Exploring the Domestication of Thermal Imaging

Yomna Abdelrahman[1], Pawel Wozniak[2], Pascal Knierim[3], Dominik Weber[4], Ken Pfeuffer[1], Niels Henze[5], Albrecht Schmidt[3], Florian Alt[1]
[1] Bundeswehr University Munich,[2]University of Utrecht, [3]LMU Munich, [4]University of Stuttgart, [5]University of Regensburg

ABSTRACT

Recent work demonstrated the opportunities of thermal imaging in the development of novel interactive systems. However, the exploration is limited to controlled lab setups. Hence, little we know about how thermal imaging could be useful for a broader range of daily applications by novice users. To investigate the potential of domestication of thermal imaging, we conducted an exploration with a technology-cultural probe. Ten households (26 individuals) used a mobile thermal camera in their daily life. We collected thermal photos taken by the participants and conducted interviews after using the camera. We found that the users were excited about using thermal cameras in their everyday lives and found many practical uses for them. Our study provides insights into how novice users wish to use thermal imaging technology to augment their vision in daily setups, as well as identifying and classifying common thermal imaging use cases. Our work contributes implications for designing thermal imaging devices targeted towards novice users.

CCS CONCEPTS

• **Human-centered computing → Displays and imagers**; *User studies*; *Mobile devices*;

KEYWORDS

FLIR One,Thermal Cameras, Everyday use

ACM Reference Format:
Yomna Abdelrahman[1], Pawel Wozniak[2], Pascal Knierim[3], Dominik Weber[4], Ken Pfeuffer[1], Niels Henze[5], Albrecht Schmidt[3], Florian Alt[1] [1] Bundeswehr University Munich,[2]University of Utrecht, [3]LMU Munich, [4]University of Stuttgart, [5]University of Regensburg . 2019. Exploring the Domestication of Thermal Imaging. In *MUM 2019: 18th International Conference on Mobile and Ubiquitous Multimedia (MUM 2019), November 26–29, 2019, Pisa, Italy*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3365610.3365648

1 INTRODUCTION

In recent decades, novel tools were developed that use cameras which capture images beyond the visual spectrum. Especially thermal cameras are widely used in certain domains e.g., health care and firefighting. Until recently, they were used primarily by firefighters to make potential hazards such as gas leaks or hot objects visible and to search for persons or sources of heat, as thermal radiation is less scattered by smoke. Furthermore, researchers explored potential applications for thermal imaging. However, most of these applications address specific domains ranging from augmenting the vision in special scenarios [3, 6] to interactive surfaces [24]. While thermal imaging has proven to be useful for specific domains, it is not widely used in everyday settings. This is likely to be caused by two factors. First, with prices starting at multiple thousands of dollars, thermal cameras have been too expensive and bulky for private use. A second factor is a lack of use cases for thermal cameras. Researchers highlighted a range of potential applications e.g., firefighting, medical applications and energy auditing [3, 13, 18], it is unclear if thermal cameras are useful beyond specific domains and appropriate for domestication.

Due to the availability of thermal detectors in terms of cost and size, cheap lightweight thermal cameras have become available. They come in different forms, for instance integrated into the phone [1] as a mobile attachment [12]. Additionally, there is a DIY move towards building your own thermal cameras [23]. Where there has been a vast technical move in making thermal imaging available, however, there is a clear research gap on the human factors side and regarding how thermal imaging could be used domestically by novice users. This brings us to our research questions:

(1) **RQ1** How do novice users experience thermal camera?
(2) **RQ2** Is there potential for domestication?
(3) **RQ3** Can novice users understand it's implications?
(4) **RQ4** Why would novice users use thermal cameras?

1.1 Research Approach

To address these questions, we investigate the potential of the advanced usage of thermal imaging for private home use without focusing on specific applications. We conducted an exploration with a technology-cultural probe in 10 households over ten days. We analyzed potential users' reaction to thermal imaging and collected promising use cases. This paper contribution is presented in the novel, first exploration of thermal imaging domestication, as informed by real users rather than online exploration [22]. This paper contributes the following:

(1) Through a study in form of a technology-cultural probe in 10 households for 10 days, we built an understanding and categorization of the common domestic use of thermal imaging.
(2) We discuss the constraints and opportunities connected with domesticating thermal imaging.
(3) Based on the findings, we draw design implications and guidelines of domestication of thermal imaging.

