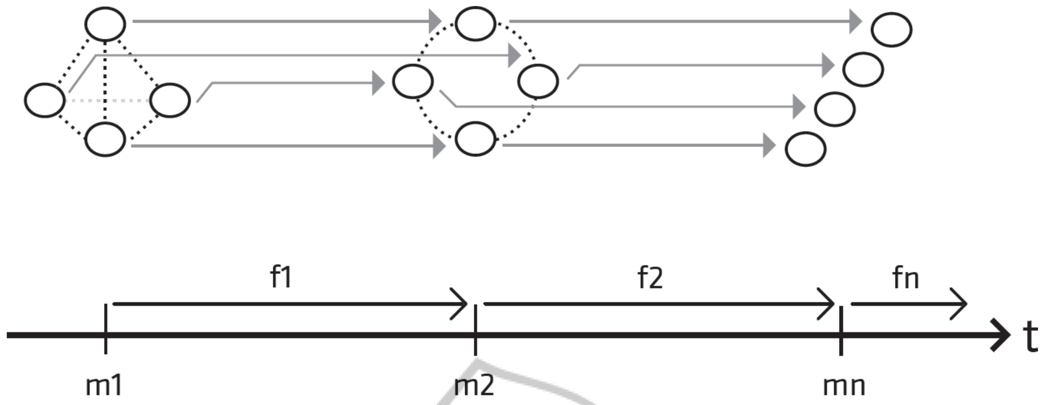

Figure 1: Spaxels moments (m_1, m_2, m_n) in relation to Spaxels flow (f_1, f_2, f_n).

Pennsylvania University (Michael et al., 2010) and the Flying Machine Arena of the ETH Zurich (Schoellig et al., 2010) received a lot of acclamation for their ground-braking experimental work.

Our concept of Spaxels extends previous works in the field by proposing a controllable swarm of lit objects in 3D space and time that is not connected to a cabled system. Instead Spaxels are floated independently by means of aviation. Our vision is of a transformable display of pixels in space, hence the coining of the term Spaxels: Space Pixels.

3 NATURE OF SPAXELS

To illustrate the concept of the Spaxels two aspects have to be considered, the nature of a single Spaxel and the nature of a collective of Spaxels that form a Spaxel Sculptural Image (SSI).

3.1 Nature of Singular Spaxel

In a general sense Spaxels are analogous to volumetric pixels (Voxels) with the addition of the property of movement. A Spaxel has the following defining properties: colour, position in physical 3D space, and a trajectory vector. Orientation and shape are optional properties to extend Spaxel functions.

3.2 Nature of Spaxel Sculptural Image

Considering free floating physical objects in the generation of sculptural images it is needed to reflect upon two overall aspects; the first aspect is the sculptural image itself; and the second is the transition towards this sculptural image. This can be compared to classical animation strategies like “key frames” and “in-betweening”. Subsequently we call the discreet state “Spaxel Moment” and the transitional state “Spaxel Flow”. Both need aesthetic consideration when constructing visual representations with Spaxels.

3.2.1 Spaxels Moment

Spaxel moments describe a specific state of the sculptural display at a discrete moment in time. They can be compared to frames in traditional display technologies. There are several thinkable ways of how such a frame or Spaxel moment can be defined in the course of a specific visualization. Spaxels can be controlled by a global instance that is synchronizing their properties, transmitting commands and therefore guaranteeing the overall image. This instance can be either integrated into one specific Spaxel (leader of the swarm) or located outside on a remote location (remote control). Additionally Spaxels can also self-organize based on predefined models and algorithms and reach distinct layouts in time and space based on local data and decisions.

3.2.2 Spaxels Flow

In designing an authority that computes and defines discrete states of the Spaxel display, it is necessary to consider the transitions in between these Spaxel moments. This integrated capability is a mandatory property to maintain a coherent overall visualization. We refer to this as the flow of the Spaxels (see Figure 1). As one of the main aspects of the flow of Spaxels is – amongst aesthetic considerations – the avoidance of collisions and the overall react ability, this capability can imply complex algorithmic requirements. Simple implementations like shortest path algorithms might be substituted by more complex swarm-like behavior (Reynolds, 1987) or generative and autonomous algorithmic strategies (Bürkle et al., 2011), depending on the resolution and Spaxel density of the display.

