Towards Ubiquitous Sensing:

Staking Out the Best Paths To And Through the Upcoming 3D Data Avalanche

Ashley M. Richter

We live in the most visually connected point in time in human history.

We can find images of just about anything online these days. It's a far cry from the situation less than 200 years ago, when only the wealthy could afford a portrait of themselves or see the sights of the world. Now, any one of us can quickly search for a photo of anything. And what's more, we can snap a photo on our phones ourselves. We can share it over a variety of different social media mechanisms. If we feel so inclined, we can do more than take a single photo, we can shoot a quick video, or take a 360 panorama or make a quick GIF. The social media platforms we use regularly have given these media types a home, thereby encouraging their use.

What was once an expensive art and technical feat by an expert photographer is now a rapid click of a few buttons. Where once most people would have had one drawing or one photograph of themselves (if that), we now have hundreds, if not thousands of photos documenting our individual existences. We're barely 20 years into this new paradigm of personal data collection and widespread visualization of the world via crowdsourcing, and yet it already seems commonplace. It has already shifted to become the norm. And having a robust digital presence online is seen as validation—both personally and professionally. But this is only the beginning….

By creating technologies that provide a mechanism to collect data and a place to show it off with a streamlined pathway between them— suddenly the collection of data (which sounds so erudite and dusty)—is something that everyone does all the time, often without even thinking of it as data. Thus, collecting data has become increasingly democratized---allowing for an even greater amount of information from unique vantage points to be created and shared, and thereby available for potential analysis.

But right now, the state of the industry of quickly shareable, open source intelligence content, is rooted firmly in the two-dimensional.

With the exception of a few emerging archives like Thingiverse and Sketchfab for hobbyist 3D photogrammatrists and the handful of industries like autonomous vehicles, structural engineering and architecture (aka building information modelling or BIM) and archaeology and museum sciences (aka digital heritage)—large scale preparation for 3D data collection at the handheld level is still in its infancy. But it won't be there for long.

This paper is a brief overview of the likelihood of ubiquitous sensing allowing everyday users to collect and share phenomenologically appropriate 3D data sets of their surrounding world, thereby creating an endlessly updating virtual digital scaffold of the planet at increasingly high resolutions. This paper is an exploration of the historical trends in technology development and anthropological trends in content creation, sharing, and privacy that support the willingness of humanity at large to build such potentially invasive technology and then to use it. This is a paper highlighting the need for national security groups to work with interdisciplinary 3D imaging stakeholders to push the best, analytical versions of a 3D imaging pipeline into creation for general and government use.

Before we delve into the evolution of imaging technology and its multidimensional future, it's important we take a quick dive into the evolution of humanity and communication systems in order to understand why we would consider expanding the information we share into a 3D phenomenological space.

Why are we willing to share information?

Why are we willing to put pieces of ourselves on display in public for all to see?

The answers are multifold, and could take up the interiors of thousands of books. But what it most often comes down to in all of those tomes, is our biological programming. Like all flora and fauna the world over--we are programmed to replicate ourselves by having children. In other words: we are programmed to create. And for humans, in order to raise those children to term and provide for them, we have to be able to communicate with each other and with them. Scale those two concepts of creating and communicating and apply them to digital systems, and Facebook starts to make a lot more sense.

Add in some of the psychological anthropology and historical concepts attached to human society over time regarding creation and sharing and it clicks together further: Existentially, we are aware of our mortality, of the shortness of our time here. And that has prompted artist and author and politician alike to stand up and create things. To leave behind memorials to themselves and the time and place that they came from. To say 'I was here' by leaving behind a painting, or poem, or pyramid. We desperately want to be remembered as individuals. We want our stories told. Our biological tendency to create is to pass along our genes, so that our genes are remembered. Our artistic tendency is to create anything whatsoever so that we can be remembered by it as a genetic proxy. Social media mechanisms like Facebook and Twitter open the possibilities of creation and memorial to a wider socio-economic distribution of the human population than ever before, at a rate never seen before. And in so doing, it has opened up increasing pathways of communication regardless of geographical proximity. This connectivity to people and ideas and their created content has strengthened the human compunction to participate online, and will likely continue to do so as more mechanisms to create and communicate are conceived of.

