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Novel Data Visualizations Of X-Ray Data For Aviation Security Applications Using The OTAP Platform

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Abstract. This work will demonstrate the implementation of a traditional and non-traditional visualization of x-ray images for aviation security applications that will be feasible with open system architecture initiatives such as the Open Threat Assessment Platform (OTAP). Anomalies of interest to aviation security are fluid, where characteristic signals of anomalies of interest can evolve rapidly. OTAP is a limited scope open architecture baggage screening prototype that intends to allow 3rd-party vendors to develop and easily implement, integrate, and deploy detection algorithms and specialized hardware on a field deployable screening technology [13]. In this study, stereoscopic images were created using an unmodified, field-deployed system and rendered on the Oculus Rift, a commercial virtual reality video gaming headset. The example described in this work is not dependent on the Oculus Rift, and is possible using any comparable hardware configuration capable of rendering stereoscopic images. The depth information provided from viewing the images will aid in the detection of characteristic signals from anomalies of interest. If successful, OTAP has the potential to allow for aviation security to become more fluid in its adaptation to the evolution of anomalies of interest. This work demonstrates one example that is easily implemented using the OTAP platform, that could lead to the future generation of ATR algorithms and data visualization approaches.

INTRODUCTION

Airports in the United States currently use two different methods for screening passenger baggage: carry-on baggage is screened using dual-energy X-ray systems, and checked baggage is screened using X-ray computed tomography (CT) systems. Both carry-on and checked baggage screening systems utilize a class of algorithms called "automated threat recognition". These algorithms are capable of characterizing materials and identifying anomalies of interest. Images coming off these systems are displayed in colors representative of the types of materials found in the scanned bag [7].

There is a growing interest to invest in solutions that enable a rapid response to emerging threats in aviation security, including the development of new integrated technologies. However, there are challenges with the current system. The TSA Security Capability Investment Plan states

> "…current systems are highly complex and proprietary with little data, image or interface standardization. This means that OSC must depend solely on the equipment manufacturer and existing contracting mechanisms for software, algorithm, component or operational upgrades. This limitation prevents OSC from engaging new and innovative partners to solve problems and can slow response to the emerging needs."

And

"The static and inflexible nature of these capabilities makes it difficult to adapt to changes in the aviation threat landscape in a timely, cost effective manner. This often leads to the deployment of procedural workarounds that increase cost to TSA or negatively impact throughput." [12]

The development of new integrated solutions and interface standardization could potentially allow for a far faster and efficient deployment of certain types of upgrades. To this end, Sandia is working on a limited-scope prototype to design and implement a modularized approach to aviation security X-ray and CT systems, the Open Threat Assessment Platform (OTAP). The ability to plug-and-play algorithms, software, and hardware into field-deployed systems has the potential to reduce the cost of upgrading technology in the face of an ever-changing security environment. By allowing for new algorithms to be pushed out to systems already in the field, adaptation speeds could potentially be increased in response to new anomalies of interest and techniques of concealment.

OTAP could potentially lead to new innovative solutions that can leverage new sources of data relevant to aviation security and the detection of anomalies of interest. The work being presented on stereoscopic imaging from CT and field-deployed X-ray systems is one example, and leverages human vision and the brain's ability to interpret 3-dimensional information. Humans view the world using binocular vision, and because of this are able to perceive the depth between objects in a given field of view. Binocular vision provides humans with two different viewpoints projected into the eyes, and the brain is capable of interpreting the parallax between these two viewpoints as depth information. Parallax can be defined as the position of an object viewed along two different lines of sight, and is measured by the angle of inclination between the two lines, as shown in Fig. 1.

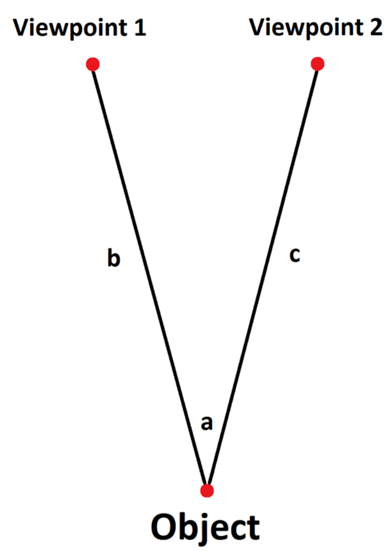

FIGURE 1. The parallax between viewpoints 1 and 2 is defined as the angle *a* along the lines of sight *b* and *c*.

