Mediation of Multispectral Vision and its Impacts on User Perception

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ABSTRACT

As augmented reality head-mounted displays (HMDs), such as the Microsoft HoloLens and the Magic Leap One, become more accessible and ubiquitous, users are gaining access to a wealth of computer-mediated information that can be presented around them in 3D space. At the same time, camera and sensor costs and their physical footprint continue to decrease to the point where they can be easily integrated or mounted onto HMDs. Such cameras and sensors are capable of retrieving many different types of data from the user's environment, and when combined with such HMDs, can give users the ability to sense stimuli that are typically outside the range of human perception such as the thermal infrared and ultraviolet spectrums. Recent studies involving this combination of sensor and display technologies in the field of augmented reality have shown that the method of presentation of sensor data in different modalities can impact the user's perception of their environment. There are many different approaches by which sensor data can be conveyed visually or through other means that have yet to be explored. The work presented in this paper gives an overview of two human-subject studies, one involving perception of temperature using thermal infrared and augmented reality displays, and one involving multispectral vision which combines thermal infrared and ultraviolet vision into a single working implementation. This prior work is discussed in detail along with potential avenues for future work.

Index Terms: Human-centered computing—Visualization—Visualization techniques; Human-centered computing—Visualization—Visualization design and evaluation methods

1 INTRODUCTION

With increasing availability of augmented reality (AR) technologies such as head-mounted displays (HMDs) and decreasing sizes and costs of sensors and cameras, we are approaching a time where we can extend and enhance human perception through the combination of these technologies. Modern AR HMDs host a wide variety of integrated sensors, such as infrared and traditional RGB cameras, which are used internally by the device to map the user's environment and track movement. However, these sensors can be used in a multitude of different ways besides their traditional purpose.

Sensors, such as thermal infrared and ultraviolet cameras, are capable of gathering environmental information that is typically out of reach of normal human perception. However, through integration of such sensors into AR HMDs, that information can be accessed and conveyed to a user in a wide variety of different manners. Our efforts have so far been in mounting additional thermal infrared and ultraviolet cameras to the Microsoft HoloLens in order to extend its capabilities and enhance the perception of its user.

In this paper, a current working prototype of an AR HMD with multispectral vision is described, two completed user studies are described, and avenues for future investigation are discussed.

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The remainder of this paper is structured as follows: Section 2 gives an overview of thermal infrared and ultraviolet radiation, and presents prior research that utilizes these spectrums in conjunction with AR HMDs. It also presents a brief overview of research that investigates human perception through the use of AR. Section 3 presents our past work in the field and our most recent results. Section 4 discusses our findings and presents future work. Section 5 concludes the paper.

2 RELATED WORK

There have been several different prior studies that highlight some of the uses of thermal and ultraviolet sensors in the field of AR.

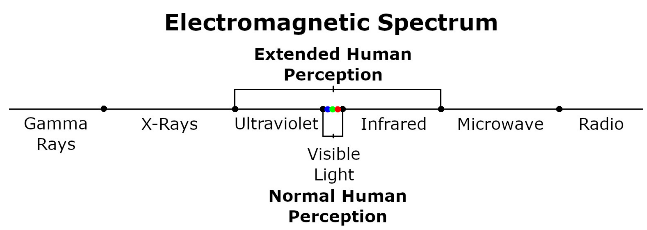

Figure 1: The electromagnetic spectrum, with areas that indicate normal human perception and extended human perception through the use of our multispectral vision prototype.

2.1 Thermal Infrared Spectrum

The infrared (IR) spectrum has been studied extensively in the past, and has been combined with AR HMDs across a wide range of domains, including healthcare, and firefighting. The thermal infrared spectrum lays between visible light and microwaves on the electromagnetic spectrum and covers a range of wavelengths between 8 and 15 µm (see Figure 1).

Thermal infrared cameras are often used in the surveillance and defense industries, as they are capable of sensing the relatively hot bodies of people or other animals in contrast to the environmental temperatures that surround them [2]. These sensors also come in radiometric varieties, where they are capable of obtaining accurate temperature measurements without coming into contact with the object of interest.

These sensors have also been used extensively in firefighting, where Bennet and Matthews and, more recently, Sosnowski et al. integrated the sensors into an HMD for use in navigating smoke filled environments [1, 8].

