Horizon Scanning Series

The Internet of Things

Ubiquitous Interfaces and Pervasive Augmented Reality

This input paper was prepared by Tobias Langlotz and Holger Regenbrecht

Suggested Citation

Langlotz, T and Regenbrecht, H (2019). Ubiquitous Interfaces and Pervasive Augmented Reality. Input paper for the Horizon Scanning Project "The Internet of Things" on behalf of the Australian Council of Learned Academies, www.acola.org.

The views and opinions expressed in this report are those of the author and do not necessarily reflect the opinions of ACOLA.

Ubiquitous Interfaces and Pervasive Augmented Reality
Tobias Langlotz and Holger Regenbrecht

The IoT is often seen as a concept where devices and sensors that are increasingly networked communicate with each other to serve end users and can be considered as an extension of the internet to physical devices. One can even think of the IoT as giving virtual information stored in the internet a physical extension while also allowing machines and devices to talk to other machines and devices.
The origins of the IoT can be dated back to two other concepts: ubiquitous computing and pervasive computing. Ubiquitous computing was first introduced by Mark Weiser when presenting his vision of the Computer for the 21st Century[1]. His vision triggered a new wave of concepts where computing capabilities become omnipresent while also receding into the background of our everyday lives. Since then other terminologies have been introduced often describing the same vision or aspects of it (e.g. calm computing, hidden computing, post-PC computing). Pervasive computing is focusing more on building models of the environment in which technology is embedded and the context of use while ubiquitous computing is adding mobility in the sense that the environment and its context of use can entirely change and thus requiring dynamic reconfiguration[2]. Similarly, in the context of IoT is the importance of the user interface within ubiquitous computing when compared to pervasive computing[3]; current IoT technology can be seen as a form of pervasive technology that is immobile and embedded into the environment capturing information about its environment.
The user interface of current IoT technology usually evolves around using dedicated mobile apps and is not striving for natural interaction or a natural user interface as envisioned in the concept of ubiquitous computing. As IoT exposes an unprecedented amount and quality of data and information, IoT will benefit from, if not even demand new human-information interfaces beyond human-computer interaction with computers, mobiles, and interactive displays. One of the biggest challenges is to create a unified and omnipresent interface for ubiquitous computing and IoT that does not require to "start a dedicated app". Ubiquitous IoT interfaces are "always on" while working in different contexts (e.g. environments) and for different purposes, dynamically changing their appearance and behaviour.

Ubiquitous Augmented Reality

The user interface concept of mixed and augmented reality technology dates back to before the concept of ubiquitous computing. Despite different terminologies and definitions, augmented reality as a user interface can be summarized as the concept of integrating digital information into the physical world using precisely registered (visual) overlays. Augmented reality has been considered as an interface for ubiquitous computing[4] but faced technical challenges such as the requirement for precise tracking, the availability of affordable AR displays, and the general computing and battery power required for tracking and rendering the visual overlay. However, as a result of massive investments from leading players in the IT industry (e.g., Microsoft HoloLens, Google's stake in Magic Leap and AR SDKs, and Apple's acquisition of AR companies) many of these technical challenges are

---

[1] Weiser, M. (1993). Ubiquitous computing. Computer, (10), 71-72.
[2] Lyytinen, K., & Yoo, Y. (2002). Ubiquitous computing. Communications of the ACM, 45(12), 63-96.
[3] Abowd, G. D., & Mynatt, E. D. (2000). Charting past, present, and future research in ubiquitous computing. ACM Transactions on Computer-Human Interaction (TOCHI), 7(1), 29-58.
[4] Rhodes, B., & Starner, T. (1996, April). Remembrance Agent: A continuously running automated information retrieval system. In The Proceedings of The First International Conference on The Practical Application Of Intelligent Agents and Multi Agent Technology (pp. 487-495).

close to be overcome and augmented reality could be the one user interface for future ubiquitous computing and IoT technologies. In his vision of the Worldboard, Jim Spohrer already pointed out how the internet and augmented reality technology could fuse[5]. The Worldboard describes an extension to the Internet where internet addresses are augmented with GPS coordinates so that information and services can be linked to every position on the globe. In this vision, augmented reality is the interface to all information and services and it is easy to see how IoT will fit into this vision. While being only a vision, there were already approaches demonstrating the technology to implement the vision of a Worldboard using mobile phones providing AR interfaces[6].

Pervasive Augmented Reality

However, the challenges of an augmented reality interface that is being "always on" have only recently been brought to our attention[7]. For instance, Microsoft's HoloLens is completely designed around the concept of augmented reality as the central user interface. It is easy to foresee that future iterations will be smaller and lighter, almost resembling traditional glasses and there are first approaches of computational glasses that explore this technology as a vision aid[8,9]. For an AR interface to be always on ("Pervasive Augmented Reality"), the system needs to be context aware and to respond to its current environment and the task of the users. This requires additional sensing and input modalities that are not fully explored yet. Fortunately, IoT technology could be the key technology as a source of information to dynamically adapt to the current environment as well as an application scenario in the sense the AR can be used to visualize and interact with the relevant data and IoT devices (e.g. showing and manipulating the current settings or position of IoT devices).