How can such a projection be made? By comparative analysis of the trends of other communication technologies that predate the internet in all its glory. We touched briefly on the history of photography in the opening of the paper and its movement from a highly specialized art towards democratized status quo. It should also be noted how much other technology was derived from the sudden boom in photography. From those early technologists working on photographic systems we not only got better cameras, we got moving pictures---cinema, television, and ultimately systems like Youtube and Netflix. There was a domino effect at play. Running alongside the technology development, was the same opening up of use. Amateur filmmakers became big studios monopolizing cinema and controlling who made what content. And Now we have a system where content is still king, but can be made and shared by any pauper with sufficient time and energy. This pattern of "hobbyist" to "professional" to "casual/ubiquitous use" repeats itself frequently throughout the history of technology. Consider quickly the printed word. The original printing presses were small, hobbyist affairs. But the next

several centuries were dominated by publishing houses controlling the content, giving way to newspapers doing the same. And yet now, with digital systems—anyone can (fortunately and unfortunately) blog online.

The timelines of each is also worth nothing. The printed word cycled over centuries to its present state, but photography, emerging at a time where the printed word was already in place to share information about the new technology, evolved through its own version of the cycle much more rapidly. With both these and other technologies in place to promote the use of emerging technologies, it can be presumed that those new technologies would cycle through to ubiquitous use much faster than its predecessors.

When this pattern of hobbyist to professional to ubiquitous is compared to the emerging technologies that capture 3D images of time and space--like photogrammetry and laser scanning, we find ourselves at an interesting cusp point wavering between hobbyist and professional. Rapid photogrammetry is the domain of both depending on scale---hobbyists lead structure from motion capture technologies that create 3D models from the ground, while professional and commercial entities dominate photogrammetry collected from on high for wider 3D swathes, but with lower resolution imagery. Laser scanning or LiDAR is likewise a mix of both. Terrestrial LiDAR is used most often in obscure commercial circumstances or on the more 'hobbyist' end by enterprising archaeologists. Aerial LiDAR is, like photogrammetry, dominated by professional, often government related, entities and captures a lower resolution as compared to its terrestrial counterpoint. But, like the camera, printed word, and other communication technologies before them, if the right pipelines of development and use are put in place for humanity to utilize these 3D systems, people will use them and push them farther. If you build it, they will come. And then we'll all have holodecks.

With the rise of virtual, augmented, and mixed reality (VR, AR, MR) interests, there is already increasing pressure to sort out the translation of real 3D data pipelines into these new multimedia systems (as opposed to the created, game or CAD style content that currently fills VR et al). Many of the commercial grade VR and AR systems already out even involve a certain level of proprietary local mapping of use space to even set up their equipment. But if it is only *commercial* pressure on the new imaging systems, the government will be left to cope with new multimedia mechanisms instead of being involved in their design and tactically engaged in setting them up for future analytical benefit like they were with early imaging technologies. Nor are the systems likely to realize their full potential without significant government engagement.

If the government were to push advances in the areas that are currently holding these 3D technologies back from ubiquity, the 3D floodgates would open. This means supporting advanced computing processing systems (everyone wants and needs quantum systems anyhow), encouraging the development of smaller, cheaper sensors (if your phone or ring has a LiDAR system on it, you will play with it and then want to show your living room to your grandmother), emphasizing the need for integrated multimodal data systems (a living 3D model of the world is only the beginning, add in some more of the spectra and you start having a particularly beautiful analytical tool for any frontline or fieldwork focused work, and then some), and pushing for collaborations to create or creating its own front-facing software app with appropriate creative commons copyrights that streamlines the data capture into the already prevalent social media streams (i.e. building the Instagram system for 3D scene capture that connects directly to Facebook, LinkedIn, Oculus, MagicLeap, or whatever the future mechanism might be). But most importantly of all, much consideration and growth needs to be applied to machine learning in

3D venues so that automatic change detection and feature searching will aid the analyst in these new virtual realms.