2.2 Ultraviolet Spectrum

The ultraviolet (UV) spectrum lays between X-Rays and visible light on the electromagnetic spectrum, and covers a range of wavelengths between 100 nm and 400 nm (see Figure 1). Long term exposure to certain wavelengths within this spectrum can cause a variety of problems from skin conditions such as melanoma to eye conditions such as cataracts and macular degeneration [5, 7].

In 1997, Fulton showed how UV cameras could be used to capture the presence of skin conditions that arise from UV exposure, and suggested that they be used to educate patients about the effects of UV [4]. Since then, these cameras are now common among dermatology clinics.

Work has been done in the past by Zhang et al. in creating a prototype AR HMD that pairs UV sensors with an HMD. This device is capable of sensing the amount of UV light in the user's environment and creating visualizations that represent how the UV exposure will affect the user's skin after variable lengths of time [10].

2.3 Mediation Methods

Among the virtual reality and augmented reality communities, several prototypes have been developed that mediate data from integrated or mounted sensors to a user in real time. One such instance is by Orlosky et al., called VisMerge, which presents a framework to calibrate a video see-through HMD with an infrared sensor, and evaluates visualization techniques which use several different manners of combining RGB and thermal IR sensor feeds [6].

2.4 Perception

An interesting phenomena sometimes occurs when viewing imagery presented by the AR HMD, in that the user's perception of their own body or of their environment is occasionally changed in response to what is being displayed on the HMD.

In BurnAR, Weir et al. noticed that participants tasked with viewing dynamic AR flames coupled with sounds of fire occasionally noticed that they felt warming or tingling sensations on their hand where the fire was displayed [9]. Our first delve into this domain examined whether or not this could be achieved by viewing thermal infrared imagery that suggested a participant's body or environment was warming or cooling when it was actually remaining at a constant temperature [3]. This study found significant results and will be discussed in detail below in Section 3.1.

3 Own Prior Work

In this section, an overview of two prior research studies is presented along with with a discussion of their main findings.

3.1 Influencing Temperature Perception

In a paper published at ISMAR 2019 [3], we examined the effects that AR-mediated thermal IR information can have on a user's perception of temperature. In this study, an initial prototype was built that integrated two thermal IR cameras onto a Microsoft HoloLens, which would give users a stereoscopic thermal IR view of their surroundings (see Figure 2). An implementation was designed using the Unity engine that displayed 20 different conditions to the participant. Due to the lack of available USB ports on the HoloLens itself, sensors were plugged into a PC running the Unity implementation in holographic remoting mode, where data from the sensors was streamed to the HoloLens over WiFi. The independent variables involved in the study were the simulated temperature, the location of effect, and display mode (thermal IR or 3D AR effects).

Temperature changes could be simulated by either selectively altering the thermal imagery being displayed to the user, or by displaying 3D AR effects that shared the room with the user. The 3D effects were chosen such that participants would associate a temperature to them based on previous experiences with the stimulus, which led us to choose fire (due to its association with warmth), and a dense icy fog (due to its association with cold). These simulated temperature changes could occur on one of five different levels:

- **Moderately Cold:** A moderate amount of icy fog was displayed to the user, or a negative ten degree Celsius temperature shift was simulated in the infrared display mode.

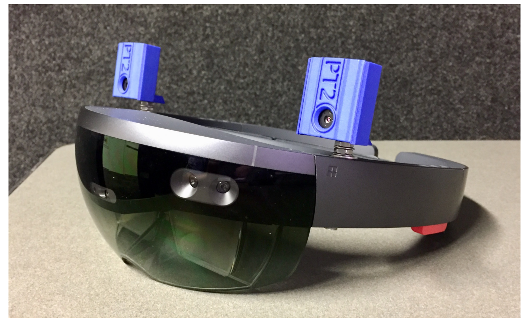

Figure 2: The initial prototype consisted of a Microsoft HoloLens with two FLIR 3.5 radiometric thermal infrared cameras housed in Lepton PureThermal 2 boards.

- **Somewhat Cold:** A small amount of icy fog was displayed to the user, or a negative five degree Celsius temperature shift was simulated in the infrared display mode.
- **Neutral:** No AR effects were displayed, and the infrared display mode was unaltered.
- **Somewhat Warm:** A slight amount of fire was displayed to the user, or a positive five degree Celsius temperature shift was simulated in the infrared display mode.
- **Moderately Warm:** Moderate amount of fire displayed to the user, or a positive ten degree Celsius temperature shift was simulated in the infrared display mode.

Further, these effects could be displayed in a manner which affected either the user's body or the environment around them.

