Augmented Reality and the Internet of Things

Report

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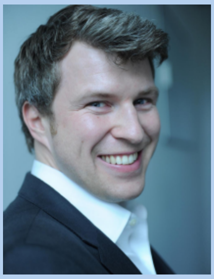

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Business Processes & Applications

Abstract

The Internet of Things allows for the development of hybrid solutions merging physical products with digital services. After the widespread adoption of Internet of Things in supply chains, we are now witnessing a surge of consumer Internet of Things applications. Due to the proliferation of smartphones, Internet of Things applications gain personal, interactive, and behavioral context. Smartphones thus take up a gateway role and mediate between and among people, physical and digital things, and/or the environment. In this article, we discuss why Augmented Reality technologies are essential for evolving this gateway role in the Internet of Things and how alternate form-factors of the smartphone (e.g. glasses, watches, contacts, gloves, etc.) might impact context-aware service interactions.

Keywords: Internet of Things, Augmented Reality, smartphones, services, smart objects, digital biomarker, field-of-view interactions, object recognition

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1. Introduction

The Internet of Things (IoT) represents the paradigm that the Internet extends to the physical world. Eventually, every physical object will be connected to the Internet and serve as digital nerve ending for novel applications and services.

Sanjay Sarma's seminal paper on the 5 cent tag has identified the critical path for making it economically feasible to use IoT applications for a wide range of supply chain processes (Sarma, 2001). Radio-frequency identification (RFID) and barcode applications have since then become an integral part of any supply chain operation.

With the first large scale deployments of IoT applications in the field, Fleisch (2010) elaborated on the economic perspective of the IoT and illustrated seven key value drivers. He demonstrated that IoT technologies drive the marginal costs for sensing towards zero. As the price of a sensing event declines, it becomes more attractive to sense more often. When measurements are taken in higher spatial and temporal resolution, processes can be managed in entirely different ways. Fleisch et al. (2014) reflected that this High-Resolution Management (HRM) thinking will unlock a new digital value proposition and drive the industry towards service business models.

While previously IoT was mainly concerned with machine-machine communication, the smartphone entered the user into the equation. Smartphones act as gateways that mediate between and among people, physical and digital things, and/or the environment (Figure 1). They make it easy to augment physical objects with additional information or access related digital services. Smartphones are the computers that know us best and accompany us throughout our daily lives. They also can provide feedback that may guide us or change our mind.

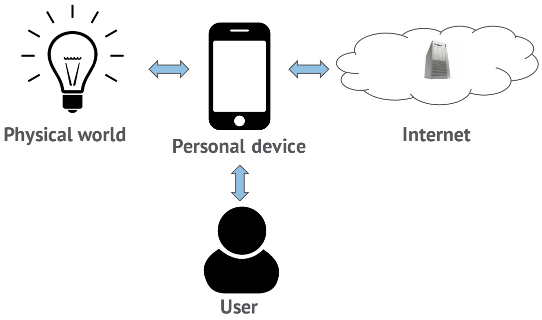

Figure 1. Personal devices act as gateways in the IoT with interfaces to physical objects, the user, and the Internet

With the vision of computers becoming more invisible and fading into the background, Augmented Reality (AR) technology has the potential to further enhance the role of the smartphone in the IoT. We discuss why AR technologies are important to evolve the IoT and how alternate form-factors of smartphones (e.g. smart glasses, watches, contacts, gloves, etc.) might impact context-aware product-service interactions.

2. AR devices as digital service gateways

Thanks to the built-in camera and recent gaming hype, Augmented Reality applications have become popular on smartphones. Big companies are currently experimenting how to further leverage the AR paradigm by putting the smartphone into new form factors.

