Advanced Swarm Imaging for Three-Dimensional Mapping

Martin Duncan
University of North Carolina-Wilmington
U.S.A.
E-mail: duncanm@uncw.edu

Paul Weil
Pluribus Technologies, Incorporated
Lafayette, California, U.S.A.
E-mail: dark.illuminations@gmail.com

Thomas Klemas
Sensemaking-PACOM Fellowship
Cambridge, Massachusetts, U.S.A.
E-mail: tklemas@alum.mit.edu

***Abstract*—The richness of detail and ease of usage of three-dimensional mapping has grown by leaps and bounds, but the equipment to create these images is very expensive to purchase and use. Inspired by the Internet-of-Things, Pluribus Technologies has developed a novel imaging approach that combines cybernetics and a plethora of tiny, inexpensive sensors with cloud-based data streaming, Web service and API-based image manipulation software, and cutting-edge Web technologies to enable advanced data visualization and imaging capabilities for numerous applications which previously were cost prohibitive or impossible due to practical limitations of size or space. This system repurposes pre-existing hardware and software components to transmit many streams of low-resolution visual data to a cloud-based server. These streams can be composed into a single detailed 3D image, which can then be viewed, downloaded, or edited collaboratively in real-time 3D on a Web-based client application. Swarm Imaging is achieved through potentially disposable components mounted on an aggregate of mobile units with a modern user interface for the client. Data can then be analyzed from images obtained in physical areas where humans do not wish to, or cannot, venture. Users will benefit from an end result of viewable, manipulable images processed using a high quality Web application client functioning on any device equipped with an A-grade browser. This invention will provide unprecedented terrestrial visualization for purposes of remote data analysis and sensemaking.**

***Keywords: Swarm Imaging; Internet-of-Things; cloud services; digital imaging; mapping; data visualization; high-resolution 3D imaging; Web services; APIs; sensemaking*.**

I. INTRODUCTION

When data sets are extremely large, very complex, or the data is changing rapidly, analysis requirements exceed the capacity of most humans. Analysis reaches a complexity and throughput level at which humans are unable to consider the full scope of the data and lack the capacity to keep up, derive insights, and make decisions. In today's world of increasingly smart and interconnected systems, more and more sensors are deployed in civilian, medical, industrial, and military systems. Almost every object used at home or in the workplace contains some form of embedded microchip. The rise of wireless technologies such as Bluetooth and WiFi promotes ever more frequent networking of these devices within programming (automation), monitoring, and remote control. These networks furthermore facilitate software updates, enable interactivity, and enable related objectives. This Internet-of-Things, or IoT, allows much richer and smarter applications in new technology. A well-known example is the Google Nest family of products, allowing such innocuous consumer electronics as a thermostat controller, a smoke/CO alarm, and an indoor/outdoor Web camera to communicate with each other and provide rich aggregate data to home or business owners via Web application. The user monitors and controls the home or office facility on the basis of rich data composited from simple sensors. The trend that all of our possessions can "talk" to each other, from our car to our phone to our wristwatch to our refrigerator, allows for a sort of collective intelligence capable of learning and adapting to users' needs [1].

The emergence of the IoT, as well as increasingly inexpensive 3D printers, has driven the creation of relatively cheap circuit boards for use among a grassroots community of "Makers" who represent a new open-source hardware movement similar to the open source or free software movement that was prominent during the early days of computing. More and more people are building their own devices and robots and programming them using a variety of languages from their personal computers. There are "Maker Faires," or conventions, and people share designs over the Internet, with downloadable specifications and projects analogous to allowing other developers to copy or fork projects on GitHub. President Obama has even created a Federally funded America Makes program. All of this promotes the creation of simple devices and sensors pooling data to deliver much more detailed and robust results. Makers use inexpensive, easily programmable circuit boards and sensors to create their own smart devices [2].

State-of-the art 3D cameras are bulky and expensive, and drones can be used to map a large area in 3D, but they are noisy, cumbersome and hindered by heavy cameras. The method proposed here provides visual data processing that synthesizes the fundamentals of remote imaging, access, and data visualization, implemented in a Web application that facilitates surveillance from multiple angles or manipulation of the image. The Pluribus cybernetic swarm system is intended as a wholly more efficient alternative to 3D cameras, regardless of their attachment to drone vehicles. Furthermore, we anticipate demand for our apparatus in many problem spaces currently underserved by 3D remote imaging technology.