The study was designed to measure the participant's subjective sense of temperature of their environment and body (i.e. how hot or cold they perceived the environment or their body to be) after immersion in the condition for 90 seconds.

We found a significant main effect of the display type (which could be either AR effects or thermal IR vision) on the participants' estimates of their body temperatures, and in general found stronger responses for the AR virtual effects than we did for the thermal vision based conditions. In addition, we found interaction effects between the location of the stimulus and the simulated temperature, as well as between the display mode and the simulated temperature. We additionally found significant effects of the simulated temperature on participants' perception of their body temperature as well as their environment temperature for the conditions with AR effects. We did not, however, find a statistically significant result for the thermal vision based conditions. The results are discussed in detail in the paper [3].

3.2 Multispectral Vision in Daily Activities

Our second study in this domain evaluated the potential uses and practicality of having access to multispectral thermal infrared and ultraviolet vision in daily situations at home and at work.

For this study, the prototype described previously in Section 3.1 was extended to include a pair of ultraviolet cameras in addition to the already mounted thermal infrared cameras (see Figure 3). Additionally, a backpack computer was used to allow users to move freely around their environment. Cameras were plugged into the backpack computer which would be running the study implementation on Unity in holographic remoting mode, which allows for streaming of sensor data from the PC to the HoloLens.

As participants progressed through their allotted time of an hour, they were asked to keep track of the amount of time spent performing specific activities, such as amount of time indoors and outdoors, the

Figure 3: The revised prototype consisted of two additional ultraviolet cameras (XNiteUSB2S-MUV 2 Megapixel) mounted to the HoloLens.

amount of time spent alone and communicating with others, as well as the amount of time spent walking, at work and at home. Participants were also asked to take screenshots of any interesting features or phenomena that they encountered during their trial. Some of these screenshots can be seen in Figures 4, 5 and 6.

Several applications of multispectral vision were found that are of benefit to the user. For example, some participants noticed that due to residual heat that is visible in the thermal infrared spectrum, recently pressed buttons on keyboards and keypads could be identified in a manner that may allow a user of a multispectral vision device to guess a password (see Figure 4). Other participants noticed that multispectral vision was useful in identifying people who had warmer or cooler temperatures than usual. In particular, one participant was able to identify someone in their environment who had a diagnosis of low blood pressure, based on their consistently low temperature readings across measurements in multiple environments (see Figure 5). When used outdoors, some participants noticed that areas of their skin that were covered with sunblock appeared darker on the UV cameras (as shown in Figure 6).

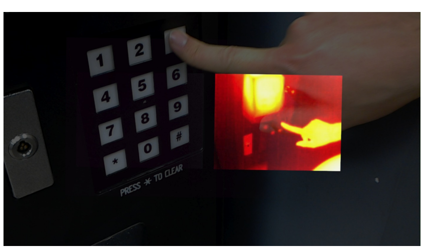

Figure 4: Thermal infrared vision reveals residual heat that highlights recent button presses on a keypad.

4 Discussion

4.1 Effects on User Perception

The results of the temperature perception study yielded several interesting insights in how AR visualizations can affect the user's sense of temperature. We were able to show that the user's sense of temperature could be affected either through effects that were displayed directly on the user body or through effects that were displayed in close proximity to the user. Further, we showed that warming sensations could be induced by displaying fire based effects and cooling sensations could be induced by displaying cold fog based effects. These results are promising and suggest that other AR visualizations may be able to impact user perception in similar manners.

Figure 5: Signs related to medical conditions were observed in thermal IR vision that helped to identify a person with low blood pressure (left).

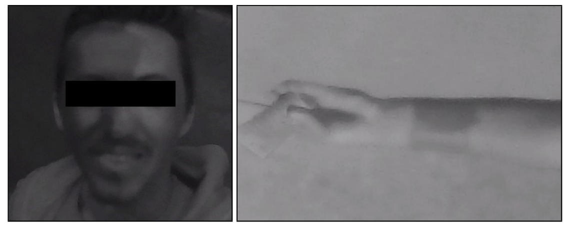

Figure 6: Effects of sunscreen on the appearance of one's skin in UV vision. Skin areas protected by sunscreen appear darker in UV vision.

