Assistive Technology for Vision-impairments: An Agenda for the ICTD Community

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ABSTRACT

In recent years, ICTD (Information Communications Technology and Development) has grown in significance as an area of engineering research that has focused on low-cost appropriate technologies for the needs of a developing world largely underserved by the dominant modes of technology design. Assistive Technologies (AT) used by people with disabilities facilitate greater equity in the social and economic public sphere. However, by and large such technologies are designed in the industrialized world, for people living in those countries. This is especially true in the case of AT for people with vision impairments – market-prevalent technologies are both very expensive and are built to support the language and infrastructure typical in the industrialized world. While the community of researchers in the Web Accessibility space have made significant strides, the operational concerns of networks in the developing world, as well as challenges in support for new languages and contexts raises a new set of challenges for technologists in this space. We discuss the state of various technologies in the context of the developing world and propose directions in scientific and community-contributed efforts to increase the relevance and access to AT and accessibility in the developing world.

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Management, Documentation, Economics, Experimentation, Standardization, Legal Aspects.

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Assistive technology, Accessibility, Disability.

1. INTRODUCTION

Since 2007, global concerns over Accessibility and the availability of low cost Assistive Technology (AT) access have increased following the signing of the United Nations Convention on the Rights of Persons with Disabilities (CRPD). The convention dramatically increases the need for low-income countries to expand their commitment to providing appropriate technological accommodations for disabled citizens. However, most prevalent assistive technology is neither at a reasonable price point for widespread access outside of the industrialized world, nor are the functionalities with regard to issues such as infrastructure or language aligned with the contextual needs of the developing world.

Research in ICTs and Development, though significantly invested in a range of issues relating to underserved populations in the developing world such as low-cost computing for education, governance, data collection, and healthcare, has been surprisingly silent on issues of Assistive Technology and Accessibility. We can divide the scholarly work on disability in the developing world into two broad classifications. The first may be called a medical model approach, examining disability in terms of disease burden [1-4], focusing on the enumeration and prevention of disability, or examining the impacts of disability through one specific variable of analysis. The second is anthropological and philosophical work on disability, approaching it from cultural frames of social or rights-based models [5-8].

Although there has been some work on the scope of the UN Convention [9] and on the education of children with disabilities in relation to the convention [10], there has been little research on the engineering or business aspects of developing low-cost AT for the developing world. In the backdrop of an extremely active community in the WWW space working on issues of accessibility, it is thus foreseeable that the immediate future may hold much hope for work in this direction, with the development of an appropriate research agenda. We argue in this paper that work with low-cost AT and accessibility solutions for low-resource regions presents valuable directions from the practical perspective of work that has immediate real-world potential as well enough new technology challenges to present a scientific research agenda.

2. ASSISTIVE TECHNOLOGY AND VISION IMPAIRMENTS

The medical definition of vision/visual impairment is vision loss of a person to such a degree as to qualify as an additional support need, through a significant limitation of visual capability resulting from either disease, trauma, or congenital or degenerative conditions, that cannot be corrected by conventional means like refractive correction, medication, or surgery. According to the World Health Organization, there are approximately 314 million visually impaired people around the world, a majority of who live in developing countries.[1]

AT options for the visually-impaired ranges from basic and relatively inexpensive walking canes or magnifiers, to expensive electronic devices used as communication aids. Towards the end of the last century the increasing ubiquity of computing in

[1] http://www.who.int/mediacentre/factsheets/fs282/en

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everyday tasks, has made the interface with computers an essential tool in social and economic participation for the vision-impaired.

Choice of appropriate assistive technology and output formats (visual, auditory or tactile) will depend on the user's level of functional vision. To generalize, among computing and communications technologies, a family of technologies around image and text magnification are available for users with low-vision, audio and tactile technologies exist for blind and legally-blind users, and tactile devices exist for blind and Deaf-blind users. For low- and sensitive-vision users, these include devices such as high-resolution screens, oversize monitors, glare guards, and screen magnifiers. For users with no vision or hearing, the primary means of communication would be Braille displays which allow for tactile information display alongside Braille keyboards, as well as other forms of Braille material. For users with hearing, but no vision, in addition to the Braille technologies, there exist Screen Readers that communicate computing screen output in audio formats. Screen readers typically work alongside a range of other augmentative technologies, depending on the kind of device in use. In this paper, we describe some of the major technologies in each category, and discuss the challenges in building low-cost options for each.

3. ASSISTIVE TECHNOLOGY TOOLS

In this segment, we look at the various AT tools available based on the point on the function thread at which they are used. These tools are primarily related to navigation or communication. The communication-related tools increasingly need to communicate with web-based technologies.

3.1 Back-end tools

The back-end tools refer to some of those technologies that conduct either OS or Application-level functions, but do not directly interface with the AT user. Such back-end tools may perform the functions relevant to one specific or a range of AT, irrespective of output format.

