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Web Standards to Enable an Accessible and Inclusive Internet of Things (IoT)

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Abstract

The Internet of Things (IoT) is expected to have an unprecedented impact on our daily lives. In particular, "smart environments" will change how we interact with our surrounding and with each other, including at home, in public spaces, and at the work place.

This provides an opportunity to ensure equal access for people with disabilities. For example, operating doors, windows, and physical objects through voice makes such environments more accessible to people with physical disabilities and inclusive to many more.

Yet there are still many challenges to address, without which the Internet of Things (IoT) threatens to be more of a disabler than an enabler. In particular, the current lack of interoperability makes it hard for assistive technologies to easily tap into IoT systems.

Web standards could extend the open web platform to resolve many of these issues, much as it did on the traditional internet. This Web of Things (WoT) provides a robust application layer for innovation to thrive on the underlying Internet of Things (IoT).

This paper outlines the relevance of IoT for people with disabilities and the specific challenges it currently poses. It then discusses how the Web of Things (WoT) could help address these challenges, and highlights research questions that still need to be tackled.

CCS Concepts

• **General and reference~Computing standards, RFCs and guidelines** • **Information systems~Computing platforms** • **Information systems~World Wide Web** • *Security and privacy* • *Networks~Network services* • Social and professional topics~Management of computing and information systems • Computing methodologies~Artificial intelligence

Keywords

Internet of Things (IoT); Web of Things (WoT); Open Web Platform; Accessibility for people with disabilities; Inclusion; Web standards; World Wide Web; Assistive technology.

1. Rise of the Internet of Things (IoT)

There is no single and universally accepted definition for Internet of Things (IoT). In fact, the concept of connected computers is not new – it is the miniaturization of computers and their networking capabilities that is facilitating uses considered as less feasible until recently. Yet IoT is not only about the connected objects but also about the communication and interaction between these objects.

The Internet Society (ISOC) describes the Internet of Things (IoT) as follows: "*Internet of Things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention.*" [1]

An important aspect is "*items not normally considered computers*". For example, we do not typically consider the door bell, light bulb, fridge, or even television as *computers*. Yet exactly these objects are becoming increasingly computerized and connected. Generally, such connected objects are referred to as "smart objects".

Another important aspect is the flow of data between the connected objects. A network-enabled light bulb is not as useful on its own, but becomes much more useful when it can be operated through the television or another device. Together the individual objects create an environment of ubiquitous sensors and actuators that can fulfill complex tasks so far only presented in science fiction novels.

Finally, also "*with minimal human intervention*" alludes to another important aspect of IoT – the swarm intelligence that emerges with connected objects, to accompany the otherwise static connectivity. For example, the right software can turn the connected light bulb and television into a sophisticated solution for home lighting that can increase the quality of life and save energy at the same time.

In fact, the concept of IoT is often associated with Big Data – large amounts of data generated by various sensors and actuators – and of Artificial Intelligence – human-like perception, anticipation, and reasoning of behavior. Together these facilitate the development of smart environments at home, in public spaces and at the work place, which promise to revolutionize the way we work and interact.

For example, network-enabled projectors do not only allow devices such as laptop computers, tablets, and mobile phones to present, but they also allow these devices to access the presentations directly on their screens. That is, the unidirectional role of projectors changes into a shared white board that allows multi-directional interaction. Thus the deployment of such smart projectors changes interactions in the classrooms, meeting rooms, conferences, and much more.

2. Relevance for People with Disabilities

The potential opportunities provided by the Internet of Things (IoT) impact people with disabilities in particular. For example, the smart projector previously described adds to the quality of interaction for everyone. Yet, if designed well, it could provide improved access for people with disabilities. For example, people with low vision could access the presentations on their own screens and magnify them to the desired level according to their individual needs.

One particular area of interest for people with disabilities is "smart homes". This extends the concepts of home automation and assisted living, which have been pursued in the disability community since many years. Yet the mainstreaming of home automation systems and their widespread availability in local hardware and furnishing stores makes them much more robust and affordable to people with disabilities then when they were niche, custom-made solutions.

The Global Initiative for Inclusive Information and Communication Technologies (G3ICT) identifies that: "*Of all the Internet of Things applications that have the potential to improve life for persons with disabilities, home automation — or "smart home" — technologies are among the most promising.*" [2]

The potential of home automation is further multiplied by the recent introduction of various artificial intelligence systems specifically designed for this purpose. This includes Alexa by Amazon, Cortana by Microsoft, Google Assistant by Google, and Siri by Apple. Yet beyond controlling television screens and other home appliances, it is imaginable that such smart systems will soon also enter work places, transportation, and public spaces, and become part of our daily surroundings, to unleash the era of "smart environments".

