Thermal Interaction & 3D Data Visualization

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ABSTRACT

I propose the use of thermal interaction to interact with 3D data visualization. The first section will go over the use of thermal sensors to utilize most surfaces with mobile technology. The second section will discuss spatial augmented reality as a tool for 3D data visualization. Taking these ideas and putting them together is the goal of this paper. A phone that has the ability to know exactly where a user puts their finger on a surface, and correlate that to a program or some other process, would be helpful in advancing the use of smaller mobile technology. Other advances would include being able to interact with charts, maps, or graphs without having to touch an electronic device. This can reduce the amount of electronic devices needed for modern life. I will discuss both studies, and then join them together in a way to minimizes the limitations that each has. This paper will discus the possible applications that would be possible when joining these methods and how they benefit us.

Keywords

thermal interaction, 3D data visualization, augmented reality, AR, spatial augmented reality, SAR

1. INTRODUCTION

Imagine being able to touch a table and have a phone know the location of the interaction. Now envision the same scenario, but this time the phone says the number 0 was pressed because the area touched corresponded to the number 0 on a dial pad that your phone depicts is on the surface. Research by Kurz [2] addresses this topic, being able to use thermal technology to accurately tell if a surface was touched by a finger and where. Kurz [2] states that as wearable technology becomes more prominent, alternative solutions to touch screens will be sought after. With that in mind being able to interact with technology with a screen would help advance the wearable technology.

Now, conceptualize a table that has a cone on it with projectors displaying data on the cone. This is how Thomas et al. [3] describes one of the ways to utilized spatial augmented reality as a tool for 3D data visualization. Using technologies to track where the user is and being able to move the cone to define a new visualization is how Thomas et al. [3] proposes using SAR for 3D data visualization. Also, mentioning the scalability of the proposed system. CAVE systems would be the larger versions of the table-top design mentioned above.

Before talking about how those types of applications work, an overview on background material is needed. After that, there will be a discussion on the use of thermal interaction with mobile technology. The discussion will then go over the hardware used in the experiments, tracking the objects being interacted with, detecting the thermal interaction, the materials used in the experiments, and the applications possible. Then moving onto the overview of 3D data visualization with spatial augmented reality. We will discuss the importance of data visualization, the applications possible, and the limitations. After the two overviews there will be a discussion on combining the two approaches, followed by a conclusion.

2. BACKGROUND

Before starting this paper, there are some concepts that should be made clear. It will be helpful to have a clear understanding of the differences between virtual reality, augmented reality, and spatial augmented reality. Also, knowing the concept of six degrees of freedom is beneficial.

2.1 Virtual and Augmented Realities

Virtual reality (VR) is when a system "artificially creates sensory experiences, which can include sight, hearing, touch, and smell" [5]. The most common experiences that VR creates for a user are through the use of sight and sound. A recent example of Virtual Reality is the Oculus Rift. An earlier take on this type of VR is the Virtual Boy, from Nintendo in the 90's. Like the Oculus Rift, the Virtual Boy is a device that strapped to the head of the user and is used to simulate a virtual world. As you turn your head, the field of view in the virtual world will change accordingly. An earlier example would be the view master. It is a stereoscopic toy that uses circular inserts that require the user to look into a light source to illuminate the picture. Being more primitive, the view master creates a 2D visual experience that does not move.

Augmented Reality (AR) can be described as augmenting the environment of the real world. It is different from VR because it is based in the physical world instead of the digital world. An example is Google Translate: using the camera

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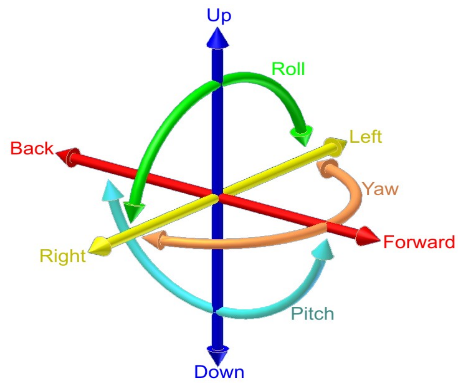