[1]https://www.catphones.com/

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.
MUM 2019, November 26–29, 2019, Pisa, Italy
© 2019 Association for Computing Machinery.
ACM ISBN 978-1-4503-7624-2/19/11…$15.00
https://doi.org/10.1145/3365610.3365648

2 RELATED WORK

2.1 Thermal Cameras

Thermal cameras capture a heat map of the scene [20]. Usage of thermal cameras has been targeted at special users, hence use-cases. It has been widely explored for firefighting usage [3, 5, 6, 9, 10]. In a recent survey, Gade and Moeslund provide an overview of current applications of thermal cameras [14]. They highlight that thermal cameras are continually getting cheaper and available. This enables thermal cameras to be used in a diverse set of applications by enhancing existing application scenarios and creating new ones [1, 2, 7, 8]. Sahami Shirazi et al. explored how *thermal reflection* can be used to increase the interaction space of projected surfaces [4, 24].

Despite the fact that thermal cameras captured the attention of researchers, little has been targeted towards novice users. For instance, there is only the work of Demisse et al. [13], which explored how non-expert users use thermal cameras for energy audits in their daily lives [13]. Recently, Mauriello et al. analyzed Youtube videos for thermal imaging everyday use [22]. However, the existing research either focused on special home use case e.g., energy auditing or used online data by technology early adapters e.g., users how are excited about the technology to capture videos and upload them to Youtube, rather than home novice users. In this paper we aim to explore how to utilize it in a daily setting with more generic applications, to gain deep insights about designing such emerging technology from novice users. With this technology becoming affordable and accessible to end users, the next step is to investigate how novice users would accommodate and adopt such technology.

2.2 At-home Experiences

Recent work has highlighted the value of involving end users in the ideation for technology investigation, aiming to provide insights into users' natural technology interaction [17, 26]. In-home experience [17, 19, 21, 26–28] includes culture probes. These were first introduced in 1999 by Gaver et al. [15]. It is a method to elicit creative thinking by asking users to document their ideas and actively involving them in the design process [29]. It has been beneficial exploring technologies in this way before they become widely available and used by non-experts. In this paper, we explore the feasibility and appropriateness of domestication of infrared imaging. To examine the home experience, we leverage the advances in miniaturization and reduction in the prices of these devices and conducted a technology-cultural probe with 10 households aiming to provide insights into the appropriateness of future domestication of infrared imaging for everyday users. We utilize the in-home experience to explore the natural technology interactions.

3 DOMESTIC THERMAL IMAGING

Our research methods build on previous research in using cultural design probes and in-home experience [17, 19, 21, 26–28]. Culture probes were first introduced by Gaver et al. [15]. It is a method to elicit creative thinking by asking users to document their ideas and involving them in the design process [29]. It has been beneficial exploring technologies before they become widely available and are used by non-experts. On the other hand, Schmidt [25, 26] highlights the importance of functional prototypes. In this paper, we focus on infrared imaging, hence we combine technology-cultural [16] probes by using a functioning commercial device, diaries and notes for cultural probe deployed in users' homes. As most users do not understand how infrared cameras operate, in our study we focused on experiencing the technology. Furthermore, we used interviews to acquire a deeper insight into the users' lives. We conducted the exploration in the form of a technology-cultural probe, and as we aimed to gather results of high environmental validity, we decided to use commercially available imaging technology and deployed state-of-the-art consumer-grade thermal cameras in households for 10 days. To fully explore the usage of thermal imaging, we prepared a probe kit including diaries, note cards, and a commercial mobile phone with an attachable thermal camera FLIR one as shown in Figure 1.

Figure 1: Probe kit: FLIR one mobile thermal camera, Android phone, notebook, pen and markers.