Embodied Augmented Reality Agents

The fusion of augmented reality, intelligent virtual agents, and the Internet of Things can lead to novel Pervasive AR interfaces.[10] As an example, an embodied augmented reality agent would have some sort of intelligence implemented within the system, but the data required for this intelligence is received from IoT technology that allows to "sense and influence the real world". The augmented reality interface visually blends the virtual agent into the environment also utilizing the sensor information from IoT devices. Using an AR interface to IoT with digital agents can increase trust and confidence in the technology to assist the user[11].

Beyond Visual

---

[5] Spohrer, J. C. (1999). Information in places. IBM Systems Journal, 38(4), 602-628.

[6] Langlotz, T., Nguyen, T., Schmalstieg, D., & Grasset, R. (2014). Next-generation augmented reality browsers: rich, seamless, and adaptive. Proceedings of the IEEE, 102(2), 155-169.

[7] Grubert, J., Langlotz, T., Zollmann, S., & Regenbrecht, H. (2016). Towards pervasive augmented reality: Context-awareness in augmented reality. IEEE transactions on visualization and computer graphics, 23(6), 1706-1724.

[8] Hwang, A. D., & Peli, E. (2014). An augmented-reality edge enhancement application for Google Glass. Optometry and vision science: official publication of the American Academy of Optometry, 91(8), 1021.

[9] Langlotz, T., Sutton, J., Zollmann, S., Itoh, Y., & Regenbrecht, H. (2018, April). Chroma Glasses: Computational glasses for compensating colour blindness. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (p. 390). ACM.

[10] Norouzi, N., Bruder, G., Belna, B., Mutter, S., Turgut, D., & Welch, G. (2019). A Systematic Review of the Convergence of Augmented Reality, Intelligent Virtual Agents, and the Internet of Things. In Artificial Intelligence in IoT (pp. 1-24). Springer, Cham.

[11] Kim, K., Boelling, L., Haesler, S., Bailenson, J., Bruder, G., & Welch, G. F. (2018, October). Does a Digital Assistant Need a Body? The Influence of Visual Embodiment and Social Behavior on the Perception of Intelligent Virtual Agents in AR. In 2018 IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (pp. 105-114). IEEE.

When talking about Mixed and Augmented Reality, we usually refer to visual augmentations. However, the concept of audio augmentation and hearables is evolving fast and allows for augmenting different modalities that could be less distractive in certain contexts and can be easily combined with visual augmented reality[12,13]. This can be further extended by augmenting tactile information.
Overall, while augmented reality as an interface to ubiquitous computing and IoT is only in its infancy, it would allow for a unified and omnipresent interface to digital information. Furthermore, it would allow for tailoring the interfaces towards different users and groups of users by incorporating user modelling and data-driven personalization.

Pervasively Augmented Cities

The implementation of IoT as part of a smart cities and regions technical infrastructure will allow pervasive augmented reality interfaces to develop to their full potential. It will enable citizens to participate in the informational enrichment of our environment—making way for Augmented Reality 2.0[14]. This will also raise some ethical questions[15] on the possible invasion of public and private places with virtual augmentations, including questions around who should be allowed to augment the environment and about privacy and anonymity in the age of omnipresent information augmentation. It will also require a discussion about the desire, necessity, and quality of blending virtual and real environments to a degree that they are indistinguishable from each other. Regulations might be required to mark-up virtual content and to inform the public about real versus virtual and augmented reality.
Pervasive augmented reality can allow for a more inclusive integration of people into the planning and management processes of smart cities. A participatory design approach incorporating all stakeholders and all IoT opportunities can be made possible. (see [16] and [17]).

Augmented Future

Extrapolating current trends in IoT and user interface technologies it is safe to assume that in the near future products and services will surface which aggregate and combine IoT data with pervasive augmented reality interface technology based on mobile and wearable technology. There is significant potential for novel, geo- and context-associated content delivery, software and user interface development, and ecosystems for user-generated augmented reality. Also, in the foreseeable future, less obtrusive interface technology, like glasses with visual, auditory, and tactile augmentation capabilities linked to other mobile and wearable technology will be available to make information access and interaction even more ubiquitous and pervasive. Finally, IoT and pervasive AR might form the predominant form of technology-mediated perception of and interaction with our social and physical environment in a very similar way as the internet and mobile phones have shaped the last three decades economically, socially, and environmentally.

---

[12] Higginbotham, S. (2019). NOW HEAR THIS. IEEE Spectrum, 21-22.
[13] Crum, P. (2019). Hearables: Here come the: Technology tucked inside your ears will augment your daily life. IEEE Spectrum, 56(5), 38-43.
[14] Schmalstieg, D., Langlotz, T., & Billinghurst, M. (2011). Augmented Reality 2.0. In Virtual realities (pp. 13-37). Springer, Vienna.
[15] McEvoy, J. (2017) Six Ethical Problems for Augmented Reality, Becoming Human: Artificial Intelligence Magazine
[16] Winter, S. (2019). Computing Ethics. Who benefits? Communications of the ACM, July 2019, Vol. 62 No. 7, 23-25.
[17] Clarke, R., Heitlinger, S., Light, A., Forlano, L., Foth, M., & DiSalvo, C. (2019). More-than-human participation: Design for sustainable smart city futures. interactions, 26(3), 60-63.