The Case for Integrating Needs and Preferences in the Internet of Things

Andy Heath
Axelrod Access For All
Sheffield, United Kingdom
andyheath@axelrod.plus.com

Gill Whitney, Irena Kolar, Mark Springett
Design for All Research Group
Middlesex University
London, United Kingdom
G.Whitney@mdx.ac.uk , I.Kolar@mdx.ac.uk,
M.Springett@mdx.ac.uk

Abstract— **This paper was written because the authors believe the Internet of Things has enormous potential to enrich the lives of all people, but particularly those people sometimes referred to as "disabled", who are excluded from participating in normal life processes that present fewer barriers to others and by that exclusion experientially impoverished. Further, we believe that there are grounds for personalization or individualization to be the accessibility delivery mechanism of choice to meet the diverse needs of this non-homogenous group of people in diverse contexts and in fact, of all people. From demographics it is clear that if the accessibility of the Internet of Things is not approached effectively, then a problem will be created for people with disabilities and older people. The paper gives a direction forward driven both by results from practical research with real users and theoretical considerations of what approaches are available to apply to this problem. We believe that Ambient Assisted Living (AAL) is a significant aspect of the Internet of Things.**

Keywords- Internet of Things, Accessibility, Standards

I. INTRODUCTION

A. The Problem to be Addressed

This paper presents an argument for integrating accessibility in the Internet of Things (IoT) in a particular way. It describes and makes the case for an approach to integration and presents some of the requirements that need to be considered.

Accessibility is a huge and very complex domain and it is essential to address it if the Internet of Things is not to impoverish our humanity by excluding many people from its numerous benefits. There is a need to incorporate accessibility in a way that supports its use by everyone and in all environments. We approach the argument first from demographics, and then consider common difficulties in using Information and Communication Technology (ICT) devices in several use cases that demonstrate the complexity of the field. Our central argument is that accessibility is so complex, from computational and human understanding perspectives, that an approach that makes it simpler for everyone is required. We go on to suggest what we believe should be the approach of choice in dealing with the complexity of modern technology in a way that works for all users. We present all of this in a context of evolving models of accessibility and social context.

The Internet of Things is not yet well defined but is a developing field. In one view of and application of IoT, items and computers are labeled with an electronic identifier consisting of a unique number called an IP address. The attachment of the labels supports the development of networking infrastructures where devices can autonomously communicate with one another and share control and communication. The successful implementation of IoT will require:

- An IP address which can be associated with every possible source object that needs one (usually).
- Software applications that can communicate with and manage the data from an ever-growing number of the enabled devices.
- Consideration of requirements for ensuring IoT devices are accessible to all persons needing to directly access them or who are impacted by systems they connect to. We develop this in detail later in the paper.

The networking of devices has the potential to benefit people currently with requirements not well served by the design of mainstream systems and devices to date, especially if the network infrastructures or devices support the use of assistive or alternate technology. Examples might include a medicine cabinet that is continuously aware of the status of each medicine bottle stored inside the cabinet such as its name, contraindications and expiry date. It could communicate the need for replacements to the medical professional as well as to the drinks cabinet to warn of the need to avoid alcohol (if required). Another example is a fall detector linked to both the telephone system to call help, the cooker to switch off any item which the user can no longer control, and the central heating system to ensure the person is kept in a comfortable situation until they are rescued.

Practical research carried out at Middlesex University as part of a European Project has indicated a number of potential problems that occur when users require special features. The accessibility features within current ICT systems are often well hidden, meaning that users requiring those features need greater technical skills than others to reach them. This is impractical and unacceptable and could result in the IoT devices becoming a greater problem.

Many users have particular access requirements that are critical in that they are often unable to access some particular systems at all unless those systems are designed with mechanisms to meet those access requirements. Such users are often described as "disabled", which effectively places the cause of the access challenge at their door – it makes it "their fault". This is not the only way to attribute causal factors and the authors particularly reject it in favour of a more balanced view where accessibility is thought of as a relationship between user and product and accessibility challenges represent a mismatch of product characteristics to required features.

For other users the lack of particular access mechanism means that their use of the system is possible but less than optimal. We believe the needs of every user can be best met by the adoption of an equitable system that does not apportion blame but considers accessibility as a relationship and develops systems and products that can be adapted to meet individual preferences. However, the term "disabled" is embedded in our cultures and is difficult to avoid. In this paper, where we present examples and results using the term, we are referring to those users for whom particular accessibility requirements are critical. That does not detract from the thesis that adaptation to individual preferences should be the approach to meet the needs of every user.