Figure 1: 6DOF axises related to 3D space [4]

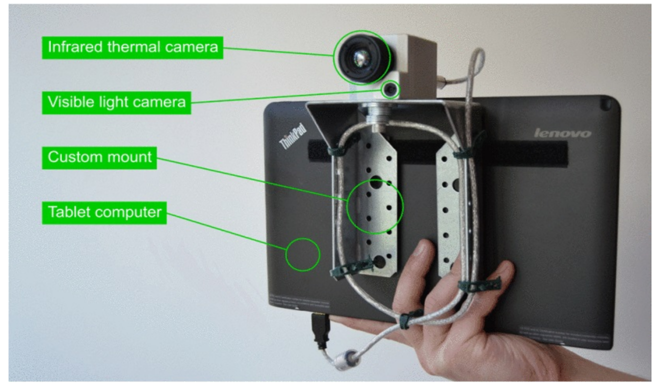

Figure 2: The hardware prototype used throughout Kurz's paper comprises a visible light camera and an infrared thermographic camera attached and connected to a tablet computer with a custom mount. [2]

from a phone, it translates foreign word(s) that the camera is pointed at. Using a program it can detect words from most languages, this works best with printed text. Then the program overlays the translation onto the sign, billboard, or menu on the screen of the device. The program uses the same font and font size as the original text. Another example of AR would be a 3DS and the 3D cards the system came with. A 3DS is a hand held gaming device that makes the game being played 3D without the use of 3D glasses. The cards that came with the system were little mini games. Placing a card on a surface and going into a special application started a game using the card the 3DS was pointed at. Creatures would pop up that the user would fight, or trying to hit bulls-eye on target. All this is done on the surface the card was placed on.

Spatial Augmented Reality (SAR) is a subsection of AR. The difference is SAR augments reality through the use of projectors, instead of using conventional monitors or other such devices. Thomas et al. [3] defines SAR as

> enhancing the visual aspects of physical objects, allowing users to better understand the virtual content. The users not only view the digital information but also gain a tactile understanding through touching the physical object.

A good example of SAR is an augmented sandbox. A user has a sandbox with a topographical map overlaid onto the sand from a projector. They could move the sand around and the system would be able to detect the height of the sand. In real, time the projector would match the peaks and valleys in the sand with the correct type of topographic overlay.

2.2 Interactions In 3D Space

In order to use any object to interact with system, it needs to know where the object is in relation to the cameras observing it. 6 degrees of freedom (6DOF) are the different ways one can move in three dimensional space. Front/back, left/right, up/down, roll, pitch, yaw are all the ways to move in 3D space. Roll is rotating in relation to the front/back axis. Yaw is rotating in relation to the up/down axis. Pitch is rotating in relation to the left/right axis. For clarification see Figure 1.

3. THERMAL INTERACTION

Kurz [2] provides a way to interact with AR applications using almost any surfaces. Using infrared thermography, his system can detect if the user touched a surface or came close to touching it. Keeping in mind that one's finger(s) are warm and the surface is presumably cool, a touch leaves a heat signature on the cool surface. Kurz's system assumes that the interaction is taking place in a controlled environment where surfaces will be cooler than body temperature. When the thermal image detects a heat signature, the same system is able to determine the 3D position on the touched physical object. A series of tests were done, using an array of materials and users to show the intuitive interaction with mobile AR and common surfaces.

3.1 Hardware

The hardware in Kurz's [2] setup was a camera mounted to a tablet computer, as shown in Figure 2. It needed to be custom fitted since the technology for thermal imagery is not typically built into everyday devices, like tablets or phones. The camera on the tablet mixes a visible light camera, and a infrared camera in one package. The visible light camera is able to capture RGB images at 480x360 pixels and the infrared at 160x120 pixels. The parameters of the visible light camera and the infrared camera along with the 6DOF rigid body transformation from both cameras were calibrated. The calibration method Kurz used had a checkerboard pattern cut into bright cardboard, then attached to a warm dark surface like an LCD screen. This is done so that the visible light camera sees dark squares on a light surface, but the infrared camera will see light squares on a dark surface.