3.1.1 Optical character recognition tools

Optical Character Recognition, commonly abbreviated as OCR, is a mechanical or electronic translation of scanned text such as handwritten, typewritten etc. into machine encoded text. It finds wide use in conversion of books and documents into electronic forms. OCR is a backbone technology for a variety of interfaces that require an application to process as digital text material available in image or other formats – the most commonly known use being scanning printed material to have it processed as text or spoken in synthetic speech. An OCR system is a great example of a technology that has started as an Assistive Technology and crossed over into a multiple usage technology that has use applicability in a range of scenarios.

a. Logistical Issues

Current generation OCR systems provide very good accuracy and formatting capabilities at prices that are up to ten times lower than a few years ago. The price range for a PC-based OCR (in 2010) system is $1,300-$2,000. There are free and open source options like SimpleOCR and proprietary software like Microsoft Document Imaging and One Note which come bundled with Microsoft Office 2007. Many OCR systems are currently available in the market today reasonably priced for both personal and commercial use – so that part of the problem is more or less solved, but challenges still exist in cross-device compatibility.

b. Future Scope

The accurate recognition of Latin-script, typewritten text is now considered largely a solved problem on applications where clear imaging is available such as scanning of printed documents. Most current OCR systems support only English as a primary language. Other areas—including recognition of hand printing, cursive handwriting, and printed text in other scripts (especially those East Asian language characters which have many strokes for a single character)—are still the subject of active research. Creating regional-language OCR systems is an important challenge for ICT4D researchers in the near future, both for contemporary use and from the archival standpoint of historical preservation of texts from around the world

3.1.2 Braille Translators

A Braille translator is the backend tool that forms the connecting link between the OS and Braille output device. The Braille file created by the translator is sent to a Braille printer or read on a Braille display or smaller personal device.

a. Logistical Issues

The cost issue is not a major concern in the case of Braille translators as a wide variety of applications are available. A number of open-source and free translators are available on the internet. In addition to these, a number of commercial translators are also available ranging in cost from $400 for single user to $6000 for multiuser business use. The Duxbury Systems' Braille translator for Windows is one of the most widely available Braille translators in the market today. The translator includes support for a wide range of languages without any additional cost. Languages supported include English, Arabic, Afrikaans, Danish, Dutch, Hebrew, Latin, Russian, Spanish, Portuguese, amongst others, though in practice the less represented languages may face significant functional challenges.

b. Future Scope

Braille translators are a component of the equation where the technological challenge is somewhat limited, since the tools currently available can generate Braille for multiple languages without any additional cost. The major challenge continues to be a strong body of engineers working on language support.

3.2 Input

Input tools refer to the means by which people with visual impairments communicate with the computing interface. Depending on the user's level of functional vision or hearing, the input devices vary.

3.2.1 Speech recognition

Speech recognition (SR) tools have significant interest within the developers of computing applications because of their widespread application for both disabled and non-disabled populations. These users include those that quite simply prefer to use speech, to others with temporary conditions including repetitive stress injuries, and users with motor impairments unable to utilize market-standard keyboards. There are currently a range of speech recognition tools available in the market, though their effectiveness can vary significantly based on the available language corpus. SR presents technical challenges of pattern recognition and machine learning, and has for several years occupied an important niche in computer science research. In recent years there has been an increase in the number of major research groups working on SR in less represented languages, an example being Microsoft Research's work on Indian languages. Speech as an input mechanism can facilitate computer usage, especially in cases where the visual format has too many options and requires some time to navigate functionally. In such cases, speech input acts as a shortcut for users. Speech can also have a security application by using voice patterns as keys for access.

a. Logistical Issues

A range of SR options are available in the market. Windows OS comes with its own SR tools. Commonly available software include Dragon Naturally Speaking priced at $99, LumenVox Speech Engine priced at $200 (Lite Version) among others. The professional grade softwares are priced around $600 to $900. Most of these software requires some amount of training by a specific user, but accuracy rates are increasing consistently, making speech recognition a much more reliable input option than it offered some years ago.

b. Future Scope

As with several of the other technologies, the main problem for speech recognition is also language support. While training can offer high accuracy for English, there is a significant component of building on the corpus of existing data in that language, which increases as the web of users increases. This represents a chicken-and-egg problem for less represented languages, especially those that are tonal, where pitch detection is an issue.

3.2.2 Braille keyboards

Braille keyboards are used to type in Braille alphabet using eight keys, 6 for each Braille dot, 1 for spaces and 1 more for special characters, capitalisation etc. These keyboards allow the visually impaired to type into a computer like a standard keyboard. Nowadays, Braille keyboards of a wide variety are available from those that can be directly plugged onto a Personal Computer's USB port to those that come with their own screen readers, in-built memory and stand alone operation capability. The price of these keyboards ranges from $70 to $300. An alternative to buying Braille keyboards is to have a Braille overlay on a conventional keyboard, in the form of stickers. These stickers are priced even lower at $20. Given this option, we do not feel that Braille keyboards are an area of significant future concern for the developing world, as the technology needed to customize is already available.

3.3 Output

As with the input devices, output for people with vision impairments depends on their level of functional vision and hearing, and accordingly a tactile, visual, or audio output system will be appropriate. Visual output devices are typically magnifiers which can be either handheld or integrated into the computing environment. Audio output would include the range of products such as screen readers or mobile based systems. Tactile output devices allow users to perceive through touch – broadly either a range of Braille-related products, or an increasingly popular new area of work of advanced Haptic devices that not only allow access to textual material as in the case of Braille, but also feedback on shapes, texture, vibrations, motion. For the purpose of this paper, we discuss only mature technologies of immediate relevance to people with vision impairments, so some of these advanced technologies are not part of our examination, but we recognize their importance especially as AT moves towards greater recognition of the broader sensory experience of people with disabilities.