If national security groups want analytical features embedded in these initial widespread systems, they need to help embed them. If national security groups want to ensure that there are security protocols in place for safeguarding that no one shares a 3D point cloud of the White House interiors, they need to play a dominate role in helping design the system. It's not enough for government groups to cope with new technology and make the best of it. An active government role is needed in developing these new, systems of imaging technology, their use functions, and their limits if they're to be as helpful as they could be to the government, and to humanity at large as a digital scaffold upon which to drape the rest of the world's knowledge and then to access it from.

It's definitely all a bit Big Brother-y. But it's virtually inevitable at this point. Ubiquitous sensing is coming. And the question is NOT how much the future of ubiquitous 3D (and likely multispectral) imaging will invade people's privacy. Our willingness to share and to be remembered will most likely override this past century's sudden concern for personal privacy (a concern that humanity, arguably, rarely felt as strongly about until recently. Security yes. Privacy no).

The question is: How are national security groups and others going to make the best of it on behalf of us all?

Bianchini, C., Borgogni, F., Ippolito, A., Senatore, L.J., Capiato, E., Capocefalo, C., and Cosentino, F., 2012. From Surveying to Representation: Theoretical Background, Practical Issues, Possible Guidelines. *IEEE Virtual Systems and Multimedia*.

Borges, J.L, 1998 reprint. The Library of Babel. *Collected Fictions*.

Burrows, W.E., 1986. *Deep Black: Space Espionage & National Security*. New York: Random House.

Chen, C.-Y. and Chien, H.-J. 2014. Geometric Calibration of a Multi-Layer LiDAR System and Image Sensors Using Plane Based Implicit Laser Parameters for Textured 3D Depth Reconstruction. *Journal of Visual Communication and Image Representation* 25, 659-669.

Chen, J., Dowman, I., Li, S., Li, Z., Madden, M., Mills, J., Paparoditis, N., Rottensteiner, F., Sester, M., Toth, C., Trinder, J., Heipke, C., 2016. Information from Imagery: ISPRS Scientific Vision and Research Agenda. *ISPRS Journal of Photogrammetry and Remote Sensing* 115, 3-21.

Dosi, G. and Nelson, R.R., 2010. Technical Change and Industrial Dynamics as Evolutionary Processes. In: Arrow, K..J. and Intriligator, M.D. (eds.) *Handbook of the Economics of Innovation*. Amsterdam: Elsvier 51-127.

Forte, M., 2000. About Virtual Archaeology: Disorders, Cognitive Interactions, and Virtuality. In: Barcelo, J.A., Forte, M., Sanders, D.H. (eds.) *Virtual Reality in Archaeology*. Oxford: Archaeopress.

Foucault, M. 1986. Of Other Spaces. *Diacritics*. 16(1), 22-27.

Geertz, C., 1973. Thick Description: Toward and Interpretative Theory of Culture. In *The Interpretation of Culture*. New York: Basic Books.

Gleick, J., 2012. *The Information: A History, A Theory, A Flood*. New York: Random House.

Hess, M., Petrovic, V., Meyer, D., Rissolo, D., and Kuester, F., 2015. Fusion of Multimodal Three Dimensional Data For Digital Documentation of Cultural Heritage Sites. *Digital Heritage* 2, 595-602.

Hodder, I., 2012. *Entangled: An Archaeology of the Relationships Between Humans and Things*. NJ: Wiley-Blackfield.

Huynh, A., and Lin, A., 2013. Mobile Analysis of Large Temporal Datasets for Exploration and Discovery. *Computer Applications and Quantitative Methods in Archaeology*.