Although AR technologies and smart glasses have been discussed in research for decades, they only recently appeared with support of the big IT companies. The first attempt to (partially) replace smartphones with smart glasses was done by Google in 2013 with their project Glass. The project failed to become a commercial success, not due to technical but mainly due to privacy and social acceptance reasons. Nevertheless, it started a rich experimentation phase especially for business applications with smart glasses. The benefits of having a smart device that leaves the hands free while providing contextual support are extremely versatile. As a further prominent example, Microsoft initiated their project HoloLens for smart glasses in 2016. It is expected that further devices and breakthroughs in this area will follow.

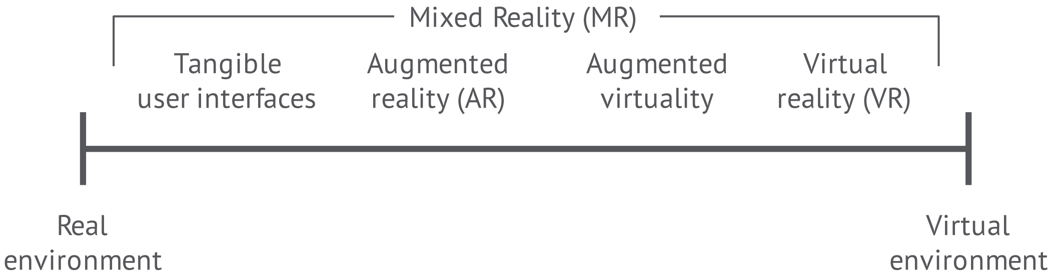

Figure 2. The reality-virtuality continuum (adapted from Milgram & Kishino (1994))

Based on the Mixed Reality continuum (Milgram & Kishino, 1994), AR extends IoT experiences from the real environment towards the virtual environment (Figure 2). In addition to enabling novel user experiences for interacting with objects and the environment, AR also reveals new insights about the user. The same sensing technologies required for high-end AR displays can be used to measure the user. This gives new insights into the behavioral, cognitive, and emotional state of the user. With these insights, product-service interactions can be reshaped on a whole new level.

The following sections review how AR can be used to accelerate developments and usage of the IoT. The focus will be on the product-service interaction. Objects will become a point-of-service, whereas services can be categorized as follows (Figure 3):

- Identification service: retrieving a digital identifier of a physical object and thereby enabling monitoring and other higher level services.
- Control services: connecting to a smart object to read or change the state of the object.
- Lifecycle services: retrieving related services to an identified object (*e.g.* ordering of spare parts). See Xu & Ilic (2014) for a comprehensive overview.

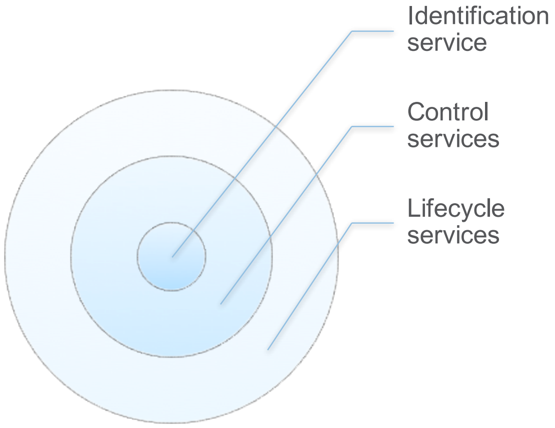

Figure 3. Product-service interaction hierarchy

Several of the ideas and concepts are applicable already to smartphones but likely will unfold their true potential only with smart devices designed for AR such as smart glasses. The following sections are therefore an extrapolation of observations and lessons learned in order to enable predictions that may guide further developers of AR-enhanced IoT applications.

The next sections are organized by the three critical interfaces personal devices provide in their function as gateway: an interface to the physical world, the interface to the user, and the Internet interface to the rest of the world.