3.3.1 Screen Readers

Screen readers are perhaps the most important domain of AT for people with vision impairments, as it is a prerequisite for a non-visual computing interface. Screen readers are software programs that through a speech synthesizer or Braille translator allow a user to interact with material on a computer screen. A screen reader is the necessary interface between the computer's operating system, its applications, and a vision-impaired user. The most widely used screen readers are JAWS from Freedom Scientific, Window-Eyes from GW Micro, System Access from Serotek, and ZoomText Magnifier/Reader from Ai Squared. A number of free and open source alternatives exist including in-built screen readers for MacOS and Linux releases, and most significantly the open-source screen reader, NVDA (Non Visual Desktop Access). Screen readers are frequently confused with text to speech (TTS) engines; screen readers operate at a level of abstraction above the TTS, interpret the entire output mechanism, and all the applications running.

a. Logistical Issues

JAWS (Job Access With Speech) and Window-Eyes are the screen readers which rank highest in functionality, and support the range number of applications, and both cost roughly $1000. Jaws Standard costs $895 and the Professional costs $1,095. In general, JAWS and Window Eyes control something of a monopoly comparable to the Windows leadership of the OS market, and wherever possible, users tend to prefer trial or pirated versions of these rather than the available open source alternatives. Even the major agencies working with people with vision impairments tend to donate copies of these rather than promote free or open source technologies. This has the debilitating effect of not adequately promoting a broad-based community of open source screen reader users, which in turn could be critical in helping develop the overall quality of these tools and their compatibility with various existing computing applications. This in turn means that these applications have limited impetus to adequately support the smooth functioning of such open source tools given their low customer footprint.

b. Future Scope

For screen readers, the issue of language support is absolutely critical, given that for a large proportion of vision-impaired populations are not speakers of the languages dominant on the net. Unlike some of the Braille-based technologies, which are largely restricted to those among visually impaired population that are relatively better off since they had access to education, audio-based output technologies have the potential for broad-based reach. This is especially true with the proliferation of cellular phones which can use screen readers.

New language support for screen readers will require building an infrastructure of developers interested in creating language add-ons, of users adding to the corpus of translated and transliterated data, and of machine-learning technologists refining the tools that translate. Currently the support for Screen Readers is already limited which is aggravated by problems of content extraction. Content extraction mainly refers to extraction of displayed text in an efficient manner and getting it to work properly with Text-to-Speech converters. A better and more efficient content-extraction system is the need for the future.

3.3.2 Speech Synthesizers

The issues with language support for screen readers actually fit best within the scope of speech synthesizers. A computer system used for artificially producing human speech is called a speech synthesizer, and it can be implemented in software or hardware. Speech synthesizers are an integral part of screen readers. The text-to-speech conversion is implemented in the speech synthesizer. Speech synthesis systems use two basic approaches. The first, "text-to-phoneme conversion," involves a large dictionary containing all the words of a language and their correct pronunciations being stored by the program and matched to the spelling. In the other approach, "rule-based conversion," pronunciation rules are applied to words to determine pronunciation based on their spelling. Speech synthesizers generally run in the background of many applications that require an input in the form of human speech. DECtalk Access32, DECtalk PC2, DoubleTalk, Eloquence, Microsoft Speech Engine are some of the speech synthesizers available on the market. Eloquence is the back end for the JAWS screen reader.

a. Logistical Issues

The cost of software based speech synthesizer ranges from $49 for DoubleTalk to $150 for DECtalk Access32. Hardware based speech synthesizers range from $175 (DoubleTalk PC) to $1,195 (DECtalk Express). The 'Eloquence' speech synthesizer is free along with screen readers such as JAWS and Window Eyes. Other free speech synthesizers available on the web are Microsoft Speech Engine, TexTalk. Although the source code for these speech synthesizers is not readily available, there are many free SDKs (Software Development Kits) available with complete documentation which enable a developer to create advanced speech synthesis applications. Microsoft Speech SDK is one of the many SDKs available.

b. Future Scope

The problem of regional languages for screen readers relates to the lack of trained speech synthesizers in many less represented languages. From the perspective of building low-cost technologies for developing regions, the text-to-phoneme approach is quick and accurate, but fails if it is given a word not contained in its dictionary. As a result, a challenge for new languages involves getting a large enough corpus of words in place. The text-to-phoneme conversion method is more convenient for phonetic scripts like Indic languages than for writing systems that use morphosyllabic characters (as are common in East Asia). Greater accessibility to speech synthesis in the developing world poses both challenges of new technology and of corpus development. For example, Mandarin Chinese is difficult to synthesize due to the range of characters which have different pronunciations depending on the context, and wherein the intonation is critical in conveying the appropriate meaning. Furthermore, dialectical differences make it difficult to obtain agreement from native speakers on what constitutes an accurate pronunciation of certain phonemes. Ongoing efforts have examined the possibility of developing a Chinese Speech Synthesis Markup Language (CSSML) which can include additional markup to clarify the pronunciation of characters and add some tonal information. An alternative is to develop concatenation-based approaches that have a small corpus of sound recordings that can be concatenated to form full words, in different tones.