3.2 Object Tracking

As mentioned above, Kurz's goal is detecting touch in 3D space with real objects, which requires the ability to transform real objects relative to the camera. Metaio is a AR company that developed object tracking software that can find the position and orientation of an object relative to the visible light camera in real time [2]. Kurz used the Metaio software so that the visual light camera on the prototype were able to get the position and orientation of the object(s) used in the experiments.

3.3 Thermal Detection

The two main obstacles that Kurz brings up are detect-

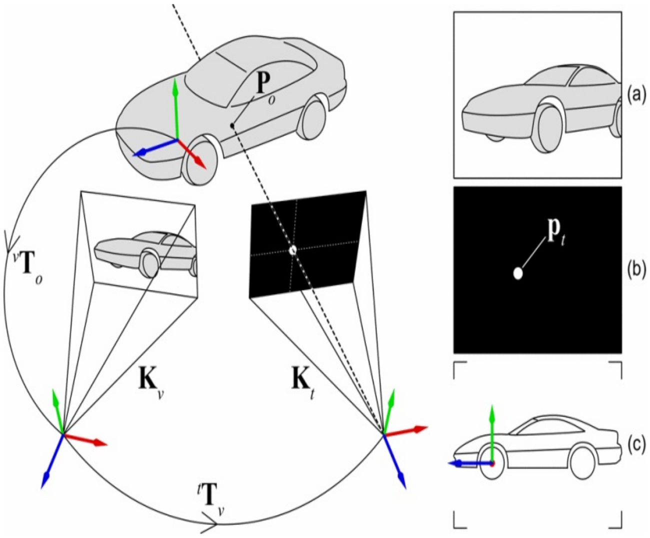

Figure 3: Illustration of the involved coordinate systems and resources:(a) a visible light camera image, (b) a thermal camera image and (c) a model of the real object to interact with.[2]

ing the touch in thermal imaging, and being able to find where the touch occurred on a 3D object. First he explored temperature profiles of a surface being touched, obstructed, or not interacted with at all. The 4 cases of temperatures profiles are: object-only, hand-only, obstruction-by-hand, and touch-by-hand. Object-only is just using the cameras to measure the relative constant temperature of an object. Hand only measured the temperature of a hand, expecting moderate temperature changes relative to fluctuating body temperature. Obstruction by hand starts with detecting an object and then having a hand come between the object and the camera, while not touching the object. The infrared camera will detect the rapid change from cool surface to a warm body, then rapidly back to the cool surface. The system is expected not to detect any interaction with these three. Touch by hand is when the object is actually touched, leaving a thermal impression. The observed temperature will start with the cool surface temperature and then rise when the warm body obstructs the area. Then once the hand moves away, instead of a rapid change back to a cool surface there is a rapid decrease to a temperature between that of the hand and the object. After this initial rapid decrease the area will slowly cool, reverting back to the starting temperature.

Theses thermal impressions are called blobs. In this situation, a blob is a collection of light pixels on a dark background. Kurz used the OpenCV SimpleBlobDetector to detect these blobs. The thermal camera will only consider blobs that are between two temperatures, t_1 and t_2. Below is how those two temperatures are calculated

$$t_1 = (1 - \tfrac{1}{16})t_{min} + \tfrac{1}{16}t_{max} \quad t_2 = (1 - \tfrac{3}{8})t_{min} + \tfrac{3}{8}t_{max}$$

t_1 and t_2 are calculated by taking the minimum and maximum temperature recorded from the thermal camera, t_{min} and t_{max}. The camera passes t_{min} and t_{max} to the SimpleBlobDetector to calculate t_1 and t_2. Once t_1 and t_2 are obtained, the system knows the expected temperature range of the interaction that might occur. The blob detector looks for a blob within a certain size range. Kurz found a size range of 0.32cm^2 and 1.54cm^2 for detecting the blobs was optimal; these numbers were determined by trial and error.