B. What is the Internet of Things?

There is no single agreed definition of the Internet of Things; different groups working in the area have different ideas of what it is. A fundamental distinction in the positions organizations take relates to whether the "people" dimension is considered part of the system. For example, The European Telecommunications Standards Institute (ETSI) [1] describe IoT in a "machine to machine" fashion as,

"Communication between two or more entities that do not necessarily need any direct human intervention. M2M services intend to automate decision and communication processes [2].

Whereas the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) [3] gives this description

"A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies [ITU-T Y.2060]" [4], which implies that people need to be considered.

In this paper, we take as a tenet that the IoT involves people at some points. There are several different ways that people might be involved.

- Some systems have direct human interfaces. In any such system, it is necessary to consider the requirements of all potential users in using those interfaces. Methods for consideration of the accessibility of interface technologies have been given much attention, for example in the Web Content Accessibility Guidelines (WCAG) 2.0 [5] and many other sets of guidelines. Technical and other guidelines, such as these, are essential but they are not always used and are not sufficient nor do they provide optimal accessibility [6] for every user.
- Some systems may have no direct human interface but cascading effects on human interfaces in interconnected systems may need to be considered. A burglar alarm monitoring a factory might raise an alert on a system that it is connected to. As well as the need to address the accessibility of any such connected human interfaces there may be implications for the humans using that system of the information content transmitted by the alarm. The High Definition Multimedia Interface (HDMI), which is a standard concerned with the transmission of video data between computer monitors, digital televisions, video projectors and related devices and might be thought of as a machine-to-machine transmission standard not involving humans, was designed without the capability to carry closed captions as required for example by The Federal Communications Commission [7], which alone had a significant impact on a large number of humans and created further difficulties in lack of interoperability between systems adopting mechanisms to get around its limitations.

To meet both these requirements (systems with human interfaces and systems without but which might interconnect with those that do) we will argue that it is needed to look at both the accessibility of the device or system under consideration and the accessibility of possibly interconnected systems with a systemic (holistic) view in a common framework and that taking the tenet that we need to build systems that can respond to and adapt to individual preferences is an approach that can do that. It can provide an approach that can be used in different parts of heterogeneous systems with consistency.

C. Structure of this Paper.

This paper describes how the Internet of Things and personalization can have a greater positive effect for people with disabilities by describing firstly what is the `Internet of Things' and the numbers of older and disabled people who could benefit. In Section II the argument from demographics using a traditional medical model is presented. In Section III the paper focus on real world accessibility issues that people with disabilities can experience with current technology. Section IV then describes the solutions that exist for users with respect to Ambient Assisted Living, in which fine-tuning the match between system design and user needs and preferences can have overwhelming positive effects for the end user. The paper continues in Section V to describe a number of models of accessibility including the medical model of disability, the one or many sizes fit all approach, the approach offered by testing a product with groups of users, usually with disabilities. This section concludes by addressing the issue that the way to optimally meet the needs of every individual consumer is to establish communication between each consumer and producer. The paper concludes in Section VI by stating that in the context of changing demographics across the world there is a need to address accessibility effectively in The Internet of Things if we are not to exclude and impoverish many people.

II. Demographics

In this section, we present the argument from demographics using a traditional medical model. This is necessary because it isn't possible to discuss demographics using "the individual" as the basis of approach and because there is so much existing culture and research that addresses it this way. In later sections, we show how the model is flawed as a way to deal with accessibility in the IoT.

The IoT has the potential to benefit many people currently not well-catered for by supporting control of information and communication systems using a personally accessible mechanism. More than one billion people in the world live with some form of disability, of whom nearly 200 million experience considerable difficulties in functioning and carrying out daily living tasks [8]. The increased ageing of the population will lead to an increase in this number and an increase in the number of people with disabilities requiring accessible interfaces. In 2000, there were 606 million persons aged 60 or over throughout the world. Fifty years later, the number of persons aged 60 or over is projected to expand by more than three times to reach nearly 2 billion in 2050 [8]. The International Classification of Functioning, Disability and Health defines disability as, "the ... result of complex relationships between an individual's health condition and personal factors, and of the external factors that represent the circumstances in which the individual lives". [9]. Technology such as Radio-Frequency Identifiers has the power to make people more or less disabled by altering the external factors and enabling people with disabilities to interact with items of technology which have been adapted to interact via a radio frequency interface.