3.3.3 Braille Embossers / Printers

Braille Embossers are printers with Braille output. They are impact printers that render Braille on special paper or nowadays, even on normal paper. These embossers are either mechanical or those using special ink. The mechanical ones involve piercing pins into the paper to form raised parts that act as Braille characters. The other type uses thermal inks that swell up on heating, producing Braille output. Another important category is the traditional Braille Printing press that is used for large scale Braille printing. This uses a completely different principle. It involves the use of metal plates on which the text is etched and then the plate is impressed upon special swell paper that produces the Braille output. The printing press has given the ability to produce books for the visually impaired.

The thermo-electric and impact based processes have evolved the standard Braille embosser over the years. Early Braille printers like the Perkins Brailler and Mountbatten Brailler were analogous to the typewriter and required a human to manually type out the entire script. Modern Braille embossers range from small portable devices that can print out small signs to commercial grade printers. However, it is important to note here that the access to a typical commercial grade printer, while clearly a rarity for most vision-impaired people, is comparable in output potential to a multifunction printer for sighted users. While the latter category of printers may cost no more than a few thousand dollars and are easily accessed by the general population either at print shops or in the workspace or educational institutions in the industrialized world, the analogous large Braille embosser is rarely available for people with vision impairments who need material printed.

Braille embossers range in cost from a few hundred dollars to approximately $80,000 depending on type of use such as personal and commercial or on type of printing i.e. single sided or double sided. Small home embossers cost between $1000 to $3000 depending on single- or double-sided printing, but the paper itself can be fairly expensive. During a recent visit to Sierra Leone by members of our group, we found that in the entire country, there was only one home-grade single-sided printer available.

There are two further problems. Commercial grade printers are very large and difficult to move and invariably need support by sighted users. Secondly, where embossers output the pin-type Braille on paper, the durability is limited, therefore there are problems with preserving the material or re-using it multiple times. In such cases, thermoform embossers are required, which need expensive special paper.

a. Future Scope

The main concern for the future of Braille embossers is the cost, which at the current price point makes it practically impossible for non-institutional purchase in the developing world. In the short term, there is indeed a case for more institutional access to commercial grade printers at locations such as at public libraries, schools, etc, but long-term, there needs to be a significant leap in technology to make inexpensive embossers. The mechanics or thermodynamics of the two dominant approaches make it difficult without a quantum leap in technology to reduce the cost of Braille printing, but a few promising directions are emerging – at Northeastern University has experimented with a $200 embosser which replaces ink cartridges with motor operated embossing wheels. [11] Although this works very slowly at present (1 character per second), there is scope that such technologies may do better in the near future.

3.3.4 Braille Displays

Braille displays provide access to information on a computer screen by electronically raising and lowering different combinations of (usually nylon) pins in Braille cells. These are typically used in addition to audio output depending on individual preferences, though where the user is Deaf-Blind, these are the primary means of communication.

Most currently dominant Braille displays are in flat panel formats – thus they have a single panel of 40 or 80 cells in a straight line, which refresh as the user moves a finger along the material. Such panel-based Braille display devices rely on piezoelectric materials for pin actuation, thus each cell (of 8 dots) has specific dots raised or lowered depending on the character displayed. Because of the complexity of producing a reliable display using these materials that will cope with daily wear and tear, these displays are expensive and out of reach for many potential consumers. The cost of the Braille display also depends on the number of characters it displays at a given point in time.

An alternative to the panel display is the rotating-wheel Braille display, in which the Braille dots are placed on the edge of a spinning wheel. This allows the user to read text continuously using a stationary finger as the wheel spins round at a selected speed. As the Braille dots are set in a simple scanning style and the Braille characters are set by an actuator, the cost and complexity of manufacturing a unit is reduced greatly as compared to traditional displays. This is therefore unlike the panel format display, in which each cell has a cost associated with its fabrication of every individual pin, the rotating wheel. A potential direction ahead consists of low-cost hydraulic Braille displays using bendable actuators made with electro-active polymers.

a. Logistical Issues

Braille displays available on the market today range from $2000 to $15000 with popular brands such as Freedom Scientific's PAC Mate. Building low-cost Braille devices is not an optional addition to other existing technologies for the blind. The knowledge and use of Braille is essentially literacy for blind populations, and its use is shown to significantly increase employment opportunities. The use of Braille displays in addition to audio-based screen readers is already common among vision-impaired professionals in the industrialized world, it is by no means a luxury, rather an essential form of tactile communication that needs to be approached as a necessity for people with disabilities. Given this, if we take into account the cost of providing Braille displays to blind populations in the developing world, we find some fairly startling figures.