Mutz, F., Veronese, L.P., Oliveria-Santos, T., de Aguiar, E., Aaut Cheein, F.A., Ferreira De Souza, A., 2016. Large Scale Mapping in Complex Field Scenarios Using An Autonomous Car. *Expert Systems With Applications* 46, 439-462.

Pan, X., Schiffer, T., Schrottner, M., Havemann, S., Hecher, M., Berndt, R., Fellner, D.W., 2012. A Scalable Repository Infrastructure for CH Digital Object Management. *IEEE Virtual Systems & Multimedia*.

Petrovic, V., Richter, A.M., Levy, T.E., Kuester, F., Visualizing and Navigating Layered Data Realities (unpublished).

Petrovic, V., Vanoni, D.J., Richter, A.M., Levy, T.E., Kuester, F., 2014. Visualizing High Resolution Three Dimensional and Two Dimensional Data of Cultural Heritage Sites. *Mediterranean Archaeology and Archaeometry* XX, 93-100.

Pintus, R., Gobbetti, E., Agus, M., 2011. Real-Time Rendering of Massive Unstructured Raw Point Clouds Using Screen Space Operators. *12th International Symposium on Virtual Reality, Archaeology, and Cultural Heritage (VAST) in Eurographics*.

Richter, A.M., Petrovic, V., Angelo, R., Seracini, M., and Kuester, F., 2013. From STEM to STEAM: Towards Aerospace Partnerships with Cultural Heritage Diagnostics. *IEEE Aerospace*.

Richter, A.M., Petrovic, V., Vanoni, D.J., Darling, J.M., DeBlasio, J., Mangan, J., Hoff, A., Levy, T.E., Kuester, F., 2013. Finding Meaning in the Data Avalanche. Presented: *Virtual Art, Museums, and Cultural Tourism Symposium Delphi, Greece*.

Richter, A.M., Petrovic, V., Vanoni, D.J., Parish, S., and Kuester, F., 2013. Digital Archaeological Landscapes and Replicated Artifacts: Questions of Analytical Phenomenological Authenticity and Ethical Policies in Cyberarchaeology. *IEEE UNESCO Digital Heritage Symposium*.

Richter, A.M., 2015. The Ban on Blueprints You Never Knew About. *Bitter Empire*.

Sapir, E., 1927. The Unconscious Patterning of Behavior in Society. In Sapir, E., *Selected Writings in Language, Culture, and Personality,* 544-559.

Scheiblauer, C., Zimmerman, N., and Wimmer, M., 2011. Out of Core Selection and Editing of Huge Point Clouds. *Computers & Graphics* 35(2), 342-351.

Shore, B., 1991. Twice Born-Once Conceived: Meaning and Cultural Cognition. *American Anthropologist* 93 (1), 9-27.

Van der Elst, J., 2010. Exploring Cognitive Landscapes: Towards An Understanding of the Relationship Between Space/Time Conceptualization and Cultural Material Expression. In Forte, M. (ed.) *Cyber Archaeology*. Oxford: Archaeopress, British Archaeological Report Series 2177, 75-84.

Wand, M., Berner, A., Bokeloh, M., Jenke, P., Fleck, A., Hoffman, M., Maier, B., Staneker, D., Schilling, A., and Seidel, H., 2008. Processing and Interactive Editing of Huge Point Clouds from 3D Scanners. *Computers & Graphics* 32(2), 204-220.

Weinberger, S., 2017. *The Imagineers of War: The Untold History of DARPA, The Pentagon Agency That Changed The World*. New York: Alfred A. Knopf.

Zhao, G., Xiao, X., Yian, J., Ng, G.W., 2014. Fusion of 3D LiDAR and Camera Data for Scene Parsing. *Journal of Visual Communication and Image Representation* 25, 165-183.

Ziman, J., 2000. *Technological Innovation as an Evolutionary Process*. Cambridge: Cambridge University Press.