To ensure that older citizens and those with disabilities can benefit from the Internet of Things it is necessary for services to be designed in a way so that they can be used by people with a sensory, cognitive, physical or multiple disabilities. It is also necessary to ensure that the functionality of the objects being controlled meets the needs of the end user. This will require designers to understand the full range of needs both in terms of utility and operational control. Addressing these needs properly would require a drastic change in the mindset of designers so that they consider all people as `normal' customers or as customers of `normal' products.

Establishing an appropriately user-sensitive design culture may be difficult. Recent research with the committee members of the British Standards Institute identified that 33.3% of those questioned said yes to the question "Do any of your standardization activities involve the standardization of products or services where the accessibility for older and disabled people needs to be considered?" Whilst 76.7% had said yes to "Do any of your standardization activities involve the standardization of products or services which are designed to be used by people? This suggests that older citizens and those with disabilities are not a typically recognized subset of the group 'people'. Also, as we explain later, the complexity of people's needs in different contexts is huge. Even without the need for a mindset change it is not realistic to expect designers to absorb and operate with that complexity. Something new is needed.

III. Current Real World Accessibility Issues

The integration of digital technology into everyday life has the potential to be of great benefit to older and mobility-limited people and people constrained by cognitive, emotional, social or other constraints by enabling them to carry out a wide range of tasks, including accessing many public services, using entertainment systems and communicating both remotely and locally.

The range of people who can access ICT systems and the contexts in which they can be accessed can both be extended by following accessibility guidelines such as Web Content Accessibility Guidelines (WCAG) 2.0 [5] and other hardware and software standards/guidelines. Such standards will have increased benefit in the design and practical application of the combination of technologies which is the IoT. As we argue elsewhere, however, they have many limitations and challenges.

Accessibility support and information provision on commercial media company websites is often hard to find and highlights an apparent lack of sensitivity to the importance and needs of customers with disabilities [10]. An inspection of three leading providers' sites on the World Wide Web illustrated this well. This inspection focused on the task of finding accessibility information pertaining to the companies' mobile products. It was found in one case that the information was not provided. In the other two sites inspected, the information was deeply buried and difficult to find. On one site a link was provided in a small font that, for example, those with vision problems are likely to miss. On another it was found that no explicit link existed, causing an extensive search, including use of keyword search and a lengthily browse through numerous options. The sub-tasks of scanning for obscure links, scanning large numbers of search results and, in general, protracted search seem to imply the assumption that all users are comfortably capable of these actions. There was no evidence of designers taking into account the difficulties that the typical users of accessibility features are likely to have.

IV. Ambient Assisted Living

The Internet of Things provides unprecedented opportunity to explore the space of possible life-enhancing solutions for specific individuals. However, the complex and varied nature of peoples' cognitive, perceptual and physical condition, and their life circumstances mean that bespoke solutions are needed. The case of Ambient Assisted Living is one where fine-tuning the match between system design and user needs and preferences is particularly critical. This is true both of the service design and of the interaction design. The nature of this type of system is that it is designed to support day-to-day living for a complex variety of user needs and contexts, and needs that are prone to significant changes over time. We identify two key distinct levels at which design for individual needs is critical. These are firstly the service level and then the interaction level.

Complexity, asynchronous processes, time dependent behavior, and safety concerns are typical of the design problem for home environments. The definition of AAL we use here assumes different possible distributions of control between the technology, user control and third party control. One of the key elements of design is how control is distributed between these actors. One is the degree of control that a user requires over the technology. Will a person, or a technology controlled by a person procedurally, or controlled by a person declaratively, or by a secondary person, or automatically by technology, or combinations of these fulfill a task? The assessment of an individual's service requirements is partly a question of designing an optimal distribution of tasks. There is a danger that AAL technology may wrest too much control from the individual.

There are also hedonic considerations in design that should be weighted appropriately alongside considerations of functional requirements. Finding the 'optimal' solution for task performance is not simply a matter of considering the efficiency of candidate design solutions, particularly with reference to the distribution of control. For example, it may be quicker to prepare meals if the beneficiary has minimal involvement. However, even a severely restricted individual may prefer to have control over the process. Tasks such as cooking are ones that have an important personal cache, and to simply surrender control to a device would not be acceptable. A further consideration is privacy. Removing control from individuals implies a greater level of ambient monitoring where data is collected from sensors embedded in the domestic environment, and possibly sharing of data with third parties. This may even include video footage.