3. Physical world interface: Object interaction

The key element for accessing the digital service component of a physical product is object identification. We distinguish between the following three types of objects:

- Smart objects: The functionality of the product is enhanced by fully integrating a computing, communication, sensing, and/or an actuating unit. The digital identifier is unique and part of the product. Smart objects provide a digital communication interface for interaction and control with the product. They also may have a direct communication link to the Internet. The number of smart devices is estimated to exceed 25 billion units[1] by 2020 and thereby representing the smallest group of objects in this categorization.
- Tagged objects: Products retain their original state and functionality, but a tag is physically attached or integrated with the object. The digital identifier is retrospectively added to the product with the tag and can be read wirelessly or optically. Since the tag is just co-located, there is no control interface for changing or reading the state of the product, which the tag is attached to. Today, the most prominent example for digital identifiers are barcodes or RFID tags used in retailing based on the standard of the Global Trade Identification Number (GTIN). However, these identifiers are predominantly class level identifiers, which means that different instances of the same product share the same identifier. For traceability, anti-counterfeiting, and marketing there is now gradually a move towards serial level identifiers. In this case, each individual instance of a product has its own unique number. The startup Evrythng alone will equip 10 billion pieces of clothing over the next three years with a unique digital identity[2].
- Plain objects: The product is not prepared in any way for the Internet of Things. The digital identifier can only be inferred with object recognition or context-labeling. In comparison to the other two types, this will still be by far the largest group of objects. Cisco estimates that currently 1.5 trillion (99.4%) of all physical objects are yet to be connected[3]. Therefore, this is one of the biggest areas of opportunity to either connect them by attaching a tag or applying technologies (such as object recognition) that derive an identifier by combining contextual factors with object properties.

The next sections review different identification technologies that are relevant for AR IoT systems. The focus is deliberately not on smart objects but rather on the topic of connecting the previously unconnected objects with a unique serial level identifier. The lessons learned are derived from a number of research projects on product-service interactions (Xu, 2016). The most recent study was conducted in a real-world office environment in Munich, Germany from January & February 2016 with 43 users. A key finding was that most existing approaches for product-service interactions are not yet ready for multi-user situations.

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[1] http://www.forbes.com/sites/louiscolumbus/2016/11/27/roundup-of-internet-of-things-forecasts-and-market-estimates-2016/
[2] http://fortune.com/2016/04/18/evrythng-avery-dennison/
[3] http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoE_Economy_FAQ.pdf

3.1. Optical codes

A typical approach to assign a digital identity to physical objects is via optical codes. These include 1D barcodes, QR codes, or novel approaches such as digital watermarking, with the code hidden in the pattern of the product[4]. These codes typically store either a unique number that can be resolved to an URL of a service point or directly a service point URL. The advantage is that these codes are cheap to deploy and can be read by any device with a camera. A disadvantage is that they require a clear line-of-sight and that the operating range is fairly limited. As a rule of thumb, the minimum size of *e.g.* a QR code is one tenth of the expected scanning distance. While QR codes have been around for a while, the scan rate by consumers remains low (Quigley & Burke, 2013). However, when used with AR devices such as smart glasses, new benefits such as hands-free working can be unlocked and increase attractiveness in a business context[5].

Figure 4. Example of a QR tagged object to invoke a supply reordering service

3.2. Wireless transmitters

Most smart products come with a built-in wireless communication capability featuring Bluetooth Low Energy (BLE) and/or WiFi integration. These interfaces allow for controlling and managing the devices directly via the user's smartphone. For tagged objects, often BLE beacons are used since RFID and NFC support is limited on today's smartphones. The beacons typically broadcast a unique identifier and/or URL such as used in Google's Physical Web project. We observed a session increase of 35% compared to QR code users due to the fact that BLE broadcasts can be received even if the smartphone is locked. However, 93% of these sessions were triggered accidently by people walking by. To reduce this spam problem, we implemented a physical button on top of the beacon that only broadcasts the service URL when needed by a user (see Figure 5). As a result, the group with the BLE button had a 2.9 times higher service usage than the group with traditional beacons. As AR devices also support wireless interfaces, it is likely that objects with wireless tags will be also fully usable in this context. A disadvantage, however, was that the button has to be placed at an easily accessible place and thus reduces the benefit of the wireless range.