In fact, some of the first examples of IoT applications include the connected coffee maker [3] and vending machine [4], which were provided at an office and a university respectively. More recently a variety of beacon systems to support indoor and outdoor navigation are being deployed, including in public buildings and other venues with high traffic. These enable people with disabilities to navigate more efficiently and independently in public spaces and buildings, and further increases the accessibility of physical environments.

Beyond the micro environment of smart homes and work places, and the mezzo environment of public spaces and buildings, there is also the macro environment of entire smart cities and regions. One particular aspect of this is smart transportation and mobility more generally. For example, connected mass transit vehicles, including busses, trams, subways, and trains allow for real-time planning of journeys. For people with disabilities this means accessible routes and modes of transportation, which can be planned in real-time.

Also self-driving vehicles are being increasingly deployed and are becoming a reality. For people with disabilities this goes beyond mere convenience and safety, but it enables for independent living and transportation in many cases. For example, for people with low vision and blindness, high degree of physical disabilities, and even for some forms of cognitive and learning disabilities, self-driving vehicles could allow access to work and other parts of daily life.

Thus Internet of Things (IoT) has the potential to disproportionally benefit people with disabilities, and allow unprecedented access to the physical world. However, if IoT systems are deployed without considerations for people with disabilities they could become more of a disabler than an enabler. For example, an IoT heating system could provide greater access through a mobile app than the physical knobs. However, if this app is inaccessible then this IoT system will be more excluding than the traditional system with physical knobs.

3. Challenges for Accessibility and Inclusion

The Internet of Things (IoT) is still evolving and bears many issues that need to be addressed. Specifically, privacy, security, and trust are less mature concepts in IoT [1]. On a broader scale, also issues of affordability, digitization, and broadband coverage are factors of IoT that could further exacerbate the digital divide [5].

Many of these issues apply to people with disabilities more directly and with more potential for exclusion. Given the relevance of IoT for people with disabilities, it is a shared societal responsibility to address the issues. Arguably, it is also an obligation with respect to the UN Convention on the Rights of Persons with Disabilities (UN CRPD) [6]. In particular, accessibility of IoT is related to articles 9, 17, 19, 20, 21, 22, and 26 of the UN CRPD [7].

3.1 Interoperability

While the open Internet Protocol (IP) provides a backbone for IoT, unfortunately many of the systems and services are currently built as proprietary applications. Particularly, the data and API layers, as opposed to the connectivity and network layers, are often based on proprietary specifications to provide separated closed systems.

One reason for this lack of openness is the lack of widely available open standards to address the specific needs of the IoT systems and services. Another reason is the lack of interest by many vendors to provide open systems due to fear of losing customers and business. In fact, many of IoT business models are currently based on closed ecosystems rather than on open models, which poses an issue [5].

It is currently unclear how this situation will evolve, though there seems to be an increasing demand for open interoperability [1]. On the long run, an open system, like the internet, enlarges the market for all vendors, developers, and consumers. This reduces costs and increases innovation, including for accessibility solutions.

Interoperability is particularly important for people with disabilities using assistive technologies and custom solutions. These often need to tap into the systems to provide alternate modes of presentation and adaptations. For example, a blind person may need to use their own screen reader to access a variety of IoT systems and services, rather than to learn and use different system-specific screen readers provided by each vendor separately, if one is provided at all.

3.2 Accessibility Support

Another essential aspect of IoT accessibility is that there is support for specific accessibility considerations on the data and API levels. For example, a simple sensor, like a thermostat, needs to provide the data in an accessible format, such as text, for it to be useable by people with different disabilities. Providing information about the temperature as images only would impede accessibility [8].

Without such accessibility support on the data and API levels, the provision of accessible user interfaces for IoT systems and services will be difficult if not impossible. Yet the considerations will often need to be more sophisticated than in the case of the thermostat. In the case of the network-enabled projector for example, the data will need to be richer than just text – ideally the projector could provide structured information including text, images, text alternatives, and captions, as well as the relationship between these blocks of content rather than providing the video output of a presentation only.