The 'calm computing' notion originally championed by Weiser (1990) [11] envisions that the environment anticipates and responds to perceived user needs. In this vision, the user is not actively manipulating devices and at times may not even be aware of the complex combination of sensors, processors and actuators around them. This is the philosophy used in 'smart home' prototypes that were designed by Microsoft and others, in which domestic technologies were activated by human movement, environmental change and timing, but not by direct intentional human input. The concern is that such a model for AAL ignores both pragmatic and hedonic requirements of users. As discussed, users desire to have tasks done a certain way or just simply to have control, means that AAL design must be conceived on an individual service level, rather than simply automating processes that the beneficiary may find difficult. It is better to see AAL as a collection of individual services for which the degree of automation relative to direct user control is determined on a case-by-case basis.

At the interaction level, the design of control devices for ambient technologies is critical both to its accessibility and its range of utility. The perceptual and motor skills of potential AAL users vary considerably. This issue is compounded by the fact that older users in particular will be prone to diminishing capacities. Such devices may be embedded in wheelchairs, domestic fittings or individual utilities, presenting a raft of potential design issues for interaction design. Therefore, design needs to allow for customization/personalization both initially and throughout the service lifecycle. Optimization of user controls such as joysticks involves the comfortable efficient and maximally effective control of the device. This may take a radically different solution dependent of the nature of the user's abilities. For example, a user may be best able to manipulate a joystick using their wrist rather than the front of the hand. Another may find that gripping a golf ball attached to the joystick allows greater control. It is important to allow for customizable input in design. The subtleties of input requirements should be researched early in projects, but the user should also be given the chance to 'finish the design'.

A further reason for supporting personalization is that user capacities are likely diminish progressively with age. Usability requirements are therefore subject to change over time. It may be that the requirements for text displays on device controls change several times during the lifetime of a product. Recent work, (e.g., Biswas et al 2011 [12]) has shown that some quite fine differences in perceptual and motor abilities can lead to significantly different requirements for interactive device design. This is particularly critical for AAL, where multiple use devices tend to be embedded in the physical environment.

Some progress has been made on providing for customization in AAL. One example is Casensa [13], a context-aware system that can be installed in houses of elderly to support them in everyday life activities. Users are given the power to create the supportive smart behavior of the house and have control over the activation and deactivation of the smart home facilities. It also allows for critical communication between ambient living devices and caregivers, which is particularly useful in cases where the elderly beneficiary may have diminished abilities, (e.g., dementia sufferers).

V. MODELS OF ACCESSIBILITY FOR THE INTERNET OF THINGS

In this section, we look very briefly at the IoT accessibility requirement from the perspective of some models of accessibility provision. We explain why it is so important to incorporate needs and preferences in IoT network and device architectures and point at some ongoing work in Needs and Preferences and supporting delivery architectures. In fact there are many accessibility models, we describe here only a few and make no attempt to be exhaustive.

A. Accessibility as a Relationship and Changing Models of Disability

Traditionally and historically persons even imagined as having characteristics not conformant with the norm have been separated from society and "blamed" for what has been often seen as "their problem". A full treatment of this and ongoing societal changes would look at perception and complexity, psychological, sociological, philosophical models, organizational theories, history, religion and indeed the nature of the universe and all that [14]. Such a treatment is beyond the scope of this paper and we rely here on anecdotal evidence and received historical wisdom of which examples are legion, ranging from the treatment of witches in Middle Age Europe to Eugenics and the treatment of disabled persons by the Third Reich [15]. Here, we merely observe and describe the changes underway.

Over a long period the view of "disability" has shifted and continues to shift, towards a view of accessibility as a relationship between system provider or producer and consumer or user. Approaches to accessibility can be seen as ways to manage that relationship.

1) The Medical Model

The medical model of disability takes the view that a "disabled person" has some characteristic(s) that lead to that person being unable to use some system or product in the fashion that some others can. Hidden behind the "in the fashion that some others can" phrase is often the view "in the way that we designed it and expect it to be used". It is a view of the situation that posits people and behaviors as completely understandable and classifiable. Unfortunately, it fails to capture the richness of human behavior and functioning.