According to Hutchinson et al. [17], probes should have the following properties: functionality, flexibility, usability, logging and design phase. Our probe complies with these factors as follows:

- Functionality: our probe is a simple Android application, with a single main function of capturing thermal pictures.
- Flexibility: we added the notes and diaries to offer an open-ended experience to allow users to reinterpret the images.
- Usability: probes are not concerned by the usability, hence we used the same kit with no iteration on the usability.
- Logging: probes should help the researchers visualize and analyze the usage of the users and further discuss innovative ideas. Our probe complies, as we logged the captured data (photos, videos and notes) as well as the time of use.
- Design Phase: our probe was conducted in the early stage of the design process.

4 DESIGN: MIXED-METHOD PROBE

We chose an easy to use form of the technology to encourage the participants to engage with it. We combined data from the technology-cultural probe with pre- and post- semi-structured interviews. The probe kit contained the following:

(1) Diary for on-the-go ideation,
(2) Pen, markers, and 50 empty cards to draw ideas on,
(3) Motorola MotoG phone to attach the camera to it,
(4) FLIR One for Android [2] thermal camera and it's application [3].

[2] http://www.flir.com/flirone/android/
[3] https://play.google.com/store/apps/details?id=com.flir.flirone&hl=en

Household	Participants / Gender / Occupation/ Age / Location
H1	1: Female Dermatologist 29, 2: Male Radiologist 33, 3: Male Retired Doctor 62, 4: 2 years old baby girl, **
H2	1: Female Dentist 25, 2: Male Dentist 30, 3: Female Retired Doctor 60, 4: 1 year old baby boy, **
H3	1: Female PhD student 27, 2: Female Project manager 27, **
H4	1: Female Housewife 29, 2: Male Student 27, 3: Male IT specialist 28, 4: 8 month baby girl **
H5	1: Female Environmentalist 21, 2: Male Student 22, 3: Male Guitarist 27, **
H6	1: Male Researcher 33, 2: Female student 19, **
H7	1: Male Student 27, **
H8	1: Female Housewife 22, 2: Male Student 23, **
H9	1: Male Student 27, 2: Male Student 21,**
H10	1: Female Student 21, 2: Female Student 23,**

Table 1: Demographics of the technology-cultural probe participants. ** blind submission

The kit enabled participants to easily use thermal camera. As it is easily attachable to the smart phone. Using the FLIR app, they can view and record thermal photos/videos. Previous work aimed to prompt the ideation via identifying a set of activities to be performed [27]. In our work we aimed to openly explore the usage in everyday settings. Hence, we did not use any prompts for activities.

4.1 Study Timeline

We designed our 10 day study as follows:

Pre-Interview Before starting the study, we visited the participants' households. We collected their consent for taking part in the study, and conducted a pre-interview to collect their demographics as well as their experience with thermal imaging.

Setting up the probe Participants were asked to place their probe kit in a location in the home that would be accessible to everyone. They were asked to document their ideas using the cards and diary, and record thermal photos and videos. Additionally, each participating household was presented with a brief introduction to the application, the capabilities of thermal imaging as well as the common properties and features of thermal radiation. We presented examples for the basic features of thermal imaging including:

(1) Viewing Thermal Information: by using the camera to view cups with different temperatures.
(2) Thermal transfer: by showing thermal image while a person touches a cup.
(3) Thermal reflection: by placing the camera in front of a reflective surface.

Semi-Structured Post Interviews After 10 days, we revisited the participants' households and gathered data including photos, videos and notes. We conducted a semi-structured interview to gain deeper insights in participants' experience and how they used the thermal camera. All household members were invited to the interview. We browsed the captured ideas and photos and asked them to provide explanation and details of the situation/use-case in which they captured the thermal photos and videos. Participants were encouraged to discuss the use-cases with the researchers as well as among themselves. The main goal of the interviews was an in depth exploration of the use-cases and the appropriateness of thermal cameras in everyday settings.

4.2 Participants

We conducted the study with 10 households over 10 days. Nine households had at least two individuals. We used snowball sampling to recruit our participants. We had 26 (23 adult) participants (11 female) with an age range of 1 -62 (mean:28.57, SD:16.97). Most participants held at least a Bachelor's degree. Three of the households had one child and two households had a dog. Only two participants were familiar with thermal imaging, and seven were familiar with the term 'thermal cameras' but had never seen one before. We used numbers for the houses as well as for the participants in each house for referral purposes. H13 means, for example, household 1 and individual number 3 in the household. Guardian consent was acquired for the participation of minors in the study.