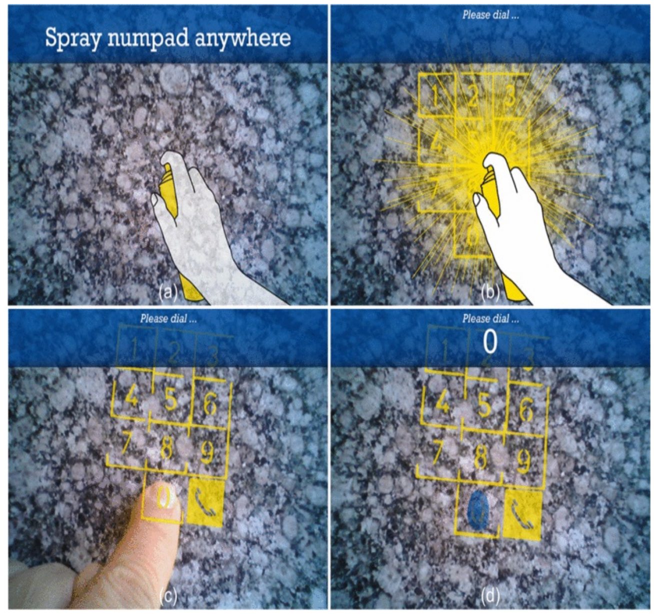

Figure 4: A number pad on a granite countertop seen through the screen of a mobile device, but the number pad is not actually on the counter top. [2]

The system needs to be able to find the location of an interaction in relation to the cameras. Given that the thermal camera detects a blob in 2D space at position p_t (see Figure 3(b)), then the system needs to figure where the 3D position of the interaction is on the object, P_o (see Figure 3). In order to find where the interaction happened, the system first needs a 3D model of the object, in this case a car (see Figure 3(c)). Using a linear algebra transformation ${}^tT_o$, the system can determine the position of the car in relation to the visible light camera K_v. Since the cameras are a fixed distance from each other, we know the distance between the two (see Figure 2). This allows us to use a linear algebra transformation ${}^tT_v$ to determine the position of the car in relation to the thermal camera, K_v. After detecting an interaction p_t, the system in now able to find P_o by using an imaginary line from the thermal camera that passes through p_t, and will then use the first point of intersection as P_o.

3.4 Materials Tested

The blob detector is designed to handle objects that differ in material and temperature. This should also work for different users that have differing finger or body temperatures. The touch time and pressure would most likely be different form user to user. Kurz tested the algorithm with an array of materials one would encounter every day. The experiment consisted of different users touching different surfaces at different temperatures [3]. Figure 5 is the testing environment Kurz used to test different materials. The materials tested are paper, plastics, glass, and metal, being placed on the table centered with the camera. The camera is positioned 300 mm above the materials being tested. The test involved four different people in a controlled office environment with ambient temperature at 25^oC. A different group of four people did the same experiment, but outside in temperature of