The International Classification of Functioning, Disability and Health [9] is a widely-accepted medical-model approach. This is an extensive complex classification of human functioning that some find difficult to understand and use. The medical model is only a model rather than a true representation of real people. As medical science advances so our understandings of conditions, behaviors and needs are refined and improved. This implies that in practice there is a gap between real needs and the model (otherwise the model would not need to develop and advance). The model isn't the person in the context, it merely predicts something about the functioning or behavior of the person and every model does this imperfectly. This gap between predicted need and actual or experienced need is often crucial in that it prevents delivery of a system from being optimal for every user. In addition, the nature of the model contributes one component of a computational complexity issue described below

2) One or many Sizes Fit All

The Medical Model has some aspects with the flavor of "One Size Fits All" ("this is what you are getting so it works for you") or "Many Sizes Fit All" ("here are a few possibilities, one of them must work for you"). Imagine selecting a suit from a rack of suits for sale and no single suit has a perfect fit and contrast this with a tailor-made suit. The suit from a rack may not fit any person perfectly and for some particular person there may be no size that fits at all. Approaches to accessibility in the "Many Sizes Fit All" camp would include bundling together media modalities in a delivery package, such as captions and Audio Description along with a video or providing multiple ways into a building, some having wheelchair ramps and some having steps only. Clearly "Many Sizes Fit All" is an improvement on "One Size Fits All" and it has been widely used as a model to deliver accessible systems and products. It suffers from a number of limitations:

- It has the same gap between system and user as the medical model because it "guesses" what the user needs.
- On the one side of the relationship we have extremely varied users and contexts. On the other side, we have solutions, which are also extremely varied and also evolve over time, particularly in ICT where we have rapidly changing technology. Bridging between these two has a computational complexity close to exponential. Without some other mechanism we can only solve a limited number of cases with exact solutions. Given the diverse nature of individual needs it may be that not all cases can be solved optimally. That is, its likely that not all users will have a solution that is ideal for them in the context they are in and possible that no user at all will have a solution with a high usability.
- Delivering all potential sizes in one package is unacceptably demanding on delivery systems and packages. In the ICT domain, trying to do so bloats data and uses unnecessary network bandwidth. In the world of supermarket car parks it means making every parking space large enough for families (which might be possible but wastes significant resources) and making each one close enough to the store that nobody has to walk far (which is not possible at all).

3) User Testing and Other Approaches

Space precludes description of all of the models which are employed to manage the accessibility relationship but all of them exist because of the complexity of the problem space and all of them attempt in some way to limit this complexity so as to make the problem solvable. The unfortunate characteristic is that in some way they all also compromise and limit the solutions, e.g., a commonly-used mechanism is that of testing a product with groups of users, usually with disabilities. This is a similar exercise to methods such as think-aloud protocols [16] which are commonly used in mainstream usability testing. The aim of such techniques is to establish generalizable results from a small sample of population. For example, if a mobile device's menu structure is found to be navigable by a sample of 15-20 non-impaired users it is broadly assumed to navigable by a whole population. However, this approach cannot be applied in the same way to a population of users with disabilities. It cannot be "exhaustive" with persons and contexts. Such exercises expose the product to only certain persons and it may not meet any individual's needs optimally. In fact, in many cases making a product meet the needs of one individual in the group may make it fail to meet the needs of another. For example, the needs of some persons for simplified information can conflict with needs associated with some cognitive "disabilities" for information to be presented in multiple forms. Individualization is the only mechanism that can get around this to deliver optimally to every user in every context.

4) Matching to Individual needs and Preferences

An implication of our discussion of models is that the only way to meet the needs of every individual consumer optimally is to establish communication between each consumer and producer – anything else will have some element of guesswork about the needs of the particular consumer or some element of putting users in groups in which they may or may not (often not) fit. However, the idea, even with modern social network systems, of having a conversation between producer and every consumer around the use of every product in every context is computationally infeasible. What is needed is some way to manage the relationship that reduces the complexity whilst optimizing the needs of both parties in the communication – consumer and producer. As we mentioned above, in the case of media, it isn't reasonable or economically possible or sensible to deliver every possible alternative media format permutation to every user in every context. But in ICT it is feasible to deliver exactly what that user needs if we can find ways to build automated delivery systems that can do that.