Figure 2: A single Spaxel represented by a quadrocopter, an unmanned aerial vehicle with preliminary LED lighting.

4 PROOF OF CONCEPT AND RESEARCH SETTING

As a research environment a set of unmanned aerial vehicles (see Figure 2) is chosen. Currently the research group works on a setup of 50 of those instances to conduct the proof of concept.

4.1 Embodiment of a Single Spaxel

Each Spaxel used for current research is represented by an Ascending Technologies Hummingbird quadrocopter ("AscTec Hummingbird AutoPilot | Ascending Technologies," n.d.). These unmanned aerial vehicles (UAV) provide a GPS based autopilot for autonomous outdoor waypoint navigation. A dedicated high-level processor controls the flight maneuvers of the quadrocopters and can be programmed by the researchers. The maximum flight time is at least 20 minutes and the maximum speed of the vessel is more than 50 km/h. The UAV is controlled by a base station transmitting commands up to a distance of 600 meters using a proprietary radio technology transmitting in the 2.4 GHz spectrum. The quadrocopter has a high-level and a low-level processor. The high-level processor is used for communication and LED control. The low-level processor does the actual flight control based on the GPS waypoints received. Each unmanned aerial vehicle is equipped with an array of RGB LEDs, which can be altered in hue and brightness through corresponding remote commands. Figure 3 shows the basic scheme of the radio communication. The proprietary LairdTech radio chipset uses channel hopping to maximize and stabilize the transmission. Therefore only one physical channel is available. Within this channel the communication follows a time-synchronized request and reply based 1:n broadcast scheme.

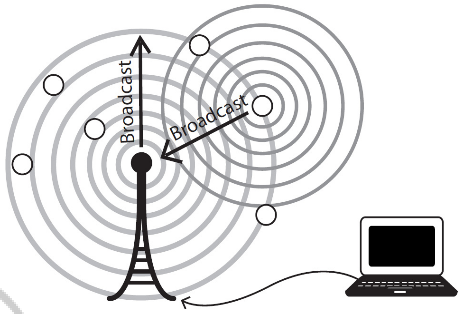

Figure 3: Basic layout of the broadcast communication scheme.

Table 1 gives an overview of available commands.

Table 1: Available control commands.

From	To	Command
SU	SP, G, A	LED
SU	SP	WP
SU	SP, G, A	L
SU	SP, G, A	P
SU	SP	R
SP	SU	U

The server unit (SU) sends broadcast packages to all Spaxel units. Each network packages has a distinct addressing scheme on application level. Individual Spaxels (SP), predefined groups of Spaxels (G) or all Spaxels (A) can be addressed. The in-flight commands contain commands to update the waypoints (WP) the Spaxel should use for the next movement path, to change the RGB value of the LED lighting (LED), to fly to a predefined parking position (P), to land (L) or a request to transmit current flight data like speed, position, altitude and charge (R). Whenever a Spaxel receives an update flight data request it has to reply within a predefined timeframe otherwise the Spaxel will be sent to parking position and ultimately be requested to land. Whenever a Spaxel does not receive commands from the server anymore it will also go to parking position. If there is no GPS signal available, the Spaxel will stand still and wait in air. Shortly before battery charge is empty it will emergency land using the barometer for approximated height measurements.