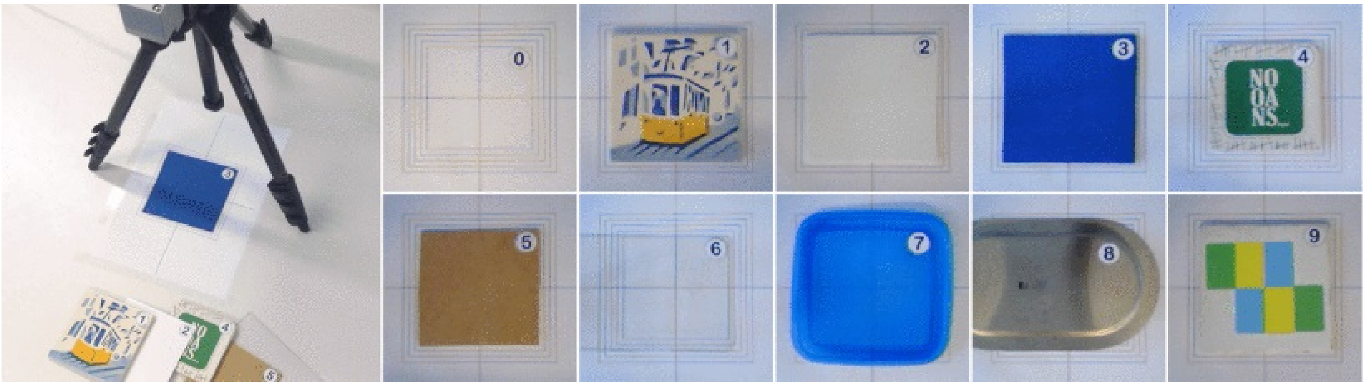

Figure 5: Different materials used in Kurz's evaluation: (0) paper on a plastic table-top, (1) ceramic, (2) rigid PVC, (3) foam plastic, (4) cardboard, (5) laminated fiber sheet, (6) glass, (7) thin plastic, (8) steel, (9) multi-layer board. [2]

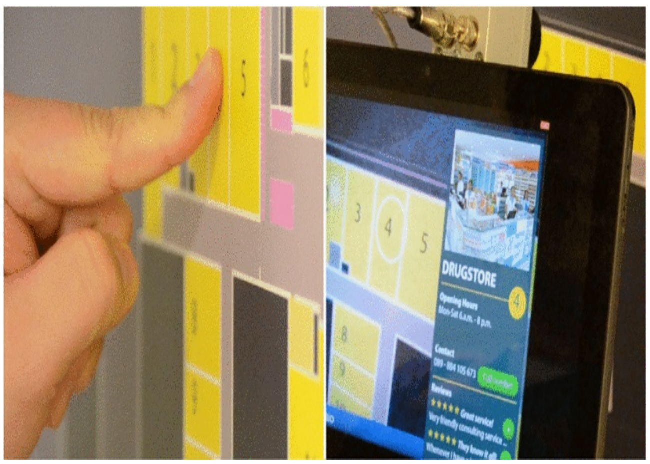

Figure 6: Interaction with a AR floor plan [2].

12^oC, leaving the test samples in the environment that they would be tested in for around thirty minutes to ensure they conformed to the environment's temperature. The test consisted of having the person first pass their hand between the material and the camera, not touching the material. After that they were told just to touch the middle of the material as if it were a key on a keyboard. Notably it was not specified which finger to use and how to have the finger leave the object, leaving that entirely up to the subject.

After this test was done, Kurz had around 400 thermal images with a time stamp and labeled according to the action, material and tester's name. The results of the tests showed that steel does not work well with thermal interaction. This is due to the high rate at which steel dissipates heat, making it difficult to detect using their method. The data collected on steel was removed from test results, because of steel's inability to retain heat. Out of the remaining 9 materials only two detected a touch in the wrong area, the rest detected touched areas correctly. Glass, from the outside tests, had false positives because the numeric sticker in the top right corner of the samples appears warmer then the glass outdoors. 7 sequences could not detect touch due to the short period of contact. The false positives in the sequences without touch were quite high. This was because the sample were placed under the camera by hand, which the camera detected at interactions.

3.5 Applications

Since the prototype from Figure 2 was a more of a hand held device, Kurz mentions that the thermal interaction could be possible with wearable technology, or head-mounted displays. A common example of wearable technology would be a smart watch, and for head-mounted displays it is Google Glass. If this method is applied to either technology, it would be a solution for interacting with technology without a touchscreen.