Hypothetically, if every one of the roughly 46,000 vision-impaired citizens in the nation of Niger, a signatory to the UN Convention (therefore committed to providing AT where needed), were given a computer with a Braille display (calculated at $2000 – assuming the user had a computer), it would cost the country about US$90 million at current prices, which would be about 1.0% of the country's entire GDP, roughly equivalent to its defense budget. Even for many of the larger developing countries, such costs mean that Braille displays are treated as rare luxuries rather than a necessity, as they arguably ought to be treated. Without efforts in research and development, the decline in prices may be too slow to reasonably fulfill the accessibility needs of the population in this generation.

b. Future Scope

Dielectric elastomers (DE) are a new direction in the development of tactile surfaces that may significantly reduce the cost of Braille displays. These electroactive polymers are smart material systems that basically transform electric energy directly into mechanical work [12]. DE have high elastic energy density but are also lightweight and can be used as electric actuators for refreshable Braille displays such as PolyBraille [13] and sheet type display panels[14].

The engineering of PolyBraille and sheet type display panels are interesting from the perspective of the future scope of materials usable for displays. PolyBraille uses a passive and an electrode polymeric membrane coupled by an incompressible fluid, serving as a Braille dot. When the lower electrode membrane is actuated, the dot is sucked in due to the incompressible fluid. The Sheet type display on the other hand uses a Nafion plate as an actuator which raises a semi spherical Braille dot when activated. These technologies are still premature and require a lot of refinement before they can be mass produced. However, they will significantly reduce the cost of Braille displays to 10% of that of the contemporary Braille displays.

3.3.5 Screen Magnifiers

Screen magnifiers can be analog devices that use lens to magnify a stationary object and thereafter project to a surface, or part of the digital software that controls the computer's graphical output. We are mainly interested in computer-based magnification, primarily used by people with partially functional vision. The most common magnifier is the windows magnifying glass which displays the area under the cursor, magnified on top of the screen. Screen magnifiers need to be adaptive to the users actions e.g. if a user open up a menu from a keyboard shortcut the magnifier focus should shift to the opened menu, ie recalibrate it to the area of a user's attention. The screen magnifiers enlarge content generally up to 16 times its original size customizable to the need of the user. Screen magnifiers have to use anti-aliasing to smooth out blocky areas of the enlarged content.

a. Logistical Issues

The main issue with magnifiers is the smooth operation of screen scrolling, and most commercial products are able to differentiate in the market based on these. On a magnified screen, the frame changes when the cursor is moved i.e. the magnifier tracks the cursor. If this tracking is too fast or too slow or jerky it may cause a mild discomfort to the user. Screen magnifiers range from $ 60 to $350. Zoomtext Express and Lunar are some of the leading screen magnifiers, but most Operating Systems have magnifiers integrated, making this less of a critical area for technology research for the developing world.

b. Future Scope

With magnifiers, we believe that the future scope lies mainly in innovative use of magnification or layering over other existing technologies. Due to the tracking problem in some magnifiers, there is much innovation on screen tracking -- recently a Nintendo Wii controller was used to track and magnify a remote screen. There are also add-ons of screen magnifiers to other devices such as hand-held devices to magnify images in different scenarios, such as product tags at supermarkets, labels, signs etc. Most popular models of such technology tend to be very expensive, though cellular phones may offer a potential low-cost alternative.

Research on low-cost devices fabricated like optical mice, with small inbuilt cameras to be placed over books to be read, and relayed to televisions. A great example is the cell-phone mounted image capture for financial transactions using small wooden cradles, used to capture images for microfinance transactions[15]. Cellular phones increasingly have very high resolution cameras and can be innovatively used as magnification devices – the Apple iPhone has a magnifier app that is available for US$ 0.99 online.

4. ACCESSIBILITY

Digital Accessibility is a cross cutting area that impacts each of the technologies above. From the use of certain file formats, to the use of colors, fonts, tables, embedded audio, images, 'Captchas', and meta-information, a range of decisions by web designers can adversely affect the accessibility of web content for people with various vision-impairments. In general, accessibility issues tend to be somewhat better represented in the developing world than many of the AT categories mentioned above, due to the existence of strong communities of practice – such as DAISY (Digital Accessible Information System) forums, which have enthusiastically taken on the task of presenting print materials in accessible formats in the developing world.

There are two aspects to accessibility that need immediate attention for the developing world. The first is the conversion of print materials to accessible formats, and the second is greater accessibility of the internet itself. On the first, we primarily have text and image formats. For text, technology has largely ceased to be a major issue for most of the industrialized world (with the exception of course of the language problem). Books are typically cut and processed through scanners, and using OCR, converted to DAISY or other accessible formats to be presented in audio or tactile outputs. The problem, per se, is intellectual property. For images, the issue is more complicated, although there are haptic devices that are beginning to create interfaces which display images for visually-impaired users, these are by and large not widely commercialized yet.

4.1 Web Accessibility

The issues of web accessibility are comparatively more complex because of the nature of interactive content and non-linear text. The problems with outputting text are similar to those discussed in the screen reader section – two additional layer of complexity here being the issues with bandwidth in the developing world, and the existence of online screen reading software. The second set of problems, with regard to the actual accessibility of content itself is much more complicated.

First, there are huge problems with compliance with major accessibility guidelines such as WCAG (W3C's Web Content Accessibility Guidelines)[2] among web content being created in much of the developing world. Research has shown that web design paradigms are significantly different for the developing world [16-17] and therefore the greater propensity to use images, animations etc, add a further layer of complexity to making online materials accessible. As a result, we have not only a legacy problem of inaccessible materials online, but also that of designers consistently adding new inaccessible content.

