1. Special Issue Title:

Special issue on Pervasive Displays

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5. Order of papers

1. Understanding visitor interaction with a Projection Augmented Relief Model Display: Insights from an in-the-wild study in the English Lake District
2. Partitioning Open-plan Workspaces via Augmented Reality
3. Supporting Intergenerational Memento Storytelling for Older Adults Through Tangible Display: A Case Study
4. Understanding public displays as a medium for place-based communication: Implications from current practices with non-digital displays
5. Child-Display Interaction: Lessons Learned with Touchless Gestural Interfaces
6. Crowdsourcing Sensitive Data using Public Displays - Opportunities, Challenges, and Considerations
7. Stereoscopic 3D Dashboards: An Investigating Of Performance, Workload, and Gaze Behavior During Take-Overs in Semi-Autonomous Driving
8. Using Large-Scale Augmented Floor Surfaces for Industrial Applications and Evaluation on Perceived Sizes
9. Exploring Pervasive Displays for Cemeteries and Memorial Sites
10. Self-Moving and Pulverized Urban Displays: Status Quo, Taxonomy & Challenges

11. Toward Tangibles and Display-rich Interfaces for Co-located and Distributed Genomics Collaborations
12. Set It and Forget It: Utility-based Scheduling for Public Displays

1. Introduction

Digital displays have become pervasive to our everyday lives. They belong to our living and working environments and are relevant to many research areas, including human-computer interaction and ubiquitous computing. Nowadays, pervasive displays range from traditional public displays and media façades in urban environments, to new forms of embedded displays and multi-touch surfaces. Recent work explored also unconventional forms of displays, such as flying (on-drone) displays, wearable and flexible displays, and head-mounted AR/VR displays. Such heterogeneous nature of pervasive displays represents a rich resource for receiving ambient information, complementing our personal mobile devices, or providing in-situ feedback in a plethora of different domains. However, designing visionary deployments that go beyond traditional digital signage, and understanding users' behavior in such diverse contexts, is far from trivial.

The aim of this theme issue was to explore new technologies, methodologies, and applications that relate to all aspects of pervasive displays, and the problems raised consequently. This special issue also contains a selection of invited papers extended from the 8th ACM International Symposium on Pervasive Displays (PerDis 2019) [16] that took place in Palermo, Italy in June 2019. The contributions came from diverse fields such as computer science, human-computer interaction, engineering, design, media architecture, and social sciences. Submissions went through a single-blind review process, with a minimum of two reviewers for each paper. Authors also received an additional meta review by one of the guest editors.

This preface summarizes the 12 articles that have been accepted in this special issue. Eight of those were extended versions of conference papers that were published at PerDis 2019. We then further discuss the steps ahead in the area of pervasive displays.

2. Accepted articles

This section summarizes the aims and outcomes of the accepted articles.

Priestnall and Cheverst [1] present findings from a collaborative in-the-wild study with the Lake District National Trust, where they deployed a projection augmented relief model (PARM) deployed in the English Lake District. The PARM display projects on a landscape model to tell the user where they are in the national park. The authors observed 221 users in a 3-day period and found that 79% of visitors noticed the PARM display, and 68% of those gave it their focal attention. The authors reflect on how display blindness is less apparent in their deployment likely due to the PARM display sparking curiosity and because non-city-wide deployments are less likely to be associated with advertisements.

Lee et al. [2] propose a solution to the problem of open-plan workspaces being associated with high levels of distraction. They developed a concept for creating virtual partitions between workers using an augmented pervasive display that acts as a visual separator. The authors detail their implementation of the prototype that is based on Microsoft HoloLens. They also report on a series of studies to evaluate the concept. The first study compared how open-plan, physical and virtual partitions influence immersion, and awareness of surroundings. A second study looked into design attributes of space partitioning through interviews with architects and interior designers. Finally, a third study with 12 office workers showed that all designs are effective for reducing visual disturbance but are perceived differently. Overall the findings show that virtual partitions reduce visual distractions and enable users to personalize the visual attributes of their space leading to an improved experience of shared workspaces.