Inspired initially by the theories and practical applications of evolutionary psychologist Steven Pinker [3] and artificial intelligence researcher David H. Freeman [4], the Pluribus Technologies research & development effort has initiated the practical implementation of their ideas by leveraging multiple, advantageous, emerging technologies. The ubiquity of "smart" household items and the demand of Maker Movement hobbyists and developers has driven the creation of miniature circuit boards which can run JavaScript, tiny video and audio sensors, and miniature WiFi transmitters. A need to transmit and aggregate multiple real-time data streams has led to businesses providing these services as a specialty. Three-D imaging industry leader AutoDesk has reimplemented many software products as the cloud-based Forge Platform, a set of Web services, APIs, and SDKs, which allows easy, granular use of their various software features in both the Web browser and the IoT [5].

The ongoing Pluribus R&D utilizes currently available software and hardware components modified minimally for Swarm Imaging objectives. Rather than reinvent the wheel, Pluribus Technologies has assembled many sorts of existing puzzle pieces together in an innovative systems architecture – rather than simply building yet another wheel, the intent is to create an entirely new luxury vehicle from existing parts. Additionally, this approach prioritizes the low price point of Swarm Imaging, and the ability to obtain images from spaces which are impossible or impractical to access with drones and/or 3D cameras, as the key to eventual marketing. The intended data visualization strategy optimizes and synthesizes the best aspects of low-cost cybernetic and sensing hardware components, JavaScript-driven swarm artificial intelligence, inexpensive and fast data streaming services, cloud-based Web services and APIs, and cutting-edge, browser-based Web technologies. This paper presents the pragmatic potential of these technologies employed in concert, and demonstrates a new way to see and make sense of the world.

The remainder of this manuscript is arranged as described herein. Section II describes the technical details of the 3D cloud-based Web services visualization aspect of Swarm Imaging. Section III provides a brief review of prototype specifications and potential applications of Swarm Imaging. Section IV offers our conclusions and anticipation of the benefits of Swarm Imaging. Finally, the acknowledgment and reference sections complete the manuscript.

II. Technical Details

Perhaps the most important consequence of the Maker Movement is the availability of inexpensive circuit boards with pared down versions of the Linux operating system, capable of running NodeJS, a server-side version of JavaScript. This is desirable for two reasons: JavaScript is a Lambda language descended in large part from the Artificial Intelligence (AI) programming language LISP, and JavaScript is the de facto language of the Web. In 2016, most data is transmitted using JSON, a JavaScript-native format, rather than XML. This will simplify the interoperability of the various components of the Pluribus system architecture; a swarm is, in a way of thinking, a distributed AI.

Another consequence of demand from Makers is the availability of microsensors such as tiny cameras and microphones. For example, the Jtron camera for Arduino costs around five US dollars; Adafruit makes an omnidirectional microphone the size of an aphid for less than $1; and Geeetech offers a very advanced motion detector that is about the size of a dime and which sells in the vicinity of $7. Particle makes a WiFi transmitter about the size of a fingernail and at a cost of approximately $10. The Kinoma chip runs JavaScript natively and is also the size of a fingernail, and comes with a simple SDK which can be used to program the chip wirelessly. The small dimensions of these components are the key to their portability, affordability and disposability. The Maker Movement has inspired Pluribus Technologies to an assertive feat of engineering in the service of data analysis. The array of microsensors to be mobilized on our platform is intended to maximize imaging capability. Although the number of sensors may vary, and their mobility may suggest erratic data, this concept is meant to ensure a single, detailed image that may be altered to the degree the user so chooses.

This proliferation of small, simple, and inexpensive off-the-shelf or custom components, combined with easy data streaming, cloud-based 3D editing and rendering Web services, and advanced front-end Web data visualization technology enables data collection from many low-resolution sources positioned around a space. These many streams can subsequently be received and relayed by a Web application running on a tablet device, unified via one of many free or low-cost data streaming and aggregation network services, and delivered to a cloud-based server. On the server, image manipulation Web services can be invoked on these input streams to create a single high-resolution, 3D image, which can then be returned to a Web application running in a browser. The image can then be further viewed and manipulated in the browser by providing Ux controls which invoke image manipulation APIs, permitting real-time collaboration and subsequent output of the file to one of the many popular 3D image formats.

According to Dr. Jingyi Yu of University of Delaware, to obtain photorealistic three-dimensional video images requires 28 sensors [6]. However, to compose a still 3D image from multiple sources could be done with as few as six sensors; the more sensors that can be deployed, the higher the resulting image's resolution and fine detail. The Pluribus camera sensors will be distributed throughout the space in order to provide as many points of view (POVs) as possible within the constraints of a given application. While the cameras will record only what falls within the lens compass, a dynamic image is nevertheless attained as the mobile units' programming orients and drives the collective's movement within the space. Their circuit boards will run JavaScript code that can package the sensor data into data streams, and use a WiFi chip to transmit the streams of data to a JavaScript client Web application running on a tablet device. The client application will relay the streams via a streaming aggregation service to the Pluribus servers, which will run NodeJS software that can call Forge Web services to compose a single 3D image from the streams. The Pluribus Web servers will serve the resulting image to the client application on the tablet, which will invoke APIs, also provided by Forge.