There are some tools that can help identify and rectify the accessibility problems in a website (W3C maintains an entire database of products such as WAVE, AccRepair etc) and even have tools to repair some of the problems. Such tools are increasingly sophisticated and handle an array of authoring programs including Flash applets, javascript, embedded video, etc. and function by browsing through existing web-based content and graphically pointing out the various errors in a page that need rectification.[3] Most errors tend to be related to graphical content and meta-data. It would be good practice for companies to make their web content pass through such tools to check for compliance, but this is rarely ever practiced, even in the industrialized world.

Most such services can only work at the level of non-interactive information. Making websites accessible requires significant undoing and re-doing, and therefore a huge human investment. Even setting aside compliance by private firms, just the task of making e-governance material in signatory countries of the CRPD accessible represents hundreds of thousands of man hours of work. There is a severe shortage of trained accessibility experts in the developing world, even countries like India that are considered software hubs lack a critical mass of companies and professionals specializing in accessibility. Given these legal trends, it is likely that the next few years will be a period of significant expansion of the web accessibility industry in the developing world, much in the same way that the ADA created a huge spike in the industry for Assistive Technologies in the United States. One likely direction, that has seen surprisingly little traction so far, is the use of crowdsourcing techniques to "clean-up" web content, using a combination of human and machine-learning techniques. Such work presents scientific and implementation challenges for the WWW community.

The awareness of accessibility issues among technology software and hardware manufactures in the industrialized world is already fairly high. This has included software companies providing accessible versions of their products (e.g. Avast! Anti-virus) to companies adding in accessibility options into their existing systems (e.g. Microsoft accessibility features) or rectifying past inaccessibility (e.g. Adobe Systems' Acrobat Professional with its read out options). Undoubtedly, the legal environment for accessibility compliance has been an important part of such actions.

The work of the DAISY consortium has been critical in the expansion of accessibility – there are a range of authoring and conversion tools now that allow material to be easily saved in the DAISY format, as well as hardware and software tools that allow for content to be accessibly outputted to the user as needed. A look through the tools available shows us that the problem here much as in screen readers as well, is tools for high quality output in new languages.[4] The expanding use of e-books has impacted the discussion on accessible content both because every new major title is being released by publishers in some digital format,

[2] The W3C launched the Web Accessibility Initiative in 1997 with endorsement by The White House and W3C members in order to make the web more accessible. The WAI has several working and interest groups that work on creating the guidelines, technical reports, educational materials and documents that are related to the various different components of web accessibility.

[3] http://www.webaim.org/

[4] http://www.daisy.org/tools/

and also because the devices themselves offer the possibility of audio format output. E-book readers are still at a price point too expensive for the developing world, but these can potentially be developed very inexpensively, and are arguably likely to transform the accessibility space in the near future.

Finally, given the possibilities of digital format files, there is also sufficient cause for development portable options such as low cost, easily navigated USB device interfaces that can be used as MP3 players to navigate through e-books or other material with appropriate upgrading of the files formats. Such devices could be easily put together, and also have the potential of turning away from the dominant paradigm in portable listening devices which tend to exclude rather than include people with visual impairments [18].

4.2 Mobile Accessibility

The growing ubiquity of mobile phones has opened up a range of possibilities for people with vision impairments. Two areas are of interest – one is navigation, wherein the overlay of locational identifiers such as GPS or RFID into smartphones allows a cellular phone or other basic mobile devices to act as a navigation or wayfinding device for the blind or deaf-blind [19-21]. There are a range of other technologies that also assist with wayfinding within restricted spaces including infrared signals[22] wherein encoded audio versions of textual signs are continuously transmitted by an infrared transmitter which can in turn be outputted in a format preferred by the user. Navigation options increase the possibility of using mobile phones to provide rich information about physical spaces, such as museum guides [23-24] using a combination of audio and vibration modes on the cellular phone.

The second area of interest is in the mobile phone itself serving as a screen reading and computing interface. Here, the ability of inexpensive mobile phones to store large amounts of data, and communicate with computing devices gives them all the possibilities that a mobile media player, or even an e-book reader would. Several devices like Voiceye's PC mate are usable as audio book readers, but also real time TTS readers and scanners. Such devices use 2-D barcodes to allow for a large amount of text information to be compressed into a single barcode, which can then be read into a device and relayed as audio data.[5] Newspapers in Korea have already started providing barcodes for accessible information in these formats, and this is now a national standard for the visually impaired. As memory gets smaller over time, such devices will continue to get smaller or better still, subsumed as software into existing cellular phones. In fact, research examining the preferences of visually-impaired users has found a that cellular phones as audio book listening methods were preferred to not only devices such as Voiceye and DAISY readers, but also the internet [25]. Nonetheless, the experience of Voiceye in South Korea is indicative of how a combination of how new technology and a policy initiative to create more accessible material for people with disabilities.