5 ANALYSIS

The interviews were audio recorded and transcribed for analysis. We used thematic analysis [11] to analyze the content of the interviews. We analyzed 270 captured photos and 563 recorded interview minutes. Interestingly, none of the participants used the notes. Two coders coded 50% of the corpus independently using nVivo [4]. Afterwards, they met to assess differences and construct the final coding tree. The rest of the corpus was coded by a single coder. Through iterative discussion, the final themes emerged from the coded quotations. We present the four main themes reflecting thermal imaging in the home: *Experiencing Extended Visual Perception, Potential for domestication, Social Implications and When and Why People use Thermal cameras?*

5.1 Experiencing Extended Visual Perception

Participants reported a positive experience regarding accessing and experiencing thermal imaging. They were interested in what thermal cameras allow them to see and sense. Participants recognized the benefits and enhancement in perceiving the environment through thermal cameras:

> It was really cool to have a tool that can compensate what you can't see in hand. *(H32)*

One participant perceived thermal vision as a way to broaden their perception of the world:

[4] https://www.qsrinternational.com/nvivo/home

> The thermal view makes it a different experience and makes me feel superior. It's kind of a new dimension of perception. *(H11)*

Others were positively surprised by the ability to notice more details of the environment and thus being able to avoid danger more effectively. One participant stated that they felt safer:

> It felt as I can see the whole surrounding even in the dark which made me feel safe. *(H22)*

Participants reflected on how using the camera changed their perception of the surroundings. H21 and H61 remarked how using the camera introduced an adaption on how they see the world:

> Surprisingly even when I don't have the camera anymore I am using the hints I already got from the camera, its like your eyes adapts to this kind of information. *(H61)*

5.2 Potential for domestication

Participants reported that they would appreciate having a thermal camera in the home. They were comfortable with the mobile form:

> I was fascinated that you can have such an imaging tool as simple as a phone attachment. *(H13)*

However, they reported that the form factor depended on the use case. For instance, some preferred to have the thermal camera as a stationary tool monitoring a room. H22, wanted to have it as a substitute for the surveillance camera and he reported the need to have it in a stationary form:

> If I have this camera in the ceiling I can monitor my sleep and my body temperature during the day to reflect my health. *(H13)*

5.3 Social Implications

Most of the participants accept the idea of other people having thermal cameras operating at home. However, one participant reported to have privacy concerns, but she only wanted to be aware of its operation state rather than turning it off:

> It is not problem if people want to use it. *(H7)*
>
> This could be a real privacy invasion so I would like to know if someone is having that advantage over me. *(H32)*

Others reported being more careful to maintain the privacy of the house owner:

> I will be cautious. Maybe they will get upset if I touched their stuff as they can see when you touch something. *(H82)*

5.4 When and Why do People use Thermal Cameras?

Participants used the thermal camera in diverse tasks. Based on our analyzes, the usage can be classified in four categories; *enhancing their awareness about the environment, objects, people and substituting current techniques.*

Environment Awareness Participants used thermal cameras to better understand and perceive their environment. For instance, H13 familiarized himself with the room's wall to know where to hang a frame away from the electric cables. H12 reported how he was informed about damage in his ceiling, at an early stage, saving him money:

> I figured out that my ceiling is damaged and fixing it at this stage saved me tons of money. Also I used to monitor if they fix it right and if the paint dried out. *(H12)*

The thermal cameras were also used in bad lighting conditions. For instance, H21 used it during the night in a dark room with her partner sleeping to find objects.

> I used the camera around the baby not to wake him up if I am looking for something I don't have to turn on the lights. And if I am looking for my phone during the night I don't have to turn on the lights and disturb everyone in the room. *(H21)*

Object Awareness Participants also utilized the camera to know the state of different objects.

> We had a problem with the sink so I took a picture, there was difference in colors. We called the specialist to fix it. At night I took another picture which had a clearer color and there was no difference in colors so we deduced that there was a problem and fixed now. *(H82)*
>
> We had an electricity cut out and I could tell from the camera that the freezer did not operate and it saved the food inside as well as the hassle of cleaning up after the food is destroyed, at that point I felt like we need this to be always monitoring the devices. *(H13)*
>
> I always open the dishwasher during its operation but I used it and found heat getting out from the dishwasher when its operating. *(H92)*

H11 remarked the ability of thermal camera to check her daughter's diaper.