Li et al. [3] introduce the design and implementation of a tangible device, Slots-Memento, that supports intergenerational memento storytelling for older adults. The authors argue that memento sharing is a cooperation process that should involve both the storytellers and listeners. In particular, they see the young generation as not only audiences of storytellers, but also memory trigger providers. The authors report on their implementation and a series of studies in which they refined the prototype then evaluated it in the wild. They recruited 8 pairs of an older adult and their child to use the prototype for one week and interviewed them afterwards. The authors conclude with a list of characteristics of older adults' intergenerational memento storytelling, and strategies of designing tangible displays for said storytelling.

Coutinho and José [4] study the use of public displays as an open medium for place-based communication. To this end, they investigate current place-based communication practices with non-digital displays by observing 40 places of various types across 3 cities in Portugal. They interviewed the place owners to identify the purposes that are being served by non-digital displays and use them as hints into possible novel uses for public displays. The authors classified the communication practices into 10 domains, including products/services, processes, place brand, events, and legal communication. This results in three main contributions: a characterization of 9 major usage dimensions for place-based communication, a characterization of the relative weight of usage dimensions across different types of places, and the identification of the primary role of externally sourced content in place-based communication. Based on this, the authors conclude with implications for designing digital public displays.

Rubegni et al. [5] investigate the use of on-screen avatars to guide children when interacting with touchless large displays. The idea is that the avatars would perform gestures to teach them to children, who can in turn use them to interact with the display. The authors report on a study with 107 children aged 2 to 10 years, in which they studied whether avatars provide interactions that are intuitive for children and thus help overcome affordance blindness, and whether this makes children's experiences engaging and enjoyable. The authors found that the children's age influences the style of child-avatar interactions, and that avatars facilitate the development of educational technologies for young children. They concluded with four learned lessons that guide the design of large display interfaces for children.

Alorwu et al. [6] argue that public displays present promising opportunities for collecting tagged data that is useful beyond a single application. Motivated by this, they present results on a 61-day deployment in which biometrically-tagged video selfies were collected through a public display in the wild. They followed this by an online questionnaire in which 53 participants responded to open and likert-scale questions. Participants generally expressed their willingness to donate specific types compared to others, but the authors also underline the need to develop clear data management policies, and allow systems to collect granular data. All in all, the article presents opportunities to leverage public displays to advance data-driven research.

Weidner and Broll [7] present an exploration into visual feedback on 3D dashboards of automated cars to support take-over requests from the vehicle to the person in the driver's seat. The authors first present three feedback strategies with different levels of realism, which they evaluate in a participatory design pre-study with 5 participants. Based on the results of the pre-study, they identify a visualization for the take-over request. They then evaluate this validated feedback strategy in four potential locations, in both stereoscopic and perspective 3D dashboards, in a user study conducted with 52 volunteers in a driving simulator. They show that the location of the take-over request influences performance, and that there are promising aspects in the use of stereoscopic 3D dashboards over perspective 3D dashboards, since they led to significantly more safe take-over maneuvers. This work informs future researchers and practitioners on the design of visual warnings for automated vehicles.

Otto et al. [8] explore how large-scale high-resolution floor displays can be used to support human size perception via six automotive production planning scenarios. In a user study with 22 participants, they investigate how people perceive the size of virtual contents using true to scale 2D data visualization. The study compares three conditions, two of them showing to scale data representation on a 54-sqm sized LED floor, and one showing relative-size visualizations on a tablet computer. In each condition, the participant is given a visual aid to help them make sense of the object's size. The results of the study show that true to scale floor visualizations provide better size judgment accuracy than relative-size visualization on a tablet display. This work provides insights into human size perception in immersive environments and opens the space to further research on large-scale floor displays.

Häkkilä et al. [9] investigate the use of pervasive displays in graveyards. Their work includes three user studies. First, a focus group with 5 participants revealed that participants felt positively towards digital signage and navigation in graveyards, but were more reserved about digital gravestones and memorials, which could undermine the dignity of the deceased. Second, they designed and prototyped an interactive gravestone display which was evaluated with 8 participants. This evaluation resulted in design considerations for personal and shared displays in the graveyard context. Finally, they evaluated a location-aware graveyard navigator designed as a mobile phone application with 12 participants in-situ in a Finnish graveyard. Their work highlights the importance of respecting the dignity of the deceased when designing content and positioning pervasive displays in such sensitive contexts. It also opens the space to future research opportunities related to graveyards as a design environment for pervasive displays and ubiquitous computing.