In short, cellular phones because of their low cost, navigational aids, and mobility have become a very important technology of promise for people with disabilities in the developing world. It is entirely possible in the next decade or so to see mobile-based devices playing an intermediate role as visually impaired populations' primary accessibility device in the developing world.

4.3 Open source options in the AT space

AT research in the developing world is fundamentally hampered by the fact that not a lot of folks working in this space are necessarily co-located, nor is there a significant institutional mechanism to allow for greater in-person collaboration. Evidence from the industry indicates that many of the developers of technology and software for the developing world tend produce expensive software, where collaboration from contributors is not always easy. This is particularly problematic in developing contextualized solutions that are relevant to the needs of small populations that may not have the wherewithal to purchase expensive software. It is here that open source software has the ability to dramatically increase the capacity of individual users and developers to contribute to software applications in the AT space. This can be particularly relevant to visual impairments, where the need for support for smaller languages is relevant. In the space of cellular phones, where open environments for application developers is already very common, the benefits of such an approach are already noticeable from the range of new development of AT tools for off the shelf mobile handsets. This is an important area of more detailed discussion.

5. AGENDA FOR EMERGING REGIONS

The United Nations Convention on the Rights of Persons with Disabilities (UN-CRPD) is an important starting point in the agenda on low-cost AT for the developing world, since it explicitly ties a number of signatory nations to providing adequately accessible conditions for their citizens, in an environment where such low-cost AT often does not exist.

As discussed, each of the individual technologies such as screen readers, screen magnification systems, and Braille displays are all expensive by themselves, and in most cases each piece of technology needs additional components that are also expensive. In some cases, there are make-do alternatives that can suffice in the short run – thus hand held magnification or scanning systems that communicate with an output device such as Voiceye are extremely expensive and possibly an ideal case scenario device, but the Windows OS comes with a free basic magnifier. Similarly, there are free screen readers, but these have a long way to go before they reach the functional capabilities of expensive preferred screen readers like JAWS or WindowEyes.

Indeed the reason for the products being expensive has inherently to do with the size of the market. Most companies that operate in this space do so with a fairly small client base, and spend significant amounts on research. For them, reducing the prices of these technologies is not entirely feasible in the short term. However, if we look back at the periods of significant drop in AT prices, we will find that these correlate with major legislation, such as the ADA, which by decree increased the size of the AT market, and thereby expanded the scope of companies in this space.

For the developing world, a first step agenda may be to build on the existing tools to polish them to the point of capabilities that would suffice for a high quality computing environment. In some domains, such as developing screen readers, a good share of the technical work can be accomplished through online collaboration

[5] http://www.voiceye.com/

by developers from around the world. This is also essential in new language support which we identify here as an absolutely critical area of technology development in the accessibility space. The use of online communities for corpus building and training, especially with TTS and Speech Recognition in new languages is going to be essential. Rather surprisingly, few of the existing labs in the developing world that work on multilingual systems do so with an open development architecture.

However, there are areas in which an open architecture may not suffice, and building teams of dedicated researchers will be necessary to impact the price point of technology. In the case of Braille displays, hardware is a very expensive, and we may need a quantum leap away from currently prevalent technologies such as piezoelectric materials to entirely new material configurations to create an order of magnitude cost reduction. This requires not only innovation in electronic and materials engineering, but also a broad support structure of collaborators working across other engineering and design disciplines. Thus, it is no surprise that most innovation with Braille displays has come from research labs or universities.

This challenge of attracting good university talent is reflected in the current geography of AT research. At present, the vast majority of such work takes place in the US, Western Europe, Japan, and South Korea. It is also critical that AT research is not conducted by engineers alone, but backed by a concerted effort in disability research. One is hard pressed to find social science research on the issues around vision impairment, or even disability generally, in the developing world.

Of greater concern is that such work rarely comes from researchers based in developing world. The community of disabled academics is itself very small, which in turn is a comment on the opportunities for higher studies for the disabled. There is little design or HCI research that examines the usability or appropriateness of existing AT in the developing world.

Establishing AT research in the developing world is going to be challenging given the overall shortage of institutional scientific research capacity. Building this capacity must be based on a significant long-term investment and a commitment from the state and higher educational institutions to reward research both academically and commercially.

AT and Accessibility represent a massive breadth of work – building expertise in speech synthesizers for new languages requires a very different skill-set from building automated wheelchairs of currency readers. The most successful AT research centers have typically had connections with university, and thereby tapped into faculty with a range of interests. These have also bridged the connection between academia and industry, but from a funding perspective have almost always been kick started by the state.

At one level, this is about an issue of creating an awareness of disability studies, which itself barely exists anywhere in the developing world. For all the policy-level discussions on assistive technology and disability, there are hardly any countries that can boast a school or college level course (or even single class) that discusses disabilities. At conferences for visual impairments in the developing world, participants frequently note that people in their home countries, including government officials, are shocked to find a blind person using a computer. If schools and colleges were talking about contemporary issues in disability and assistive technology, not only could we avoid such levels of ignorance of AT, but more importantly could get young students in engineering and social sciences interested in AT and building tools in this space right from an early age.