> Checking if she needs to change I had to run after her and stuck trying to get her dressed again. It showed if the diaper has anything without even touching her. It saved time and money. *(H11)*

An interesting use case reported by one of the participants who was a refugee and had experienced war zones. He recognized the benefits of having a thermal camera in the home to detect hidden object such as bombs. He also envisioned that the thermal camera could enable him to find monitoring devices such as hidden cameras and microphones as well as to find people. Additionally, he reflected on the ability of thermal cameras to detect invisible markers:

> They highlight the houses with wanted people using invisible paint, I think I will be able to see it using this camera. I think having it might spare my life.

People Awareness Participants also reflected the usage of the camera to know more about people's physical health state H92 or emotional state as reported by H11.

> I have a knee injury, it is always warm and if you hurt part of your body the injured part becomes warm. *(H92)*

Category	Example Use case
3*Enhanced Environmental Awareness	Checking ceiling for damages
	Checking walls for power lines before hanging a frame
	Finding objects in a dark room
5*Enhanced Object Awareness	Checking the state of the dishwasher
	Detecting issues with the sink
	Checking electric devices' states after electricity blackout
	Checking diapers
	Detecting invisible markers/paint
2*Enhanced People Awareness	Checking injuries
	Detecting emotions
3*Substituting Current Techniques	Early fire alarm
	Surveillance camera detecting past actions
	Replacing health monitoring devices

Table 2: Summary of the usage categories and example of the reported use cases for each category

> I know you can tell emotions from the temperature of the person, if I can hold the camera and know the unspoken feelings it kind of mind reading. *H11*

Substituting Current Techniques Interestingly, participants highlighted the usage of thermal camera as an advanced substitution for existing techniques and technologies.

> I would like to use it as an early alarm, because the smoke detectors work when things are already on fire and smoke reaching the ceiling which is too late. *(H23)*

> We have a surveillance camera with blind spots, with this camera I can see if someone passed by even if they are not around anymore. *(H12)*

> If you replace the Xbox camera with a thermal camera it would be a different experience. *(H22)*

H13 envisioned that a thermal camera could substitute health monitoring systems.

> If we can replace all vital sensing technologies with thermal cameras we could have a contactless health monitoring. *H13*

In summary, participants utilized thermal cameras in different use cases. Further examples include: kitchen tool, gaming camera, personal trainer, health monitoring tool and educational aid. It is worth mentioning that participants highlighted the need of applications to maximize the utility of thermal cameras.

> I think if you deploy it in form of apps like snap chat, fitness tracker, alarm systems its going to be really useful and maybe a necessity to have. *(H102)*

6 DISCUSSION

We were able to gather insights from a total of 26 individuals who lived with thermal cameras for 10 days in their home settings. Here, we present insights drawn from our analysis of the results.

Answering **RQ1**, our participants considered thermal cameras as a pleasurable tool and further considered it a vision extending tool that enabled them to see what they could not perceive with their own eyes. They used thermal imaging in the home for purposes including knowing more about their environment, determining the state of an object and emotions of people around them as well as to overcome the shortcomings of current technologies and techniques. Finally, the extended ability made participants feel safe and having advantage over the environment and its limiting factors.

During our exploration, we encouraged the participants to envision use cases with no restrictions. As a result, participants proposed use cases applicable to high-end thermal cameras as well as an application layer, e.g. an application that detects the emotions. While many of the use cases are not yet applicable to the current state of the technology, this research suggest the need of future development of thermal imaging applications for everyday users. Our study enabled us to gather information from a diverse set of users. Furthermore, the home setups enabled the participants to envision the usage of extending visual perception in daily life. Participants reflected on how extended thermal view enhanced their perception and how it built new understanding of their everyday surroundings, thus answering **RQ2** positively, where we observed that thermal imaging has a high potential for domestic appropriation.