Stereoscopic images seek to mimic the process of binocular vision by projecting a different viewpoint into each eye, and utilizing the brain's ability to interpret depth from the difference in those two images. Stereoscopic images can be created on a spectrum of depth perceived. Ortho-stereoscopic images aim to create the same amount of depth that humans perceive with their own eyes. Hyper-stereoscopic images create an exaggerated perception of depth. Hypo-stereoscopic images create a negligible perception of depth [11]. When creating stereoscopic images, as the horizontal offset between the two viewpoints used increases, so will the parallax between the images. As the parallax between two viewpoints increases, the amount of depth perceived from viewing the images as one stereoscopic image will increase. At a certain point, the brain is no longer capable of interpreting increases in depth between objects in the image, and the viewer will no longer be capable of perceiving the two separate viewpoints as one image. The point at which this occurs varies by the individual viewer.

In this research, stereoscopic images were created along a spectrum from ortho-stereoscopic to hyper-stereoscopic. It is believed that an exaggerated perception of depth when viewing a passenger's baggage could increase the capability of the viewer to locate and identify anomalies of interest. However, stereoscopic images too far on the hyper-stereoscopic side of the spectrum could lead to greater amounts of viewer discomfort [8]. The distance between an individual's pupils, known as the inter-pupillary distance, can differ greatly. Once the parallax of a given stereoscopic image exceeds the normal parallax experienced by an individual due to their inter-pupillary distance, visual discomfort can occur [9] [10]. Images were not taken in the range of ortho-stereoscopic to hypo-stereoscopic because negligible amounts of depth would not feasibly aid the viewer in identifying anomalies of interest any greater than viewing a flat image would.

It is not possible to induce parallax between two X-ray images digitally. When creating an X-ray image, certain geometrical artifacts can present themselves depending on the position of the object relative to the X-ray source. These artifacts would not be present in an image that had digitally constructed parallax. One such image characteristic occurs when part of an object is in a different location relative to the X-ray source. Parts of the object being scanned that are closer to the beam center are going to receive larger amounts of radiation, and the resulting image will reflect this. In a baggage scanning system, like those found at carry-on baggage screening checkpoints in airports, different regions of the resulting image could be colored differently due to receiving different amounts of radiation.

Due to the shape of the X-ray beam, and the distance from the object to the detector, the resulting image will also experience magnification and/or distortion. A fan-beam X-ray source, commonly used in aviation security applications, will result in magnification defined by:

$$\frac{x_2}{x_1} = \frac{SID}{SOD}$$

Where x_1 is the length of the object being scanned by the fan-beam, x_2 is the length of the resulting image plane, SID is the source-to-image distance and SOD is the source-to-object distance.

Artificially creating parallax by altering an X-ray image using image processing software will not reflect the changes in magnification that would occur if two separate scans were taken. Whatever magnification and/or distortion occurs to the resulting images will be reflected in the stereoscopic image as differences between the two original images.

APPROACH

Stereoscopic images of an object were created using two different methods. The first method used a CT system, and applied parallax to the object through slight rotations. The second method used a fan-beam radiography system, and applied parallax by translating the object horizontally.

The stereoscopic images created from scans taken on the fan-beam radiography system were on a spectrum from ortho-stereoscopic to hyper-stereoscopic. In order to achieve desired angles of parallax between each viewpoint, the 1/30th rule was utilized. The 1/30th rule is a commonly used technique to achieve a desired ortho-stereoscopic effect, and states that the distance between the two viewpoints being used should be equal to 1/30 the distance from each viewpoint to the nearest object in the field of view, as shown in Fig. 2. In order to achieve a desired hyper-stereoscopic effect, the distance between the viewpoints should tend toward 1/15 the distance from each viewpoint to the nearest object in the field of view [1] [2].