A common way to reduce the complexity of problems involving relationship between two parts is to introduce an intermediate representation. Examples include the PBMPlus Image formats conversion kit [17]. PBMPlus set out to solve the problem of converting any of M image formats to any other of those M formats. At first sight it would appear to require M x (M – 1) convertors (every format to every other format) but by introducing a small number G of general formats and converting via the appropriate intermediate general format the number of required converters is reduced to 2 x M x G. Where M is large and G is small this is a much smaller number of convertors. A similar approach was taken in [18]. The approach would appear to apply to all problems where it is necessary to map one large domain to another, as it is here (an intermediate representation reduces the combinations and "manages" the relationship). It is particularly useful where the operation is expensive (so we keep G small to minimize costs) and whilst ICT solutions that meet the requirements of an individual are often cheap (because ICT is cheap and flexible), identifying those solutions is often expensive, on the scale of the Internet of Things ridiculously so – the world cannot afford to deal with the accessibility requirements of each device, person and context separately. It should be noted also that great care needs to be taken to design the intermediate representation, itself a model, so as not to exclude particular mappings. An intermediate representation between producer and consumer then would reduce the computational complexity of managing the relationship and improve the results quality.

A great deal of work is underway in ICT Accessibility to develop individualization approaches and a common way to do this is based around sets of individual preferences associated with a user and applying in specific contexts. A small sample of that work might include:

- ISO/IEC 24751 Individualized Adaptability and Accessibility in Learning, Education and Training, currently under revision and to be re-titled as Access for All [19, 20, 21].
- IMS Access for All – a family of specifications of personal needs and preferences and matching metadata, latest version is 3.0[22].
- W3C IndieUI (Independent User Interfaces) Indie UI: User Context 1.0 [23].
- Global Public Inclusive Infrastructure (GPII)[24].
- A11yMetadata Project and Schema.org[25].
- Preferences for Global Access [26].
- Document Accessibility Profile [27].

This list is far from exhaustive and there are many technical standards we have not been able to include.

Other groups such as the ISO/IEC Joint Task Advisory group working on Guidelines for incorporating accessibility in standards and ISO/IEC Special Working group on accessibility [28] also consider individualization important enough to incorporate in their roadmaps.

Individualization based around sets of individual preferences provides an intermediate representation between producer and consumer, that being the individual preferences that a user has for that context. There are not yet completely accepted definitions of the words "preference" and "need" and different groups working in the area use them differently, but the general principle is that systems including content and human interface can adapt to a set of individual preferences at or close to delivery time and thus come closer to meeting a individual's needs optimally. There are many ways individual preferences can be used, from static adaptation of interface to fetching matching content or requesting the production of content that matches. Examples and Use Cases for Individualization Using Preferences:

- A video is being delivered with captions. That may be because the user has an expressed preference that auditory content be replaced with or augmented by textual content (for example the user may be deaf or it may be that the environment is noisy).
- A user may have some vision impairment and require that text rendered on a screen is in a large font or alternatively the contrast is enhanced (each achieves a similar result)
- A user may have difficulty using complex instructions and need that instructions are presented in simplified language. Another user might find a simplified interface frustrating and slow to use.
- A user with limited dexterity at some times of day might have a preference to operate a device by voice input at those times and by physical means at other times.
- A security video camera watching a house for movement might be set up so as to send text alerts, or video pictures to a remote location. A homeowner using such a camera might be driving and wish to be alerted to something the camera has detected by an auditory means. Preferences for that context and user (while driving) of auditory-for-visual or auditory-for-textual could trigger the delivery an auditory alert. The preference "textual for visual" might for a different context, say at the theatre, trigger the delivery of a textual (quiet) alert for the same event.

In each of these cases, given appropriate network infrastructure, a system might respond to specific user preferences expressed in ways that are machine-readable and system-interpretable. Those preferences might be expressed in terms of required media modality adaptations or substitutions or interface customizations.

Making human interfaces to IoT systems and the messaging and media in those and in connected networks individualizable is likely to improve their accessibility significantly. However, on its own that won't solve the complexity problem. To solve that standardization is needed so that when an interface uses preferences for a particular user and context the same set of preferences is used across devices and contexts. Specific preferences relevant to a device and to a context may be different but some needs remain the same or closely-related. What is to be avoided is "unnecessary difference" in technological detail. We need to find the commonality (of technical and human needs) and build approaches around that.