Participants showed a clear understanding of the technology by exploration; there was no special training or instructions needed to understand and use thermal cameras **RQ3**. Additionally, they showed an awareness of the implications of the technology at hand, in highlighting the possible privacy issues that might arise during the usage of the thermal camera. In summary, participants were excited about the use of thermal imaging to extend their visual perception at home. They envisioned potential use cases, as well as form factors. The collected insights reflect the importance of building and evaluating possible visual perception extension devices.

Concerning the future design of domestic thermal cameras, participants reported that the preferred form factor relates to the use cases, where a stationary form was preferred for always-on and environmental monitoring. However, they preferred the flexible portable form for real time explicit object exploration (e.g. checking diapers). Participants envisioned the wearable form factor as flexible and on-demand vision extension tool. These findings highlight that identifying ways to embed thermal imaging is an emerging

challenge for HCI. Our exploratory study enabled us to gather information from diverse users; additionally the home setups enabled the participants to envision the usage of extend visual perception in daily setups. Participants reflected on how alternative vision modes provided a new information layer, enhancing their perception and understanding of their everyday surroundings. Interestingly, participants were eager to utilize the extended visual perception when their own vision was a limiting factor like in a dark basement with hidden objects and non-visible traces **RQ4**.

Participants used thermal imaging in the home for many purposes including enhancing their perception about their environment, the emotions and health state of people around them as well as to overcome the shortcomings of current techniques. In particular, participants reported that the thermal camera led them to detect sources of dissipating heat as hints for re-arranging objects in their house, spot dysfunctional domestic appliances, and locate and gauge sources of heating loss. These findings demonstrate the potential of the thermal imaging to reduce costs for household heating by detecting insufficient insulation and increasing energy saving awareness (e.g. checking if all windows are closed when leaving home). Surprisingly, in one case, the thermal camera was even reported as a tool that could potentially save/protect one's life in home settings when in a war zone. This shows that hardware miniaturization and democratization made it possible for thermal cameras (commonly only available to military personnel) to reach civilians, assisting them in escaping life threatening situations. Participants also reported the potential for eliciting emotions (e.g. anxiety) during interpersonal encounters, health state or disease symptoms (e.g. fever). Participants displayed increased awareness on the privacy implications of having such a layer of extra information at hand and commented on how it could be a potential means of discrimination (i.e. detecting and avoiding fevered peers). Although we anticipated participants would deploy thermal cameras in gaming as an alternative or addition to the Kinect depth technology, only one participant envisioned using it in a gaming scenario. However, it will be interesting to explore thermal imaging in the gaming context aiming to penetrate the gaming market in a similar way to how Kinect was introduced and is now adopted in a vast set of applications.

7 DESIGN IMPLICATIONS AND GUIDELINES

To support novice users in using thermal cameras in domestic setups, and to inform researchers and designers we propose set of implications for designing future thermal camera based systems and tools that will consider the challenges and recommendations identified in our findings.

7.1 Form Factor

Future systems should use the appropriate form factor for the use case for which they are designing their system. Where it is a monitoring use case, participants preferred the mounted stationary form e.g. continuous health monitoring or object state detection. On the other hand, they recommended the mobile form factor for on demand explicit usage of vision extension and thermal cameras e.g. checking baby diapers.

7.2 Context Awareness & Social Context

Designers should consider the context of use and offer information related to the context (e.g. highlighting the hottest cup, or automatically detecting and displaying someone's emotional state). This context awareness would enhance the understanding and usage of thermal camera based systems, as it would help novice users learn about the capabilities of the camera, hence be able to best utilize it. Our findings suggests the need of including information layer in the thermal user interface.

7.3 Privacy & Social Consideration

Participants exhibited an awareness of the privacy implications of having such a layer of extra information at hand. This emphasizes the need to explore and research explicit privacy management in HCI for thermal cameras or any imaging system that displays non-visible information. For instance, designers should consider camera state notification e.g. an indicator if the camera is on.

8 LIMITATIONS & FUTURE WORK

We acknowledge that our work has its limitations. Our findings are based on qualitative analysis, as we aimed to gather insights on how novice users would naturally interact with the technology. A further limitation is knowledge bias, where thermal properties differs from the light properties e.g. thermal reflection and transfer. Also ten days might not have been a sufficient duration to fully explore the technology. One main direction of future work would be towards further investigation of the daily usage of thermal imaging in more long terms studies, and comparing the findings with other methodologies such as surveying Youtube videos to investigate the effectiveness of our approach.