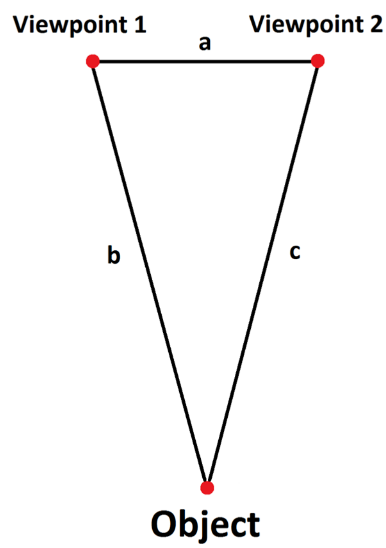

FIGURE 2. The distance *a* between viewpoints 1 and 2 is equal to 1/30 the distance *b*, where *b* and *c* are equal

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IMPLEMENTATION

Laboratory-Grade CT System

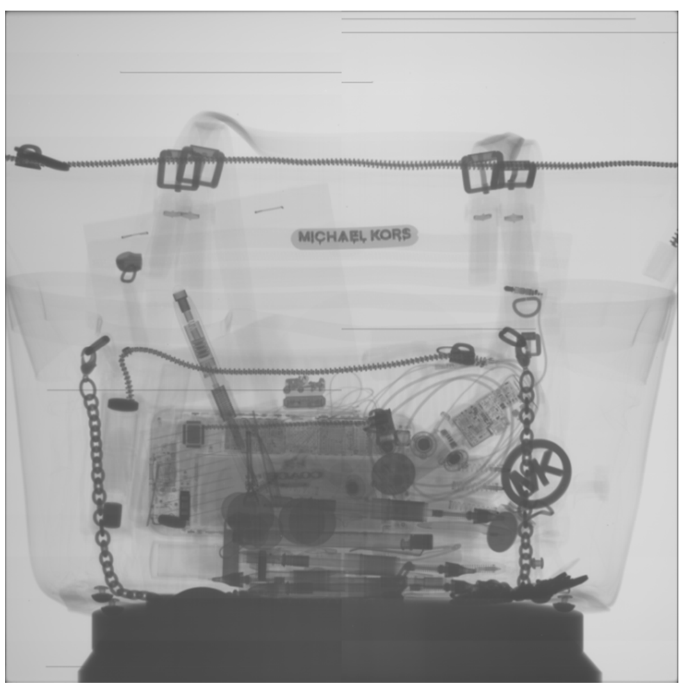

FIGURE 3. Radiography image of the packed purse at its initial position.

Scans taken on a laboratory-grade CT system were of a purse packed with typical items that may be present. The system used a Perkin-Elmer detector and Comet 450 keV source set at 225keV. The SID was 189 cm and the SOD was 174 cm. A total of 100 scans were taken of the purse, with a rotation of 3.6 degrees applied to the purse before each scan. Figure 3 shows the first scan taken, before any rotation had been applied. After each rotation of 3.6 degrees was applied to the purse, it was then secured in place to ensure that no additional movement not induced by the rotational stage occurred.

Field-Deployed System

Scans taken on a field-deployed carry-on checkpoint system were of a suitcase packed with typical items that may be present. In order to measure the horizontal offset required for each scan of the suitcase, all horizontal offsets were measured and marked on a piece of tape. The tape was secured on the system's conveyor belt, and all horizontal offsets were made with respect to the measurements on the tape. All contents of the suitcase were secured down to ensure that there was no movement amongst the individually packed objects. The suitcase was secured to the conveyor belt after each horizontal offset was applied, to ensure that no additional horizontal movement occurred. Figure 4 shows the packed suitcase at its initial position, before any horizontal offset had been applied. The following horizontal offsets were used: 1.31 cm, 1.46 cm, 1.64 cm, 1.88 cm, 2.19 cm, and 2.62 cm. The field-deployed system used produces two images from one scan. One of the images produced is of a top-down view, and the other is of a side view. All of the stereoscopic images created used the top-down images only. The SOD and SID were unknown for this system, so estimates were made in order to calculate the desired parallax. No changes were made regarding the hardware of this system, or the geometry of the hardware.