Hoggenmueller et al. [10] explore the concept of self-moving robots and pulverised urban displays as a novel type of pervasive displays. They taxonomize the notion of pervasive urban displays in two dimensions: 1. the level of physical integration of the content into the urban space and 2. the level of mobility of the technology. One key aspect of their work is the decoupling of the content and the display, in which they consider that the display technology can be physically separated from its content. This is the case with printer-type displays, as in self-moving robots that can pulverise content on the ground. The work further describes example applications and design implications for such robots as pervasive urban displays, and opens the space by presenting a series of research challenges to be tackled by the community in years to come.

Konkel et al. [11] explore the use of pervasive displays to discover and learn large datasets, through two case studies exploring tangible systems for distributed and co-located engagement with genomics datasets, in research and teaching, carried out respectively in 2012 and 2014. The paper presents the two different tangible systems including their user interfaces, multiple display strategies, and content types. It then discusses lessons learned as well as potential integration of technologies such as Virtual Reality or smartwatches as additional display types. The work concludes on a vision for tangible genomics to support future students and researchers in the field.

Bushman and Labrinidis [12] propose a novel scheduling algorithm, Lookahead algorithm, for automated content selection on public displays. The algorithm is built upon a function framework that is designed to maximize the overall usefulness of the displayed content items. This is done using a utility function that represents the viewer-perceived value of a content item over time, and which informs the scheduling decisions. The framework is designed to consider both live and static content. In an evaluation against seven other scheduling algorithms, the presented Lookahead algorithm was the only one that acquired consistently high utility while also meeting almost all deadlines. The authors discuss the deployment of a prototype of the scheduler on a public display located in the lobby of an academic building and show that while the setup is fairly complex, the system can then run independently. They conclude on the need for a user interface to specify target ratios for each displayed item.

3. The Future of Pervasive Displays

Pervasive displays have become truly ubiquitous, from digital signage in buildings to bus arrival times in cities [12], they are now part of our everyday device ecosystem. This special issue revealed that, while the original form of “public displays” as considered in early pervasive displays research is not as prominent as expected, novel form factors have emerged, such as autonomous robots that behave as pervasive displays [10]. Novel technologies are constantly providing new support and inspiration for pervasive display research, such as the increased availability of augmented, virtual, and mixed reality devices. For instance, in this special issue, Lee et al. [2] demonstrated how augmented reality can be used to project virtual partitions in open workplaces to improve people’s shared workspace experience; and Konkel et al. [11] presented a tangible interface for people to engage with large datasets in a learning setting. While these novel pervasive displays can be categorized along many dimensions, Hoggenmueller et al. [10] proposed a systematic analysis of pervasive urban displays, leading to a taxonomy which considers both the technology and the physical integration of the content within the urban space. This special issue further illustrates open challenges and future opportunities, which we describe for the whole special issue below.

This special issue revealed that there are yet some challenges that need to be addressed for pervasive displays and proposed solutions. This includes technical challenges, such as content scheduling [12], as well as human-centered design challenges, such as attracting attention [1], social acceptability [9], workload [7], and designing for different user groups [3,5]. Authors of articles in this special issue have shown that these areas require further research, and have also highlighted multiple opportunities which we divide in terms of use cases and methodologies:

Novel use cases: There are a myriad of use cases for which pervasive displays can be particularly promising. Rubegni et al. [5] and Li et al. [3] developed pervasive display applications that address challenges experienced by children and older adults respectively. A number of novel applications for pervasive displays were proposed, including creating virtual partitions between workers in open workspaces [2], place-based communication [4] and crowdsourcing [6], and even large floor displays for automotive manufacturing [8].

Novel methodologies: Field and lab studies are still widely employed to empirically study pervasive display. There are opportunities in experimenting with novel methodologies for evaluating pervasive displays. Recently, researchers have been investigating the use of virtual and augmented reality for evaluating ubiquitous systems, IoT devices and security systems [13-15]. Most relevant to this special issue is the work of Mäkelä et al. [13], which compared behavior of bystanders around public displays in the real world to their behavior around virtual displays in an immersive virtual environment. They found that user behavior is largely similar across both settings, suggesting that conducting user studies in virtual reality can be a viable alternative to real world field studies which are typically difficult, expensive, and time-consuming. The significant increase in adoption of virtual reality headsets makes this novel approach even more promising. Namely, researchers can now recruit remote participants to take part in user studies to evaluate pervasive displays in virtual environments. These participants do not need to be able to physically reach the display. Instead, they should only have a virtual reality headset available. Remote studies allow reaching larger samples, and can help researchers conduct user studies even when participants cannot come to the lab (e.g. due to a pandemic).