Also the communication and relaying of accessibility information between devices within an IoT system need support. For example, the captions, text alternatives, and other accessibility features in the source presentation will need to be communicated from the device presenting through the projector and on to the receiving devices, to allow the user interface applications to provide them to the users.

3.3 Identification and Configuration

Accessibility APIs have evolved and matured in traditional desktop computer systems over the years. This allows assistive technology to easily access accessibility information, such as roles, names, and states of objects on the screen, and relay them to the users in a mode that is accessible to them – in audio, tactile, or visual presentation. Such accessibility APIs are currently less mature in mobile devices, and it is unclear how they will evolve in IoT systems and services. For example, it is unclear how captions, text alternatives, and other accessibility information will be provided by one device, such as a television, will be discovered and accessed by another device, such as a mobile phone or tablet (remote access to accessibility features).

Related is the aspect of configuration of accessibility features and profiles for individual components and across entire IoT systems and services. For example, the fridge, oven, or other appliance may provide an accessibility setting for large text, but this option might not be configurable through external devices and applications, such as the television. Thus the use of IoT systems could become tedious and complex, and potentially exclusionary. That is, for people with disabilities there could be an additional layer of complex technical configuration of the individual devices in an IoT system, to make them usable, rather than plug and play as for most people.

Ideally accessibility settings would be carried forward across the devices in an IoT system. For example, profiles with preferences, such as "large text", could be communicated to sensors and devices across the IoT system, while retaining ownership and control with the profile owner. Such settings would also need to be kept across software updates of devices and applications in the IoT system [11].

3.4 Privacy

Privacy issues are a general concern in IoT. For example, personal data that is shared across different devices in an IoT system could disclose unwanted information. For example, the connected fridge may have access to information about food purchasing and cooking habits. This could be a desired feature, to allow services to suggest suitable products currently on sale, recipes, and shopping lists. Yet this information could also be misused, or a person may simply not want to share this information with certain services. A challenge of IoT is to allow people to control the use of their own data in a way that is transparent and easy to use also for non-technical people.

For people with disabilities additional privacy considerations might be needed. For example, beyond mere dietary preferences the fridge could also have access to private dietary and health needs. People may be comfortable sharing some aspects with third-party services, such as allergies and intolerances, but might not want to share other aspects, such as diabetes. In fact, the fridge might also have further personal information about users who enable accessibility features. Also here some of this information may be more or less sensitive, and different people may want to share more or less data. That is, privacy considerations may need to be more granular for people with disabilities, yet need to remain as easy to configure.

3.5 Security and Safety

Another general concern in IoT is security issues introduced by the user data and interaction across systems and services. For example, the private data collected by the fridge and shared with IoT services could introduce security threats if it is unprotected – for example by burglars to determine if somebody is home or on vacation. The sheer amount of sensors, actuators, and devices connected in an IoT system introduce many such potential loopholes and threats for their users. In particular, raw data coming from sensors may not be sufficiently secured due to their typically limited capabilities.

Security holes in IoT systems could mean threats to personal lives. For example, hijacking or merely hacking into self-driving vehicles could have severe consequences. More specifically for people with disabilities, security of healthcare IoT systems and services is also an issue. Besides home automation, IoT for healthcare seems to be one of the main areas of application for people with disabilities [2], yet also one of the most sensitive ones regarding security and safety threats. For example, IoT systems designed to support independent living, such as health monitoring and assistance applications, could become life threatening without the necessary security precautions.

3.6 Accessibility Guidelines

To address many of the challenges and issues described throughout this section, there is potentially the need for updated guidelines and standards for accessibility. Accessibility standards such as the W3C Web Content Accessibility Guidelines (WCAG) [9] tend to focus on user interface aspects rather than on accessibility considerations of the data and API levels below the user interfaces. As IoT systems are conceptually designed around distributed components (sensors, actuators, and devices) using different data structures and APIs, it may become necessary for user interface guidelines to also specify the accessibility requirements of these data structures and APIs.

In fact, there is potentially the need for a new approach to defining accessibility requirements based on distributed components as well as on entire systems. That is, in addition to defining requirements for websites, products, and services, requirements need to address the individual components of these. For example, an appliance may not have the necessary user interface to provide text, acoustics, and other alternatives to physical indicator lamps but should provide the corresponding information through accessibility APIs. That is, the individual components may not be able to provide all accessibility features directly and may need to rely on other components, such as the television screen, to provide an accessible system overall.