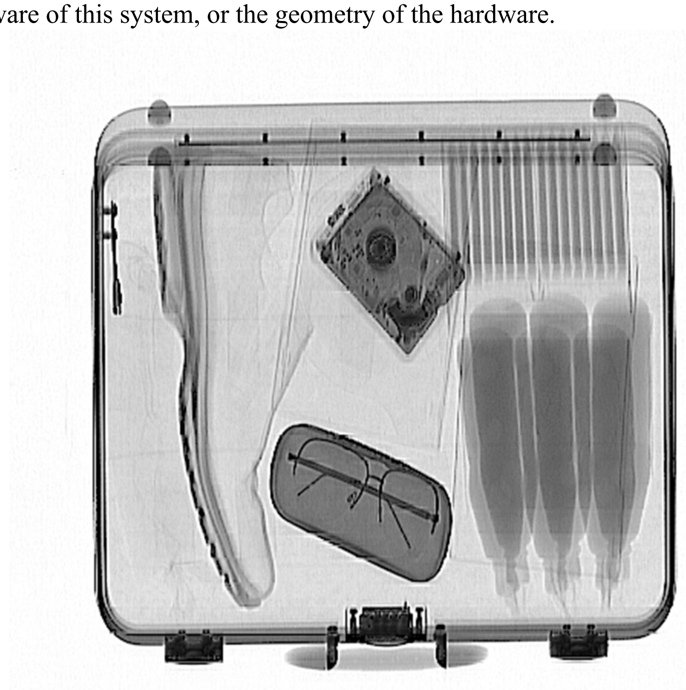

FIGURE 4. Radiography image of the packed suitcase at its initial position.

The images collected from each system were concatenated together, as shown in Fig. 5, and a video was created frame-by-frame of the concatenated images. The resulting video is rendered on the Oculus Rift virtual reality headset as a stereoscopic image.

FIGURE 5. Concatenation of the resulting radiographs. The suitcase on the right is offset 1.31 cm from the suitcase on the left.

RESULTS

Field-Deployed System

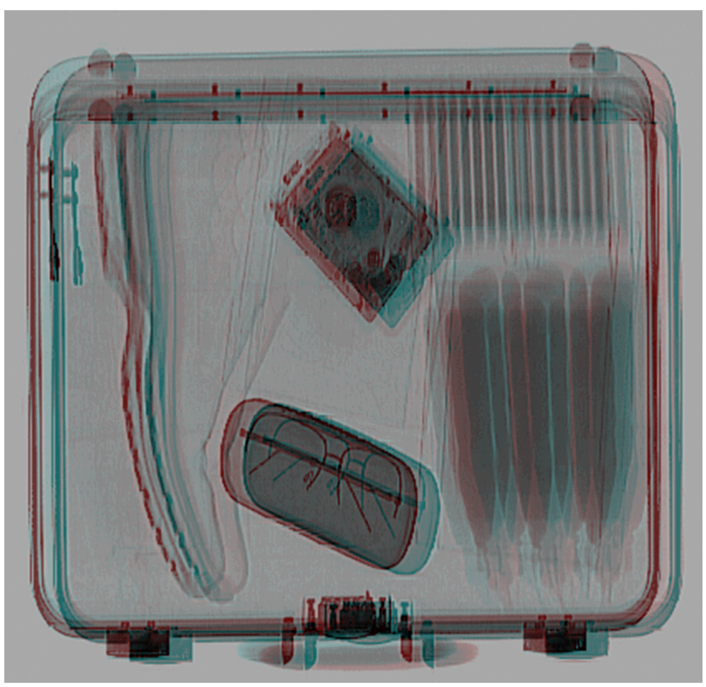

FIGURE 6. Layered image of the suitcase horizontally offset.