9 CONCLUSION

Through our review of related work, we concluded that no prior work explored the use of thermal imaging in everyday settings with the use of thermal imaging. Consequently, in this work we began our inquiry by exploring the potential use cases in daily life. This paper represents the first explorative study of the potential domestication and home uses of thermal imaging, in real homes by everyday users. We assured high ecological validity via the conducted technology-cultural probe. While our findings are limited by the sample size and the technical limitations of the prototype, we were able to gather insights from a total of 26 individuals, who lived with thermal cameras for 10 days. Our findings imply the acceptance of the usage of thermal imaging. Participants highlighted their vision to have such a tool in their home to be used in a daily fashion. As a result we had insights concerning participants' preferences regarding the form factor. We hope that designers of future thermal imaging systems can use our insights to build enhanced vision interfaces with a high user benefit in everyday usage.

10 ACKNOWLEDGMENTS

This research was supported by the German Research Foundation (DFG), Grant No. AL 1899/2-1, and the Amplify project which received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 683008).

REFERENCES

[1] Yomna Abdelrahman, Mohamed Khamis, Stefan Schneegass, and Florian Alt. 2017. Stay Cool! Understanding Thermal Attacks on Mobile-based User Authentication. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 3751–3763. https://doi.org/10.1145/3025453.3025461

[2] Yomna Abdelrahman, Anam Ahmad Khan, Joshua Newn, Eduardo Velloso, Sherine Ashraf Safwat, James Bailey, Andreas Bulling, Frank Vetere, and Albrecht Schmidt. 2019. Classifying Attention Types with Thermal Imaging and Eye Tracking. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 3, Article 69 (Sept. 2019), 27 pages. https://doi.org/10.1145/3351227

[3] Yomna Abdelrahman, Pascal Knierim, Pawel W. Wozniak, Niels Henze, and Albrecht Schmidt. 2017. See Through the Fire: Evaluating the Augmentation of Visual Perception of Firefighters Using Depth and Thermal Cameras. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers (UbiComp '17)*. ACM, New York, NY, USA, 693–696. https://doi.org/10.1145/3123024.3129269

[4] Yomna Abdelrahman, Alireza Sahami Shirazi, Niels Henze, and Albrecht Schmidt. 2015. Investigation of Material Properties for Thermal Imaging-Based Interaction. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 15–18. https://doi.org/10.1145/2702123.2702290

[5] Yomna Abdelrahman and Albrecht Schmidt. 2019. Beyond the visible: sensing with thermal imaging. *Interactions* 26, 1 (2019), 76–78. https://doi.org/10.1145/3297778

[6] Yomna Abdelrahman, Albrecht Schmidt, and Pascal Knierim. 2017. Snake View: Exploring Thermal Imaging As a Vision Extender in Mountains. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers (UbiComp '17)*. ACM, New York, NY, USA, 1067–1071. https://doi.org/10.1145/3123024.3124450

[7] Yomna Abdelrahman, Eduardo Velloso, Tilman Dingler, Albrecht Schmidt, and Frank Vetere. 2017. Cognitive Heat: Exploring the Usage of Thermal Imaging to Unobtrusively Estimate Cognitive Load. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technology* 1, 3, Article 33 (Sept. 2017), 20 pages. https://doi.org/10.1145/3130898

[8] Yomna Abdelrahman, Pawel Wozniak, Pascal Knierim, Niels Henze, and Albrecht Schmidt. 2018. Exploration of Alternative Vision Modes Using Depth and Thermal Cameras. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia, MUM 2018, Cairo, Egypt, November 25-28, 2018*. 245–252. https://doi.org/10.1145/3282894.3282920

[9] Francine Amon, Anthony Hamins, Nelson Bryner, and Justin Rowe. 2008. Meaningful performance evaluation conditions for fire service thermal imaging cameras. *Fire Safety Journal* 43, 8 (2008), 541–550.