For example, the need for enhanced visual display we mentioned above might be satisfied on one display by increasing a font size and on another by increasing the contrast and the solution adopted might be determined by the functionalities available on the device itself (consider for example the limited display functionalities of very cheap L.E.D. displays - a ubiquitous-device use case might require these) or by a combination of the display functionalities available and the environmental conditions at the time (say sunlight or shade). The "common preference" in this case would be for enhanced display and adaptation of fonts or contrast would be the solution. There are other solutions to this interaction need, such as delivering a different modality. We might in this case be able to deliver the information in auditory form – if we knew it was consumable – a factor of other user needs (being able perceive auditory content) and the environment (not too noisy to hear for that user and an environment in which sound is acceptable). However, in another case entirely it may be that increased contrast is both the preference and the solution.

There are common interoperability issues here that are often addressed by the development of appropriate standards and indeed many standards are in development to meet that need (some of which are mentioned above) and others are planned. Some specific requirements for IoT systems are developed later in this paper.

B. The Internet of Things

1) Relevance of Individualization

If we accept that the Internet of Things has many places where its necessary to have human interfaces or where there are implications for closely-connected systems and if we accept that people and contexts are so varied that there is a serious complexity issue in making those human interfaces and the information carried accessible then we must accept that building our management of the accessibility relationships in IoT is best done with personalization approaches. Any other way is too computationally expensive. It is far from feasible to expect every device designer to know about and use accessibility guidelines that characterize every "disability" and every human functionality.

An exciting use case and requirement is that of doing individualization not just "in" the heterogeneous networks that will be the backbone of the IoT but across those networks.

- Consider a user requiring screen enhancement on a television screen. It's a strong possibility that the user might require similar enhancement on any display they are using. With individualization integrated in IoT we might for example be able to know on what that user required in similar contexts and to be able to provide it without asking. This is extremely useful in situations where a user is not able to ask for what they require.
- Consider a device that transmits auditory information so a user can listen (perhaps a baby alarm) and a user who requires text-for-auditory in some contexts. It might be that the user has that requirement because the environment is noisy (preventing hearing), or it might be because the user is in a theatre listening to a performance (though not a baby alarm!) and so is unable to wear a listening device or disturb others, or it might be because the user has temporary or permanent hearing impairment. By knowing the context we might be able to infer what the user would require in a different context entirely without user input. Doing this requires architectures in which individualization is integrated with IoT.
- Consider the benefits to a person unable to cope with complexity of being able to approach a cash machine or ATM and be provided with a simplified interface without asking for it.
- Consider the benefits to a blind user travelling on a bus of information concerning the whereabouts of the bus and the next stop being delivered in auditory form directly to a personal device but consumed by sighted people as text.

2) Requirements and Issues for Integrating Preferences in IOT

In order to deliver adaptation to individual needs and preferences across heterogeneous networks to meet the kinds of use case we have described a number of interdependent technical issues need to be approached – some are open questions not yet solved. We list some here along with tentative and even speculatory suggestions for mechanisms, considerations or areas to explore towards solutions:

- Where are individual preferences stored?
  - In the cloud? How can that interoperate across different vendor clouds?
- How can we handle privacy given that in some cases we can deduce information about an individual from their preferences, particularly from multiple contexts? For example, if a user required enhanced visual access across multiple contexts it might suggest they have a visual impairment.
- Where and how are "solutions" ("this works well in that context") stored and where in IoT architectures can the engines that match solutions to devices live?

- How can we determine whether the design of a device, system, or protocol will have impact for accessibility of systems connected indirectly to it?

Finally, whilst not completely accessibility-related, how can we ensure, particularly in loosely-coupled IoT systems such as those built around RFID [29] that ethical considerations are applied to those systems in which they are embedded.

VI. CONCLUSIONS

This paper has shown that in the context of changing demographics across the world towards more elderly populations there is a need to address accessibility effectively in The Internet of Things if we are not to exclude and impoverish many people. We have argued from practical and from computational complexity and purely theoretical considerations that current widely-used models of accessibility, including "medical models" and "one size fits all" are inadequate to meet the task and even "many sizes fit all" is inadequate alone and that we will need to use a combination of "many sizes fit all" and individualization or personalization to address the problem.

Our conjecture is that combining AAL and personalization in the IoT can in the future enrich the lives of many and that we need to start building infrastructure support for that approach in the heterogeneous networks and devices that will form the IoT.

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