While we were unable to show significant results for the thermal vision based conditions discussed in Section 3.1, we did see some promising trends that suggest there is a relationship between the thermal vision stimulus and the user's perception of temperature. We believe that this lack of strong effects was due to participants being unfamiliar with thermal vision displays and not having an association built up between certain visual phenomena on the thermal display and the temperature changes that they represent. In the case of the AR based effects, users were presented with visuals of fire and cold fog, where it is likely that users had interacted with these physical phenomena in the past and had built an association between seeing fire and feeling warmth as well as being immersed in fog and feeling cold. We believe that if users were more familiar with the thermal vision representations of temperature and had in the past experienced feeling temperature changes while seeing the visual stimuli at the same time, then the effects would have been stronger between the visual stimuli and the perceived temperature. This could be tested in future work by conducting a two-part user study, where participants are given a session to build the association between the visual stimulus and feeling temperature changes, and then a second session similar to the one presented above, where we measure the effects of the visual stimuli on the user's sense of temperature.

4.2 Multispectral Vision in Daily Life

When examining the collection of observations of participants in the multispectral vision study, we found several benefits to having access to this technology for use at home and at work.

One benefit would be that users are able to **perform certain tasks more efficiently** than they would otherwise be able to without the multispectral vision device. Users of the device can tell just by looking if something is hot or cold, which enables them to make certain decisions much quicker than they otherwise would be able to.

For instance, users could tell which house plants needed watering based off the temperature of the soil (where recently watered plants would have cooler soil than ones with dry soil). As one of our participants noted, users of the device would also be able to detect the presence of abnormal temperatures in their environment such as hot air warming the area around a door frame where the weather seal was in need of replacement.

Another benefit is that having access to multispectral vision could **improve personal health**. By being able to notice if someone is running a fever, users can make the decision to avoid contact with that person and reduce the likelihood of coming down with the illness themselves. Users of the device would also be able to better tell which areas of their body are exposed to UV rays, which could prevent sunburns, skin cancer, and certain eye conditions.

4.3 Future Work

The studies that were described above led to the creation of a multispectral vision prototype that allows a user to see in thermal infrared and ultraviolet spectrums of non-visible light. With this device as a tool, many interesting avenues of investigation are opened for further research.

4.3.1 Spatial Dimension of Visual Multispectral Data

There are many methods that could be employed to mediate data from the sensors to a user of an AR HMD. These methods can be classified by their spatial dimension into the following categories: 2D, 2D stereoscopic, and 3D.

In a 2D mediation method, data from the sensors is presented to the user as if they were a security guard at a desk watching multiple monitors of security camera footage.

In a 2D stereoscopic mediation method, data from the sensors is calibrated and a separate sensor is used for each eye. In this manner, the user gains a sense of depth over the information gathered from the sensors.

In a 3D mediation method, data from the sensors or cameras is analyzed to identify 3D positions of objects of interest in the environment (e.g., objects hotter than X degrees, or objects emitting UV light). Upon realization of these 3D points of interest, the AR HMD can display icons or graphics depicting the type information that is coming from that point, for example a hot object may have an icon of a fire floating over it, whereas a cold object may have an ice cube.

We intend to research the benefits and drawbacks of these three categories of mediation methods as well as determine which are subjectively preferred by users and which influence user performance in tasks that rely on multispectral vision information.

4.3.2 Effects on Perception

Our work described in Section 3.1 showed that viewing AR effects had a significant effect on the user's perception of the temperature of their body and their environment. Therefore, it is possible that visual stimuli displayed to the user from the sensors and cameras can have other effects on the user's perception. Our work focused solely on the participants' sense of temperature. However, this is one of many senses that could possibly be affected by the sensor information. Future work in this area should examine the impacts that these stimuli types can have on other senses.

It is also possible to convey information from the sensors and cameras in a non-visual way, for example using haptic vibration to convey proximity to extreme temperatures. Future work could also examine how changing the mediation method to a different sensory pathway affects the user's perception.

5 Conclusion

In this paper we presented previous work related to the combination of thermal infrared and ultraviolet sensors with AR HMDs. We discussed two of our recently completed user studies in the field, their results, implications, and several potential avenues for further investigation.

Our work shows that the temperature perception of a user in an AR HMD can be affected by the visualizations that are being displayed to them, which suggests that other visualizations may be able to influence other senses of the user. We have also shown that having access to multispectral vision data can be of use in completing daily activities around the house and at work in addition to the specialized industry domains that have been extensively explored in prior work.

As sensor sizes decrease and AR HMDs become as ubiquitous as smartphones, we believe this combination of technologies will have a strong impact on our society and enhance the daily lives of its users.

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