Figure 6 shows the horizontal offset of each object inside the suitcase. A group of test viewers had varying degrees of success gleaning depth information from the images collected on the field-deployed system. The majority of test viewers were able to perceive depth in the set of field-deployed stereoscopic images. The remaining viewers were not able to view the concatenated images as a stereoscopic image. All viewers struggled to maintain their perception of depth while viewing these images. It was reported that the stereoscopic image would intermittently disappear, and the viewer would begin to see two images. Over time, the viewer would begin seeing the two images as a stereoscopic image again.

It was found that the further from the center of the image the suitcase was, the harder it was for viewers to perceive any depth in the image. The initial set of images from the field-deployed system had the suitcase to the right of the image center. When viewing this set of images, some viewers were able to see the stereoscopic image as one image, but unable to perceive much depth in the suitcase. As a result, another set of images was created that placed the suitcase closer to the center of the image. When viewing this set of images, viewers were able to see the stereoscopic image as one image, and were able to perceive depth in the suitcase.

Laboratory-Grade CT System

FIGURE 7. Layered image of the purse rotationally offset.

Figure 7 shows the rotational offset of each object inside the purse. All test viewers were successful in gleaning depth information from the images collected on the laboratory-grade CT system. The clarity of depth experienced by viewers was found to be much greater than in the set of stereoscopic images created from the field-deployed system. At no point during viewing the purse images did any users lose their perception of depth, as was the case with the images created from the field-deployed system. No users reported experiencing a loss of depth perception, or intermittently seeing the stereoscopic image as two separate images. Users did not report any differences in the ability to perceive depth in portions of the image closer to center, versus portions of the image closer to the edges.

CONCLUSIONS

The ability to create stereoscopic images from Radiographs has been demonstrated in the past [3] [4].These implementations all require significantly specialized modifications to existing hardware and extensive funds. The technique described in this work requires no specialized modifications to any hardware (although can be optimized with hardware modifications), and Oculus Rift headsets are commercially available.

There were multiple limiting factors in this work. X-ray images coming off of the field-deployed system used were very low resolution compared to the laboratory-grade CT system used. Due to their low resolution, objects appear blurry and pixelated, making it difficult to observe depth when viewing them as stereoscopic images. Images coming off of the laboratory-grade CT system are a much higher resolution (2048 x 2048), and it is believed that this is one possible reason for the higher success rate in perceiving depth in these stereoscopic images.

The images created on the field-deployed system differed in resolution, due the scanning process beginning when the object initially passed through the X-ray beam. In order to preserve the horizontal offset of the packed suitcase, a constant stationary object was placed on the conveyor belt in front of the suitcase to ensure that the scanning began at the same point for all iterations. The suitcase's position changed relative to the constant object, therefore the scanning process ended at a different position for all iterations. It has been shown that differing resolutions in the images used to create stereoscopic images can lead to a lower overall quality of depth perception in the resulting stereoscopic image [6]. The initial image of the suitcase before any horizontal offset had been applied has a resolution of 540 x 632. The resolution after 1.31 cm of horizontal offset were applied is 547 x 632. Each incremental horizontal offset increased the width of the image by 2 pixels.

When creating the set of stereoscopic images on the field-deployed X-ray system, the exact geometries of the system were unknown. Estimates had to be made for the detector-to-object distance in order to offset the packed suitcase appropriately to achieve the desired angle of parallax. The estimate made for the detector-to-object distance could have been substantially different enough from the exact distance that the angle of parallax for a particular stereoscopic image was too large or little for optimal viewing. However, multiple stereoscopic images were created on a spectrum from ortho-stereoscopic to hyper-stereoscopic. While it is possible that a single image would have an angle of parallax that is suboptimal for viewing, due to the number of images created, that issue should not present in all of them.