Figure 5. Example of a BLE tagged object with physical button to start the interaction

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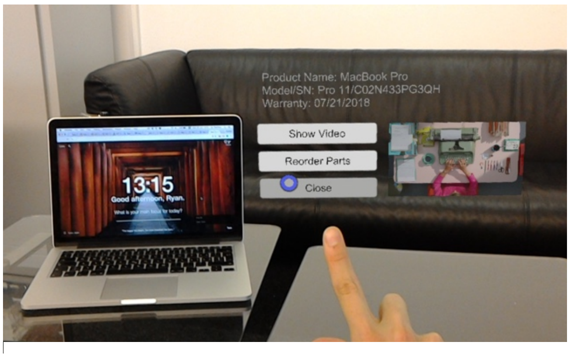
[4] https://www.digimarc.com/application/retail

[5] For examples with Microsoft HoloLens and Google Glass, please see http://www.scandit.com/tag/google-glass/

3.3. Object recognition

Object recognition is a promising technology with the potential to replace optical codes on objects. It is driven by advances in scene understanding and deep learning. Object recognition uses the camera to identify an object based on its visual features. This means that it can work instantly without any tags or special preparation of the object in question. Since objects may look very similar and are often only partially visible, the results are intrinsically ambiguous. In the best case, object recognition yields a high probability guess for the object at a class level. In order to derive useful digital identifiers, additional context information has to be used.



Product Name: MacBook Pro
Model/SN: Pro 11/C02N433PG3QH
Warranty: 07/21/2018

Figure 6. HoloLens screenshot of a field-of-view interaction prototype for retrieving contextual lifecycle services to an object. Virtual buttons instead of physical ones.

Based on the learnings of the Munich study[6], we propose field-of-view interactions - a new type of interaction suitable for AR IoT systems. FOV interactions use a hybrid approach combining object recognition with contextual cues. It overcomes the range limitation of optical codes while still being able to provide high identification accuracy. The interaction becomes more naturally since it is tied to the area of attention of the user – defined by the field of view. It provides a seamless way of supporting multi-user interactions. We used Microsoft's HoloLens for implementing proof-of-principle (Figure 6) as follows. The first step is to determine the current context and build recognition priors using one or more of the following datasets:

- Location: The physical location of the user and object in 3D space. This may leverage a semantically enriched or annotated 3D map of the environment
- Available wireless IDs: The WiFi/ BLE identifiers and measured signal strengths of the devices in proximity of the user
- Interaction history: Based on the current location and habits of the user, frequent interactions will be prioritized with higher probabilities

With the context information defined by the recognition priors, the actual object recognition is performed on a current camera image. In the proof-of-principle, this has to be manually triggered with the HoloLens clicker or the air-tap gesture. Future evolutions could potentially run this at framerate. As a last step, we run a mapping of the generated internal identifiers against a database with manual identifier labels or look-up tables. This could *e.g.* turn the Bluetooth ID of a MacBook into a serial number, which can be used to query third party repair & spare part services (see Figure 4). As a visual element, we display a virtual button superimposed in a subtle way on the recognized objects that can be opened. The user can then directly invoke a control service of the object (*e.g.* changing color of lights) or lifecycle service provided by a third party (*e.g.* ordering supplies).

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[6] https://www.autoidlabs.ch/product-as-a-service/

4. Human interface: The personal perspective

AR technology fuses the physical world with digital content and thus has the potential of further evolving our human abilities. While AR applications are already possible with today's smartphones, they are not specifically designed for AR interactions. It mostly remains a human-computer interface question when and not if different form-factors (*e.g.* smart glasses) will replace today's smartphones. But it is not only the interaction modalities that will be affected by this change. A major part of new forms of AR devices is that they enable us to measure the user on a new scale. This data gives valuable insights into the user's cognitive, emotional, and behavioral patterns, which can ultimately be used to design mind-changing and more natural applications in the IoT.