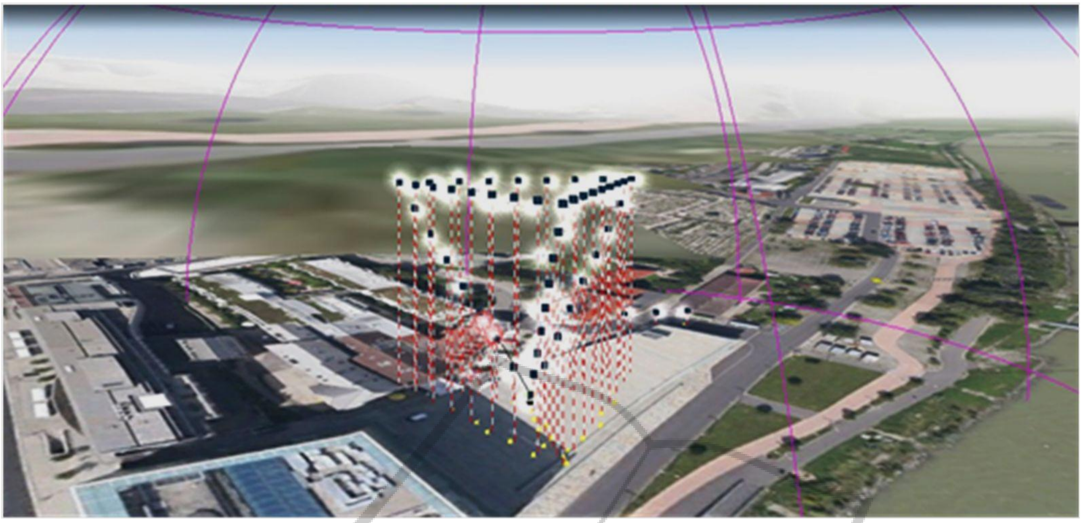

Figure 4: Screenshot of the current development state of the Spaxels simulator and control server.

4.2 Embodiment of a Sculptural Image

The first implementation of a Spaxel display will consist of a swarm of 50 individual UAVs. Each of these Spaxels is remote controlled by a central on-ground server. The server runs a virtual simulation tool that calculates patterns in space and trajectories for each Spaxel. Furthermore visual properties for the LEDs are determined based on generative patterns. Based on this data discrete Spaxel moments are computed. They are transmitted to the UAV using eight parallel physical radio channels. The UAVs interpret them as waypoints and compute the transitions as Spaxel flow locally. Furthermore, the UAVs transmit their actual position and speed to the server to update the simulation. The current data transmission and overall swarm update frequency varies at 3 to 5 frames per seconds. Figure 4 shows a screenshot of the current development state of the simulation and control server. Orthographic images are used as floor texture for the reference of the swarm operator. The current Spaxels position, flight path and illumination state is visualized. Furthermore a hemisphere restricts the possible movement of the Spaxels to a predefined maximum distance from the server unit.

The main tasks of the server unit are to synchronize and control the movement of the Spaxels, avoid collisions and alter their visual properties. Furthermore the server triggers automatically emergency routines for the case that the control over a Spaxels unit cannot be maintained anymore.

4.3 Proof of Concept Setting

The concept of Spaxels does not determine the overall scale of the visualization per se. Applications can range from indoor micro-Spaxel visualizations to large outdoor scenarios. The scope of our current research is to realize a large-scale Spaxel display for an audience of several thousand viewers.

The overall visualization space is across several hundred meters. Consideration needs to be given to the different possible viewpoints of the audience to achieve a coherent visualization. Figure 5 shows the spatial setup we are working on with an overall dimension of roughly 500 by 500 meters.

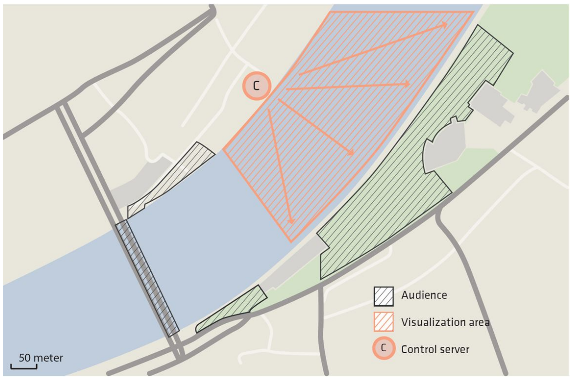

Figure 5: Proposed audience and visualization area.

5 RESEARCH CONSIDERATIONS

Spaxels open up a number of new areas for consideration like density/luminosity, immersion, rotation, field of view, scale, shape, and point cloud rendering. In general it is important to firstly identify properties that can be categorized as analogies of conventional display technology properties and secondly to identify conceptually new capabilities which go beyond.

5.1 Density of Image

The notions of scale, and resolution with and SSI become a matter of luminosity and density of image elements. In the case of a Spaxel display, density can be optimized to best suit the display of a given image or object given the resolution, or number of Spaxels. For example a Spaxel image of a human with arms by sides, being tall than wider would be shown from a topologically optimal point of view, as a more or less tall and blobby cylinder. Whereas the image of a human head would be seen as a group of Spaxels arranged in a more or less blobby sphere. The space-time configuration of Spaxels can adjust algorithmically to the content. Density can be packed to increase or decrease depending on the field of view, and are measured as Spaxels per cubic meter.