To conclude, Pervasive Displays have come a long way in the past decades. With the increasing technological advances in displays, many more research opportunities arise to investigate the tangible benefits that pervasive displays can bring to our lives. Moreover, there are still technical and human challenges remaining that require further investigations. This special issue contributed to both exploiting said opportunities and addressing today and tomorrow's pervasive display challenges.

References

[1] Priestnall, G., Cheverst, K. Understanding visitor interaction with a projection augmented relief model display: insights from an in-the-wild study in the English Lake District. *Pers Ubiquit Comput* (2019). https://doi.org/10.1007/s00779-019-01320-2

[2] Lee, H., Je, S., Kim, R. *et al.* Partitioning open-plan workspaces via augmented reality. *Pers Ubiquit Comput* (2019). https://doi.org/10.1007/s00779-019-01306-0

[3] Li, C., Hu, J., Hengeveld, B. *et al.* Supporting intergenerational memento storytelling for older adults through a tangible display: a case study. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-020-01364-9

[4] Coutinho, P., José, R. Understanding public displays as a medium for place-based communication: implications from current practices with non-digital displays. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-019-01362-6

[5] Rubegni, E., Gentile, V., Malizia, A. *et al.* Child–display interaction: Lessons learned on touchless avatar-based large display interfaces. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-020-01451-x

[6] Alorwu, A., van Berkel, N., Goncalves, J. et al. Crowdsourcing sensitive data using public displays—opportunities, challenges, and considerations. Pers Ubiquit Comput (2020). https://doi.org/10.1007/s00779-020-01375-6

[7] Weidner, F., Broll, W. Stereoscopic 3D dashboards. An investigation of performance, workload, and gaze behavior during take-overs in semi-autonomous driving. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-020-01438-8

[8] Otto, M., Lampen, E., Agethen, P. *et al.* Using large-scale augmented floor surfaces for industrial applications and evaluation on perceived sizes. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-020-01433-z

[9] Häkkilä, J., Colley, A., Kalving, M. *et al.* Exploring pervasive displays for cemeteries and memorial sites. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-019-01359-1

[10] Hoggenmueller, M., Hespanhol, L., Wiethoff, A. *et al.* Self-moving robots and pulverised urban displays: status quo, taxonomy, and challenges in emerging pervasive display research. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-020-01422-2

[11] Konkel, M.K., Ullmer, B., Shaer, O. *et al.* Toward tangibles and display-rich interfaces for co-located and distributed genomics collaborations. *Pers Ubiquit Comput* (2020). https://doi.org/10.1007/s00779-020-01376-5

[12] Bushman, K., Labrinidis, A. Set it and forget it: utility-based scheduling for public displays. Pers Ubiquit Comput (2020). https://doi.org/10.1007/s00779-020-01423-1

[13] Mäkelä, V., Radiah, R., Alsherif, S., Khamis, M., Xiao, C., Borchert, L., Schmidt, A., and Florian Alt. 2020. RepliCueAuth: Validating the Use of a lab-based Virtual Reality Setup for Evaluating Authentication Systems. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (*CHI '20*). Association for Computing Machinery, New York, NY, USA, 1–15. DOI:https://doi.org/10.1145/3313831.3376796

[14] Voit, A., Mayer, S., Schwind, V., Henze, N.. 2019. Online, VR, AR, Lab, and In-Situ: Comparison of Research Methods to Evaluate Smart Artifacts. In *Proceedings of the 2019*

CHI Conference on Human Factors in Computing Systems (*CHI '19*). Association for Computing Machinery, New York, NY, USA, Paper 507, 1–12. DOI:https://doi.org/10.1145/3290605.3300737

[15] Mathis, F., Vaniea, K., Khamis, M.. 2021. RepliCueAuth: Validating the Use of a lab-based Virtual Reality Setup for Evaluating Authentication Systems. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (*CHI '21*). Association for Computing Machinery, New York, NY, USA. DOI: https://doi.org/10.1145/3411764.3445478

[16] 2019. Proceedings of the 8th ACM International Symposium on Pervasive Displays. Association for Computing Machinery, New York, NY, USA. doi: 10.1145/3321335
Web: https://dl.acm.org/doi/proceedings/10.1145/3321335