4.1. Personalization: Learning preferences & context

Since smartphones accompany us throughout the day, we implicitly feed them with data that can reveal personal patterns and preferences. A prominent example is the automatic identification of points-of-interest (*e.g.* where we live and work) due to our movement patterns (Gambs et al., 2010). Another example is the data set of installed apps. Apps mirror our interests and personality. In a study with 2410 users, we found that 99.75% of the users have a unique set of installed apps (Frey et al., 2016). This set can be used to automatically estimate demographics, interests, life events (Frey et al., 2015) and even personality traits (Xu et al., 2016) of a user. While this data can be sensitive when shared with third parties, ongoing research points out ways on how to enable better personalization without compromising privacy. When designing IoT applications, it is important that privacy control is built-in from the beginning. The user should be in full control of her data. Promising solution approaches include *e.g.* a blockchain based method that even allows for secure sharing with third parties (Frey et al., 2016; Zyskind et al., 2015).

With AR, the topic of automatic detection of the user preferences and patterns becomes even more important. The camera provides an additional data source that tells the IoT system in which environment it operates and can help to anticipate what the user aims to do next. Activity recognition based on multiple sensors (Roggen et al., 2013) and environment recognition (Cleveland et al., 2016) will thereby play a key role to enable a fully personalized experience. Environments might also become smarter and recognize the user's intentions and actions. This could further complement the smart device's abilities. A recent example of such an environment is Amazon Go, which uses computer vision technology to automatically detect when a user picks up an item and puts it into a virtual cart[7].

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[7] http://www.geekwire.com/2016/amazon-go-works-technology-behind-online-retailers-groundbreaking-new-grocery-store/

4.2. Measuring the user: Towards digital biomarkers

AR is not just an opportunity for enabling an immersive, personalized user experience. It also provides new means for measuring the user. Digital biomarkers – the digital counterpart of classical biomarkers (Strimbu & Tavel, 2010) – represent a new class of physiological and behavioral measures. They can be monitored with consumer devices and serve as indicators for physio-pathological, neurological, and behavioral conditions. The following table lists selected examples of digital biomarkers that can be measured with smartphones and AR devices.

Digital biomarker	Data sources	Description of example
Breathing	Microphone	Asthma control: Analyzing microphone data to reveal breathing in/out patterns, chest vs. belly breathing, and estimation of the respiratory peak flow rate
Spatial orientation	IMUs, camera (visual tracking)	Early dementia screening: Analyzing the motion accuracy when performing tasks to locate virtually placed objects
Mood	Texting, calls, apps, etc.	Depression and burnout: Analyzing the phone/AR device usage patterns of texting, calling, and apps to monitor mood and workload over time
Physical activity	Step counter, IMUs, etc.	Fitness: Analyzing movement patterns and activity throughout the day
Calorie intake	Camera	Obesity: The user's food intake is analyzed through the camera with deep learning to estimate portion size and calories
Micro-motor noise	IMUs	Stress: Evaluation of micro-motor noise patterns of 2D (*e.g.* MouseTracker) or 3D input trajectories (*e.g.* head, controller, etc.)
Eye movement	Eye-tracking	Anxiety/fear: Analysis of eye movements and pupil size variations

The inexpensive, continuous, and real-time sensing abilities provided by IoT systems and AR devices will provide a myriad of data points for developing new digital biomarkers. Once validated, they may even serve as a basis for digital therapies. It is expected that digital biomarkers will foster the development of IoT applications that feature behavior change interventions and emotion-aware responses.