Swarm Imaging will leverage key concepts from neural network approaches to maximize swarm capabilities at a reduced computational cost. The capacity to engage multiple mobile sensors working in concert reduces the cost overall and minimizes the compromise in case of lost or destroyed units. The units will be small enough to be deployed in places not commonly accessible to drone or human entry.

Another novel feature of the Swarm approach is scalability. In case a rough image is all that is required, perhaps only six Pluribus sensor units need be activated. It is true that they could gather more POVs and therefore more detailed images over time; however, battery life would be a limiting factor in this employment. Certainly the more units engaged, the more POVs there will be to stream, and so it will be possible to get increasingly higher resolution images in real time by deploying a larger Swarm to a single location.

The resulting user interface of the Web application will include controls to rotate, edit, share, and export the resulting image file, in real time. The real-time streaming of data should allow for updates to render a progressively more detailed 3D image. From movies to animation, from art to architecture, the plethora of Autodesk products are ubiquitous in use. Forge allows the exporting of files to any Autodesk products' format, so users can leverage their existing software skills to consume and make use of the image as part of their existing workflow. A collaboration feature will allow sharing of the same file in the Pluribus Web application, so multiple users can make edits to the same file concurrently.

III. APPLICATION

There are already companies with offerings in this space, but Pluribus Technologies targets several applications to suit potential users discouraged by the cost and glacier paced image creation of common 3D cameras. An intrepid surveyor would certainly risk sophisticated gear--not to mention life and limb--trying to map a sewer system, for example, but could complete the task somehow. Similarly, drones can carry a 3D camera and map areas outdoors with great precision. These are, however, ill-suited for inspecting for mold or rot between roofing tiles and damage to building foundations.

The Pluribus sensors are estimated to have a production cost and sale price sufficiently low so as to make them potentially disposable. Users can be confident of acquiring a highly effective data analysis apparatus without breaking a budget or being burdened with high maintenance expenses.

Pluribus technology is conceived to leave a light footprint as a terrestrial, mobile system that delivers a flexible imaging/mapping capability. This economical solution should appeal to a variety of users seeking crucial vantage and advantage.

- Architects and designers can use it to create detailed topographical plans to aid their spatial conception, for example determining what set of furnishings will fit best into a room. The room view can be rotated or exported for editing. Most professionals in this area are using Autodesk products already, so swarm imaging will interface well with their workflow.
- City, State, and Federal agencies could use it for infrastructural planning, mapping out old, forgotten sewer systems and subway tunnels. These architects and engineers also overwhelmingly use Autodesk products.
- Real estate sellers could use it to create interactive maps of their properties; buyers would have the option to inspect the building for structural weaknesses, damage hidden out of sight, termite infestations, and so on.
- There are potential uses as stealth technology for military apps, especially scouting ahead for enemy combatants and explosive devices. Areas could also be cleared of landmines left behind from prior conflicts.
- Likewise, police might deploy the system for surveying hostage situations, a scenario during which speed, silence and low visibility are essential for saving lives.
- The Pluribus imaging architecture will be especially well-suited for search and rescue because the Swarm can be released into small, compressed areas such as a collapsed tunnel or ruined building. We can only imagine how many people may have been located with the tireless swarm imaging tool after the earthquake last month in central Italy.

IV. CONCLUSION

Swarm Imaging provides a solution to some of the most challenging problems in data analytics today. This technology is capable of putting "eyes" into an unprecedented assortment of spaces, from the mundane area under your floorboards to the menace lurking around the corner, at the bottom of a dark stairwell, or just over the next ridge. The finely-grained architecture of Pluribus technology also works fast, providing the user a sensemaking tool responsive to rapidly changing circumstances. Whatever the nature of the business during a particular operation, Swarm Imaging executes the visual groundwork so that users can concentrate on what cannot be automated, the analysis that demands human intelligence.

Furthermore, Pluribus Technologies' emphasis on this invention's relatively low cost that makes it possible to put it in the hands of hardworking professionals who want to conduct their survey accurately at an affordable price point, to make it available for civil services charged with the quality of our community infrastructures and preservation of life, to add it to the arsenal of military and police forces so that men and women in uniform can feel more confident of success and survival on dangerous missions. From these many needs comes one visionary technology soon to be available for customers with the greatest need to see and make sense of the twenty-first century.

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