Two of the main applications mentioned in the paper are Spray-On Graphical User Interfaces (GUI's), and augmented floor plans. A Spray-On GUI utilize any surface available to the user, such as a dial pad on a granite countertop (see Figure 4). Using the camera of the mobile device this application superimposes a virtual number pad onto a surface. In reality, the GUI is not on the actual surface, but is visible via the screen of the mobile device. Using the screen as a reference, the user can dial numbers by pressing the location. Once "sprayed", on the GUI location is fixed in one place. Kurz called it instance tracking, which creates an image and can track it. Spray-On GUIs need a fixed location, because mobile devices lack stability when held in one's hand. Otherwise, the user could try and dial seven, but the camera could move to the left and then seven turns into eight. When one of the keys is touched, the camera is able to determine the corresponding key that was touched based on the location in the thermal image.

The AR floor plan is used when there is a printed floor plan of a building, for example a mall. The AR floor plan allows a user to press his/her desired location on the floor plan while pointed the mobile device at the map. Detecting this interaction with the map the device is able to tell what store or restaurant is at the pressed location. It is also able to display other information such as business hours, ratings, website, and contact information. With this approach there would be no need for Spray-on GUI since the camera would use the shapes of the floor plan in lieu of virtual buttons. This type of method would work best for interfaces that users regularly access. The floor plan of a mall is the prime example of AR floor plans, but if a user had to find a dial pad sticker when they needed to make a call, that would be less appealing to users.

4. 3D DATA VISUALIZATION WITH SAR

I will now focus on a paper that explores the use of SAR as a tool for 3D data visualization [3]. As mentioned in Section 2.1, SAR uses projectors to augment what is already there. Data visualization is the representation of data through the use of images. Thomas et al. focus more on 3D data visualization, and not manipulation [3]. Being able to see and touch the data is their main focus, because using multiple senses can help the user remember the data being displayed. They define their proposed use of SAR as a tool for 3D visualization in following ways. First, they propose the use of SAR to benefit the user's ability to see, understand, and manipulate 3D data visualization. Second, is the table-top SAR prototype (see Figure 7). Third, is the large applications of SAR, called *CAVE* which stands for Cave Automatic Virtual Environment. Being similar to the table-top method, the CAVE has its own advantages that will be discussed later in this section.

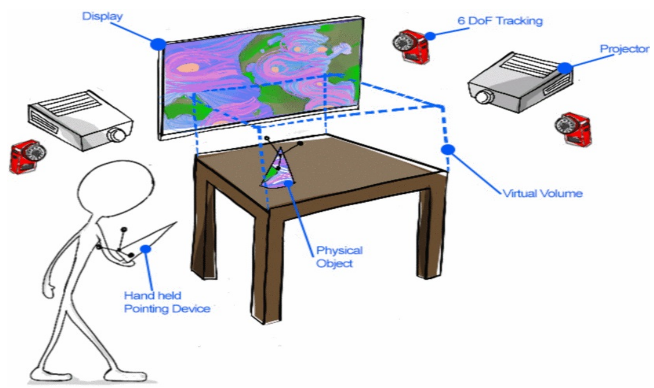

Figure 7: the table-top set up that Thomas et al. propose [3]

4.1 Visualizing Data

Some basic examples of data visualization would be pie charts, scatter-plots, and bar charts, etc. Data visualization is used in many fields. For example the census might need to show the demographics of a neighborhood. An astronomer might want to displaying how many shooting stars happen over the course of a year. Meteorologists use weather maps to easily show the forecast. Visualizing data with pictures is an effective way to show someone information quickly and efficiently. Humans tend to recall and process pictures more easily than words, that is part of why humans have so many ways to display data.

4.2 Applications

Thomas et al. [3] mention two ways that 3D data visualization can be applied in the real world. The main one they mention is the tabletop method. This is a proposed system where there is a 2D display, a table with the physical object(s) that is being projected onto, the virtual volume, the hand held pointing device, 6DOF trackers, and the projectors (see Figure 7). Thomas et al. [3] built a version like the one in Figure 7. The large display is used to provide detailed views of the data being visualized, providing a reference to where the user is in the 3D volume. The virtual volume is the space around the table-top, starting from the surface of the table extending up a foot or two. In the virtual volume a user could zoom in, or out, on the data being visualized on the physical object using the hand held device. An example of this action would be displaying the weather maps of North America, then zooming in on the north west region, or zoom out to displaying more of the world. The physical object is what the projectors are using to visualize the 3D data. As mentioned, the hand held device is used in the virtual volume, but it is tracked by the 6DOF trackers to track where the user is in the room.