4. Web of Things (WoT) as an Enabler

Alike on the traditional internet, the world wide web could provide the universal and open platform for the Internet of Things (IoT), to address many of these challenges to accessibility and inclusion. In particular, the interoperability of individual components, systems, and services could be further facilitated through the open standards and protocols of the world wide web, to provide a Web of Things (WoT) that builds on and extends the Internet of Things (IoT).

Many standards to build the Web of Things (WoT) already exist today, in particular on the base level of data and APIs. Specifically, the semantic web provides technologies for open data specification and exchange. These could be implemented on sensors and objects with limited capabilities through mini HTTP servers.

Dominique D Guinard and Vlad M Trifa describe a possible model based on the following layers [10]:

- **Networked Things:** infrastructure of connected sensors, actuators, and devices

- **Access:** provides access to connected things, including HTTP, WebSockets, etc.

- **Find:** enables the findability of connected things, also through the semantic web

- **Share:** supports sharing, authentication, and access control of connected things

- **Compose:** supports the compositions, to create the actual products and services
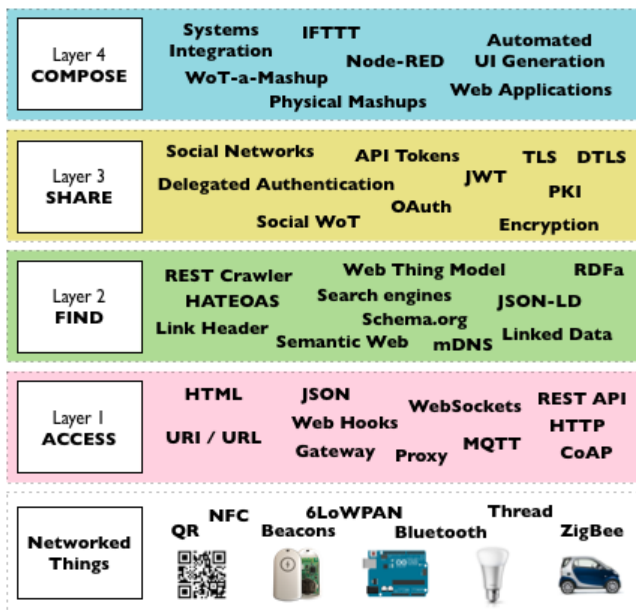
Figure 1: Web of Things (WoT) layers illustrated (details available at: http://webofthings.org/book/)

A benefit of the open web platform as a common denominator for IoT systems, is the continued commitment of the World Wide Web Consortium (W3C) to universality. W3C standards are developed with built-in support for accessibility, internationalization, privacy, and security, and ensure royalty-free licensing [12]. Currently W3C is increasing efforts on developing standards to support the Web of Things (WoT) as a potential IoT application platform [13].

5. Increased Need for Accessibility Research

It is currently a critical time for accessibility research to provide the much needed input into the development of W3C standards for the Web of Things (WoT). Some of the standardization activities in this area are either in incubation or early development stages with many open accessibility research questions that need to be addressed. It is a rare opportunity to influence an evolving technology, to ensure accessibility from inception rather than as an afterthought.

Some of the areas with more need for accessibility research include:

- **Web of Things (WoT) accessibility use-cases** – currently the WoT Working Group [13] is in early stages of standardization. Accessibility use-cases covering protocol, data, and API level needs are needed to help mature the relevant standards in this area. Also aspects of configuration, user profiles, and practical usage need to be documented with specific use-cases.

- **Web accessibility guidelines and standards** – also input into future developments of the W3C Web Content Accessibility Guidelines (WCAG), the User Agent Accessibility Guidelines (UAAG), and of the Authoring Tool Accessibility Guidelines (ATAG) is needed. Currently there is early exploration efforts on developing a universal set of Accessibility Guidelines [14].

Direct contribution of research and development results into these groups is welcome. In addition, the Research Questions Task Force (RQTF) [15] of the W3C Accessible Platform Architectures (APA) Working Group provides a forum for coordinated exchange and accessibility input into W3C standardization. It maintains a specific wiki page on WoT accessibility [16] with opportunities for input.

6. Conclusion

The Internet of Things (IoT) promises unprecedented opportunities for people with disabilities and many more people, if the design challenges are addressed in time. This paper invites accessibility research and development in the rapidly evolving area of Web of Things (WoT) as a potential way forward to making IoT accessible.

7. Acknowledgments

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