5.2 Transformations

Rotation and translation–affine transformations–of the SSI around and past the audience's field of view is possible. The entire SSI can be transformed in the airspace surrounding the audience. The audience can be surrounded, and immersed in the SSI. Research already undertaken in virtual reality could be extended with larger and more physical contexts.

5.3 Field of View

Another research consideration is a focused field of view; memorably explored in cinema by Lucasfilm in the Star Wars saga through the assorted holographic projections that serve as centrepiece displays for communication and visualisation. The holographic projection of Princess Leia appears as a monochrome cinematic feed with a bluish tinge projected into the air and showing only a limited field of view. The key research issue is separation of the object of focus from the background, when considering an entire scene of 3D data, the time for a Spaxcel to move from one position as part of a mountain 100's of miles away to a closer position of an object in the foreground, an act accomplished in one frame of film. Lucasfilm's approach, it seems, was to imagine a zone of recording, and objects outside this zone, such as backgrounds are completely ignored. The same occurs in Kinect recognition software, information beyond a certain distance threshold is ignored.

5.4 Point Clouds and Spaxels

3D scans from consumer devices such as Kinect produce a data set containing X,Y,Z and RGB values in relation to the devices lenses, The data sets are expressed as point clouds, that when viewed collectively, and with a high enough density form a recognisable image. Point clouds are a suitable way for capturing the three-dimensional world around us, in most purposes they merely form the starting point for an algorithm to calculate a 3D mesh. But the question still remains, once we have this information, how do we get back into the real world, we can make a 3D print or static sculptural object. Spaxels offer a method to express dynamic point clouds in real time, in real space.

5.5 State Switching vs Transformations

We have identified two methods for animating images: state switching and transformations (figure 6). State switching involved a matrix of Spaxels that alternately switch on and off, and a transformation involves physically moving an individual Spaxel. The transient time for the transformation compared to the speed of switching will become an artistic decision, though contributing factors like Spaxel density will influence the decision computationally.

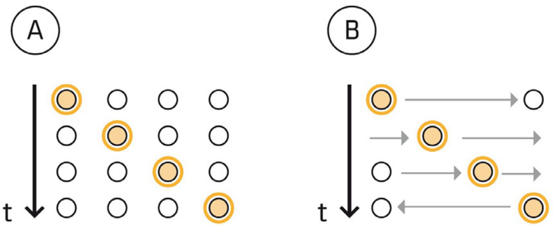

Figure 6: State switching (A) vs Transformations (B).

5.6 Shape

The shape of an individual Spaxel, including the scale and geometry, can be morphed through robotic transformation using a method similar to our research in robotic origami systems (Wang-Iverson et al., 2011). Such transformations could increase or decrease the local image density through the change in size and shape of a light diffuser.

5.7 Future Work

Our current research is focused on the first realization of a Spaxel display, which fulfills the requirements described in this paper. The display itself will work in the first implementation with 50 individual Spaxel units. The core research question is to derive requirements for aesthetic music based visualization for a large crowd audience. This will include the precise and responsive control in air, synchronization among the Spaxel units and overall aesthetic considerations. Future research will include scaling up the number of Spaxels, as well as developing concepts for making the shape dynamically transformable. We are hard at work, and expect first ground-breaking results within the coming months.

In our current work Spaxels are controlled by a central server unit. A future step for future work would be to decentralize control of the Spaxels swarm by using rule-based agents. Rule-based agent systems for visualizations have a long history in computer graphics. (Reynolds, 1987) presented a model that simulated the behavior of a flock of birds by the use of a few relatively simple, global rules. This effective steering scheme is manifested by rules for group cohesion, alignment and separation to avoid collisions with other swarm entities. Building on these results a next step would be to calculate the Spaxel flow locally and distributed on the Spaxel units themselves. This could lead to a lower need for synchronization and therefore to a higher overall responsiveness of the display.

6 CONCLUSIONS

In this paper we introduced a new paradigm for spatial displays. Spaxels extend the concept of Voxels from a discretely ordered matrix to a continuous space. Furthermore we also introduced the work on the first embodiment of this concept based on unmanned aerial vehicles. This research opens up a whole new field of visualizations in physical space. Two core concepts for these sculptural displays are the notion of the moment as representation of a frame and the flow as the transition in between. Both need to be redefined based on the novel technological constraints. The kinetic and dimensional potential of Spaxels significantly extends the scale and mode of visual expression.

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