DISCUSSION

This work demonstrates a potential future capability that could potentially be integrated into aviation security systems through and open systems architecture such as the OTAP platform. Scans were taken on an unmodified system, and the resulting data was removed from the machine and transferred to a secondary machine. The algorithms necessary to create the stereoscopic images were used on this secondary machine, and viewing was done on the Oculus Rift. The different capabilities detailed in this process do not exist in airports today, and if implemented, could potentially increase the capability of checkpoint screening agents to locate and identify anomalies of interest. Open systems architecture could also implement the capability for new algorithms to be remotely pushed out to airports across the country, which is logistically challenging due to the highly complex and proprietary nature of current systems deployed at security checkpoints. Due to the current method of new development for baggage checkpoint screening systems, there is no easy path to participation for 3rd parties to develop new algorithms. If an open-systems architecture platform like OTAP is implemented by the TSA, then it is possible that incentives for 3rd party capability developers will improve and increase the number of capabilities available in the market. If necessary, new algorithms could potentially be developed and deployed rapidly in the face of new anomalies of interest or methods of obfuscating anomalies of interest [12].

Stereoscopic baggage scanning could lead to new developments in automated threat recognition algorithms for X-ray systems. It is possible that utilizing the depth information provided by stereoscopic images could advance automated threat recognition in X-ray systems to a more comparable level relative to those found with CT systems. It has been shown that 3-dimensional coordinate information can be extracted from stereoscopic images by analyzing voxels created from the two overlapping fields of view in a stereoscopic image. Accumulating multiple stereoscopic images of the same object in different positions will allow for the extraction of larger amounts of coordinate information using this method [5]. Being able to extract coordinate information could help to better visualize anomalies of interest, and identify characteristics such as shape and size.

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CITATIONS

1. Yancong Lin, Jiachen Yang, Zhihan Lv, Wei Wei, and Houbing Song. A Self-Assessment Stereo Capture Model Applicable to the Internet of Things. In Sensors 15(8), 20925-20944, (2015).
2. Wei Chen, Jérôme Fournier, Marcus Barkosky, and Patrick Le Callet. New stereoscopic video shooting rule based on stereoscopic distortion parameters and comfortable viewing zone. In Stereoscopic Displays and Applications XXII, 786310, (February 15, 2011).
3. Kang-eui Lee, Myung-Jin Chung, Young-hun Sung, Jong-ha Lee, and Kwang-eun Jang. Method and system for providing stereoscopic X-ray image. US 8908955 B2 (Dec 9, 2014).
4. Philipp Bernhardt and Martin Spahn. Method and system unit for stereoscopic x-ray imaging. US 8908826 B2 (Dec 9, 2014).
5.
6. J P O Evans. Stereoscopic imaging using folded linear dual-energy x-ray detectors. In Measure Science and Technology 13, 1388-1397. (July 31, 2002).
7. Lew B. Stelmach and W. James Tam. Stereoscopic image coding: Effect of disparate image-quality in left- and right-eye views. In Signal Processing: Image Communication 14, 111-117. (November 6, 1998).
8. Domingo Mery, Vladimir Riffo, Irene Zuccar, and Christian Pieringer. Automated X-ray object recognition using an efficient search algorithm in multiple views. In The IEEE CVPR Workshops, 368-374. (2013).
9. Filippo Speranza, James Wa, Tam, and Namho Hur. Effect of disparity and motion on visual comfort of stereoscopic images. In Proceedings of SPIE 6055. (February, 2006).
10. Wa James Tam, Filippo Speranza, Sumio Yano, Koichi Shimono, and Hiroshi Ono. Stereoscopic 3D-TV: Visual Comfort. In IEEE Transactions on Broadcasting 57, 335-346. (June, 2011).
11. Mark T. M. Lambooij, Wijnand A Ljsselsteijn, and Ingrid Heynderickx. Visual discomfort in stereoscopic displays: A review. In Proceedings of SPIE 53(3). (February, 2007).
12. Luis E. Gurrieri and Eric Dubois. Stereoscopic cameras for the real-time acquisition of panoramic 3D images and videos. In Stereoscopic Displays and Applications XXIV, 86481W (March 12, 2013).
13. U.S. Department of Homeland Security, Office of Security Capabilities. Transportation Security Strategic Capability Investment Plan. (May 30, 2014).
14. U.S. Department of Homeland Security, Office of Security Capabilities. Strategic Five-Year Technology Investment Plan for Aviation Security. (August 12, 2015).