4.3. Persuasive computing: Influencing behavior

Kahneman (2003) explains our decision-making behavior with two different systems. System 1 is governed by intuition and utilizes heuristics and biases to come to fast conclusions. System 2 relies on rationality and therefore can produce completely different results than system 1. Several researchers showed that system 1 provides a major opportunity for systematically influencing behavior on a large scale. With so-called nudges the predictability of the mistakes of system 1 can be exploited (Thaler & Sunstein, 2008). This can be further enhanced and automated when combining this with information systems (Fogg, 2002). Smartphones are already used today on a large scale as mind-changers and support us in *e.g.* adopting healthier habits (Higgins, 2016).

AR systems could take this to a whole new level, since they can not only expose us in a subtle way to nudges, but also potentially trick our brain in visually experiencing digital objects similar to physical ones. This is best explained with the psychological concept of presence (Figure 7). The term has been coined over 30 years ago by Minsky (1980) and gained significant popularity in the past few years due to the rise of mainstream virtual reality and augmented reality applications (Sheridan, 2016). In addition to user characteristics, the following factors are required to establish presence (Ijsselsteijn et al., 2000):

- Extent and fidelity of sensory information: This refers to the technical ability to create appropriate inputs for the human perception system and includes properties such as field-of-view, resolution, or spatial audio.
- Match between sensors and the display: This refers to sensor-motor contingencies i.e. the link between a user's actions and their perceptible results in the system. This includes *e.g.* the tracking of a user's head and corresponding real-time updates of the display.
- Content factors: These refer to the ability to modify the environment, one's own representation in VR/AR, autonomy of the environment, and social elements such as reactions by other actors (virtual or real) as response to one's verbal and non-verbal communication cues.

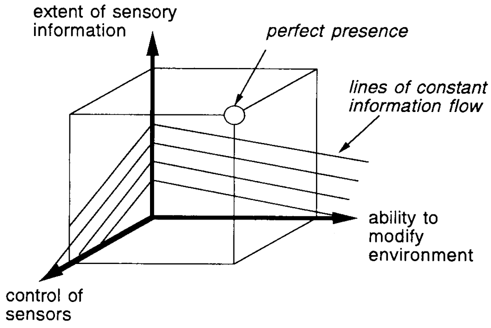

Figure 7. Illustration of the concept of presence (Sheridan, 1992)

In other words, an AR/VR system with digital objects is perceived as real in our head when perfect presence is achieved. This makes it suitable to train our system 1 in a systematic way. As an example, this explains the popularity of Virtual Reality Exposure Therapy (VRET) applications to desensitize memories surrounding trauma. Therefore, it is expected that when interacting with things, nudges in AR systems will become a powerful way to assist us in our daily lives. Of course, this also means that developers of IoT systems have to be more aware of the privacy and ethical implications when designing such powerful systems.

4.4. Affective computing: Influencing emotions

Gaver et al. (2003) highlighted that we might develop unexpected emotional attachments to smart things due to repeated interactions. One example is the study of Sung et al. (2007), who explored the phenomenon of seemingly social relationships between vacuum robots and their owners. System 1 will decide to a great degree of how successful the adoption of a smart thing will be. Fleisch (2010) stresses therefore the potential of emotional product features that can be unlocked with the IoT.

As the affective computing paradigm (Bailey & Konstan, 2006; Tao & Tan, 2005) suggests, this requires the ability to sense and recognize emotion of a user. Thanks to the rich sensor suite (*e.g.* microphones, cameras, IMUs, etc.) associated with AR systems, digital biomarkers now become possible for the IoT. For example, micro-motor patterns give insights into mental processing patterns (Freeman & Ambady, 2010) and our eyes provide data on focus, attention, mental effort, and decision processes (Cavanagh et al., 2014; Kahneman, 1973). One example of how this can be used in AR is by Augereau et al. (2016) who use smart glasses to determine the language proficiency level of a user. Furthermore, by combining proximity sensors with machine learning, AR glasses are able to recognize a user's emotions (see Figure 8).