The second method to discuss is the CAVE system. SAR systems will project onto the object of interest; whereas in a CAVE the object being projected onto becomes a window to the virtual world, making the area of focus on the data instead of the object itself. Thomas et al. [3] used the CAVE system as a large scale version of the tabletop method. CAVE systems require more space than the table-top method due to the need for more 6DOF tracers and projectors. Other then that, how the user interacts with CAVE is the same as the table-top system. The scale of the CAVE system requires many walls, that would be would be projected on by the projectors as the large display. The physical objects and virtual volume would be larger. As illustrated in Figure 8 the physical objects are larger than the small cone from the table-top method. The benefit the CAVE model is being able to increase the number of collaborators/viewers. Figure 8 is one of a couple CAVE configurations possible with this technology. Other configurations just change the shape and size of the system. The CAVE would be a better choice, over the table-top method, if the needs required more collaborators, or the need to display the visual date to a larger audience.

4.3 Limitations

The initial experimentation with Thomas et al.'s [3] prototype showed a couple limitations. The first is the lighting in the room must be controlled, as details in the gradients of the projected data may be lost with too much ambient lighting. Like anything projector-related, it works best in dim-to-dark rooms. Upgrading to a more powerful projector would help. This would allow the system to operate in a environment that is not as dark.

4.4 Conclusion

The goal of Thomas et al. [3] was presenting SAR as a tool to enrich the process of visualization. They laid out a plan for using SAR with three goals. They start by explaining the benefit to the user's abilities to interpret and retain the data being presented. The second goal was the implementation of the table-top they proposed. Letting the user manipulate the data by zooming in or out, the user handles the data, improving retention of the information. Lastly, increasing the possible applications of visualizing 3D data with SAR by proposing the CAVE system. The CAVE would allow more people to view the data being displayed at one time.

5. COMBINING THERMAL INTERACTION WITH 3D VISUALIZATION

Section 3 discusses using thermal heat signatures to detect interaction in AR, where Section 4 discusses using SAR as a tool to visualize data. This section will discus how they could work together. In Section 4, a 6DOF object is needed to track one's position, but with the thermal interactions the camera is able to detect positions of objects using visible light cameras. Knowing the position and orientation of the object one can find the position and orientation of the person

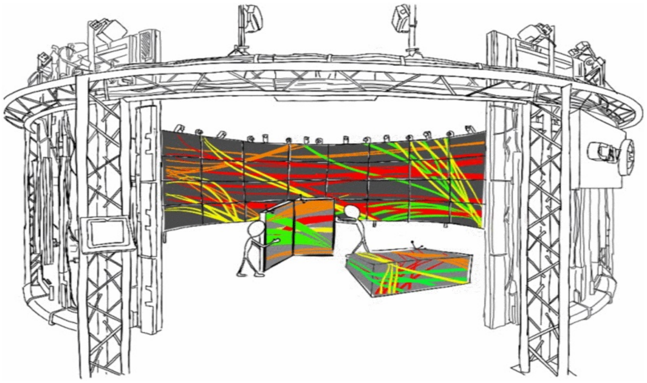

Figure 8: One of the CAVE systems mentioned by Thomas et al. [3]

looking at it.