[10] Francine Amon and Colin Pearson. 2009. Thermal imaging in firefighting and thermography applications. *Radiometric Temperature Measurements: II. Applications* 43 (2009), 279–331.

[11] Ann Blandford, Dominic Furniss, and Stephann Makri. 2016. Qualitative HCI research: Going behind the scenes. *Synthesis Lectures on Human-Centered Informatics* 9, 1 (2016), 1–115.

[12] Seek Camera. 2018. Seek Camera. Retrieved Accessed: September 21, 2018 from https://www.thermal.com/

[13] Girum G Demisse, Dorit Borrmann, and Andreas Nüchter. 2015. Interpreting thermal 3D models of indoor environments for energy efficiency. *Journal of Intelligent & Robotic Systems* 77, 1 (2015), 55–72.

[14] Rikke Gade and Thomas B. Moeslund. 2014. Thermal cameras and applications: a survey. *Machine Vision and Applications* 25, 1 (2014), 245–262. https://doi.org/10.1007/s00138-013-0570-5

[15] Bill Gaver, Tony Dunne, and Elena Pacenti. 1999. Design: cultural probes. *interactions* 6, 1 (1999), 21–29.

[16] Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans, Heiko Hansen, et al. 2003. Technology probes: inspiring design for and with families. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 17–24.

[17] Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B. Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans, Heiko Hansen, Nicolas Roussel, and Björn Eiderbäck. 2003. Technology Probes: Inspiring Design for and with Families. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '03)*. ACM, New York, NY, USA, 17–24. https://doi.org/10.1145/642611.642616

[18] Stephanos Ioannou, Vittorio Gallese, and Arcangelo Merla. 2014. Thermal infrared imaging in psychophysiology: potentialities and limits. *Psychophysiology* 51, 10 (2014), 951–963.

[19] Pascal Knierim, Pawel W. Wozniak, Yomna Abdelrahman, and Albrecht Schmidt. 2019. Exploring the Potential of Augmented Reality in Domestic Environments. In *Proceedings of the 21st International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI 2019, Taipei, Taiwan, October 1-4, 2019*. 31:1–31:12. https://doi.org/10.1145/3338286.3340142

[20] J Michael Lloyd. 2013. *Thermal imaging systems*. Springer Science & Business Media.

[21] Leah Maestri and Ron Wakkary. 2011. Understanding repair as a creative process of everyday design. In *Proceedings of the 8th ACM conference on Creativity and cognition*. ACM, 81–90.

[22] Matthew Louis Mauriello, Brenna McNally, Cody Buntain, Sapna Bagalkotkar, Samuel Kushnir, and Jon E Froehlich. 2018. A large-scale analysis of YouTube videos depicting everyday thermal camera use. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 37.

[23] Kedar Nimbalkar. 2018. Thermal Cameras DIY. Retrieved Accessed: September 21, 2018 from http://www.instructables.com/id/Make-Infrared-Thermal-Imaging-Camera-for-Cheap-Con/

[24] Alireza Sahami Shirazi, Yomna Abdelrahman, Niels Henze, Stefan Schneegass, Mohammadreza Khalilbeigi, and Albrecht Schmidt. 2014. Exploiting Thermal Reflection for Interactive Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 3483–3492. https://doi.org/10.1145/2556288.2557208

[25] Albrecht Schmidt. 2017. Understanding and Researching Through Making: A Plea for Functional Prototypes. *interactions* 24, 3 (April 2017), 78–81. https://doi.org/10.1145/3058498

[26] Albrecht Schmidt, Lucia Terrenghi, and Paul Holleis. 2007. Methods and guidelines for the design and development of domestic ubiquitous computing applications. *Pervasive and Mobile Computing* 3, 6 (2007), 721–738.

[27] Rita Shewbridge, Amy Hurst, and Shaun K Kane. 2014. Everyday making: identifying future uses for 3D printing in the home. In *Proceedings of the 2014 conference on Designing interactive systems*. ACM, 815–824.

[28] Ron Wakkary and Leah Maestri. 2007. The resourcefulness of everyday design. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*. ACM, 163–172.

[29] Jayne Wallace, John McCarthy, Peter C Wright, and Patrick Olivier. 2013. Making design probes work. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 3441–3450.