Figure 8. Smart eyewear prototype that is able to recognize emotions by using photo reflective sensors in the frame and machine learning (Masai et al., 2016)

It is expected therefore that the tracking of head, hands, eyes etc. Amft et al. (2015) will provide a basis for embedding interactions with things into a more useful context of the user's state and lead to unlocking emotional value propositions in the IoT.

5. Internet interface: Connected to the rest of the world

The third core element of the IoT is the connection to the Internet. IoT systems are generally not limited to single users, but greatly benefit from a connection to the rest of the world. We already outlined the challenges of product-service interactions in local multi-user environments and extend the discussion to a global setting. While the opportunities for the global service perspective have been reviewed in detail, we only briefly recap particular points from an AR perspective:

- Discovery and invocation of remote services: By using digital identifiers of objects and providing a metadata context, suitable services by third parties can be made instantly accessible on a global scale. This would lead to an open market to find the best services available for any specific object and issue at hand.
- Connection with other users: As several examples show, the social and collaborative aspect of AR can be unlocked in scenarios such as remote support or virtual meetings. For example, this might include the usage of holograms as suggested by Microsoft.
- Leveraging global databases and collective intelligence: Local information can be collected, analyzed, and enriched when combined with global databases and repositories. User generated content can be shared and thus help to contribute to a better mapping of the physical world to the Internet.
- Global optimization and prediction: By observing the data of multiple users, predictive algorithms can help to optimize a system to a level surpassing the scope of any local optimization. For example, a smart heating system of a building would adapt differently if it had data from multiple users and habits over a longer time compared to the limited possibilities of local control.

Since the business models in this area are still evolving, it is hard to predict how these services will be monetized and what the killer applications will be. However, it is already clear that this will pose new challenges for standards (*e.g.* digital identifiers), shared data strategies (Lebeck et al., 2016), and collaborative machine learning applications (Robert et al., 2016).

6. Implications and outlook

As outlined, the IoT can benefit a great deal from AR. Starting with smartphones, the IoT was enhanced by a personal gateway that connects physical objects, the user, and the Internet. This role will further evolve with the use of AR technologies as outlined in this article.

Smartphones will be replaced by specific AR devices

While supporting AR applications, smartphones are not designed for this purpose. Thus, it is highly likely that over the next decade, smartphones will be replaced by specific devices in new form-factors (*e.g.* glasses) with superior performance in conveying presence in AR experiences.

AR will connect more objects to the IoT

By bringing in a heavy focus on visual computing and object recognition, AR will offer additional ways to automatically assign digital identifiers to physical objects. This will help to expand from specially manufactured smart objects and tagged objects to the vast majority of plain objects. Thus, more projects can be turned into points of service for accessing lifecycle services.

AR will enable shared interactions with objects

Today, most IoT systems require a setup that authorizes only a fixed set of people to access their control or lifecycle services. This limits these applications for a multi-user environment. In this article, we have introduced FOV interactions leveraging a hybrid object recognition approach to improve the user experience and enable proximity-based service interactions in a spontaneous way.

VR will serve as a sandbox to improve IoT user experiences

Although Mark Weiser sees the ubiquitous computing approach of IoT as “roughly the opposite of virtual reality” (Weiser, 1999), VR will still play a key role to accelerate the development of IoT applications. Similar as A/B testing for websites, VR offers the ability to understand and optimize people’s interactions with objects in simulated environments. It represents a sandbox especially for spontaneous reactions and interactions driven by our system 1. Thus, VR can be seen as a distraction-free area to craft new, seamless user experiences that later can be deployed in the field via AR.

Digital biomarkers will enable a behavior and emotion-aware IoT

More than smartphones, AR devices will enable the understanding of the user’s context in terms of behavior, health, and emotions. Currently, most IoT products are designed in a very rational way. Digital biomarkers measure the user and enable the design of behavior and emotion-aware IoT applications. In the future, we hopefully see smart things smiling back at us and offering help when they sense that we are confused. After all, smart things should not exist to keep us busy, but rather to make our lives easier.

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