Some possible applications that combine thermal interaction and 3D data visualization are in education and transportation fields. With education, a possible idea would be for a class to wear head-mounted displays (HMD). The HMDs would contain a visible light camera and a thermal camera, similar to the camera from Figure 2 but smaller. Also, each of the students' desks would essentially become the table-top system from Figure 7 with a physical object, such as a sphere. The system would either use HMDs or projectors to visualize the data on the physical object. The students would be able to interact with the sphere using their hands. The system would use the thermal technology to detect interactions, and zoom in or out depending on the interaction. The lesson in this example is geography, and the sphere on each students desk has the map of the world being displayed onto its surface. The teacher would have control over the zooming in and out, for use in his/her lesson. The teacher could give the class control over their own spheres, so they can explore the map or answer questions related to the lesson.

Transportation would benefit from the ability to detect an interaction with a map showing where a user wants to go. The system would be able display the information pertaining to the route a use wants to take. This could be at train stations, bus stops, or other forms of public transit. Using the AR floor plan system from section 3.5 in the form of a train or bus route, a system could detect someone wants to take a bus to the local store. In turn the projector would highlight the best route and where the closest bus on the route is. Also, the system would display if the user would have to take multiple buses to reach their final destination.

6. CONCLUSION

The goal of Kurz's [2] study was to interact with surfaces using mobile and thermal technologies. He accomplished this by using a camera with both visible and thermal capabilities. Kurz [2] used the Metaio software to obtain the position of the interaction, and the SimpleBlobDetector to determine if an interaction actually occurred with an object. By utilizing those two together, Kurz was able to use most surfaces to interact with a device. Having this type of interaction with a device is beneficial for developers that want an easy way to interact with technologies that have little or no screens. One example would be head mounted displays (HMDs), that do not have screens, and this would be a possible way to interact with them. Normally, to interact with a HMD one needs to use voice commands or a wireless remote.

The goal of Thomas et al. [3] was presenting SAR as a tool to enrich the process of 3D data visualization. They laid out their plan on using SAR with three goals. They start by explaining the benefit to the user's abilities to interpret and retain the data being presented. The second goal was the implementation of the table-top they proposed. They let the user manipulate the data by zooming in or out. Since the user interacts with the data manually it improves the user's retention of the information. Using the CAVE system, it would be able to increase the possible applications of 3D data visualization. The CAVE would allow more people to view the data being displayed at one time.

As mentioned above, education and transportation are just a few areas that would benefit from the union of these technologies. Using both the thermal interaction and 3D data visualization systems, one can reduce the weaknesses each had. For example using head-mounted displays instead of projectors would make data visualization possible in more areas than inside dark rooms. Another consideration when thinking about AR is the ethical implications. Heimo et al. [1] mentions that the government could use this technology as a means of surveillance. In an age where government surveillance is almost everywhere, an increase in AR technology could lead to self surveillance.

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7. REFERENCES

[1] O. Heimo, K. Kimppa, S. Helle, T. Korkalainen, and T. Lehtonen. Augmented reality - Towards an ethical fantasy? In *Ethics in Science, Technology and Engineering, 2014 IEEE International Symposium on*, pages 1–7, May 2014.

[2] D. Kurz. Thermal touch: Thermography-enabled everywhere touch interfaces for mobile augmented reality applications. In *Mixed and Augmented Reality (ISMAR), 2014 IEEE International Symposium on*, pages 9–16, Sept 2014.

[3] B. Thomas, M. Marner, R. Smith, N. Elsayed, S. Von Itzstein, K. Klein, M. Adcock, P. Eades, A. Irlitti, J. Zucco, T. Simon, J. Baumeister, and T. Suthers. Spatial augmented reality – A tool for 3D data visualization. In *3DVis (3DVis), 2014 IEEE VIS International Workshop on*, pages 45–50, Nov 2014.

[4] Wikipedia. Six degrees of freedom — Wikipedia, The Free Encyclopedia, 2015. `https://en.wikipedia.org/w/index.php?title=Six_degrees_of_freedom&oldid=683426652,[Online;accessed1-November-2015]`.

[5] Wikipedia. Virtual reality — Wikipedia, The Free Encyclopedia, 2015. `https://en.wikipedia.org/w/index.php?title=Virtual_reality&oldid=688517336,[Online;accessed1-November-2015]`.