A facilitative environment for quality, well-rounded AT research may benefit from the confluence of a number of skillsets including academic departments in rehabilitative medicine, computer science, human computing interface research, usability, materials engineering, and in disability studies. It is also additionally valuable for such research to be conducted in near proximity to AT producing firms. There are very few AT Research organizations in the developing world that have a significant presence in the international research, One notable exception consists of work in Thailand [26]. At most international events, AT research in the developing world is typically represented by groups like Daisy Consortia, or by researchers working out of North America and Europe. This needs to change.

In an ideal case scenario, this would mean building a scenario where people can think of research as a career – from graduate studies onward either towards academic careers or industrial research positions. Given that the larger goals of building scientific research can be anything between very challenging to completely infeasible for a number of smaller countries, for the purposes of AT research there are three short-term possibilities.

First, a leadership role needs to be played in the larger among developing countries, such as Brazil, China, India, which have existing research institutions but also have a vast breadth of populations with disabilities living in varying economic or geographic conditions, many comparable to developing regions elsewhere in the world. A bulk of the technological elements of research can be conducted in some of these countries initially. Building such capacity can start small – it is certainly possible to adapt curriculum on AT and Accessibility for university classes alongside modest research centers for starters. It is both surprising and concerning that there are few courses on disability studies offered in universities in the developing world, and this can be changed at little expense. A small but active critical mass of young researchers can be created with very limited resource, and can contribute exceptional work in the short term, even where funding is scarce.

A model of accessibility reform was funded by the United States Department of Education that includes an 8 step approach towards implementation of accessibility reform. These include:

1. Gather baseline information
2. Gain top-level support
3. Organize a web accessibility committee
4. Define a standard
5. Create an implementation plan
6. Provide training and technical support
7. Monitor conformance
8. Remain flexible through the changes

Such models could be contextualized and adapted by other nations in order for to implement web accessibility reforms. A number of countries across the world have also taken varied measures for improving accessibility at the technology procurement process, and some countries have already passed legislation to make it legally binding for websites to be accessible. An interpretation of the CRPD could be for countries to require the same from web content originating within their borders, which in turn could have significant impacts not only on the availability of accessible material, but also on the social recognition of accessibility, and thereby of disability in the workforce.

Second, countries need to invest in user testing and social research. Every nation that has signed on to the CRPD must publicly commit to some resources towards social research on disability. For instance, there is scant data on the number of people with various kinds of vision impairments, their occupational characteristics, their use of AT and literacy in Braille throughout most of the world. Rich qualitative and quantitative research can not only offer a base for testing design, but also help build a base of information for national consciousness on social inclusion. For most research institutions building assistive technologies, finding appropriate field partners in the developing world is a constant issue, and as such collaborations are essential for more open and agile design for products. The existence of institutions also means a permanent home for disability research in country, thus helping move away from a paradigm of ‘parachute science’ in which researchers from industrialized contexts conduct field work in the developing world only to fly back with samples that in turn add no knowledge or capacity to researchers at on the ground in country.

Finally, people with vision impairments must be organized. Several studies have shown that one of the critical problems for people with vision impairments in participation in the economic and social sphere is social isolation, especially in the period following the end of institutional education [27]. While there is a critical need for greater integration of people with disabilities in society, there is also a need for creating active forums through which people can voice their opinions, concerns, and organize as a group. In line with inclusive design principles, now widely accepted in the HCI community [28], we recommend that AT projects are built with input from the user population, with the eventual goal that this population will develop technologies for its own use.

6. CONCLUSIONS

The ICTD community is founded on the fundamental principle of ‘activistic’ design and development in areas where market forces have failed communities that technology can benefit. In the case of Asssistive Technologies and Accessibility, the case is clear – it is time for the ICTD community to step up.

The goal of low-cost AT is one that is relevant not just to the developing world, but for low-income populations with vision impairments throughout the world. The adoption of the UNCRPD has already established a very significant business case for AT, but outside of the business and social equity reasons for why this is a good domain of interest, there is also the case of AT presenting a range of very challenging and interesting research problems that will need innovative work to solve. In addition, there is also very good professional case for pursuing research in this space. Practically each category of AT for persons with vision impairments discussed above, there is a need for innovation and multi-disciplinary work by researchers with expertise working with new technology adoption, and with interface design.

The increasing use and widespread access to cellular phones is an important development that holds promise for AT use in the developing world, since most new cellular phones are coming with in-built accessibility features for vision-impaired users. While the developments with cellphones are indeed encouraging, the scope of work to be done remains massive. As we note here, the challenges with screen readers, low-cost Braille displays, and language support remain of critical importance and will need considerable immediate interest from research in the developing world.

As recent research has shown, the issue of visibility of people with disabilities in the public sphere remains a major concern, especially when users of AT join the workforce in white collar positions alongside sighted computer users [29]. Indeed, Assistive Technologies represent a very small area within the broader issues of equitable access in the social and economic spheres. However, there is much reason for hope that the investment into AT will both set the stage for international recognition of prevalent lack of accessibility throughout much of the world, and increase access for people with visual impairments across professional careers. For a community typically invested only in the engineering aspects of accessibility, many of the social aspects of disability discussed here may seem outside of the typical scope of such a venue. But the fundamental cross-disciplinary nature of the issues inherent in creating a more accessible public sphere dictate that accessibility in the technological sphere cannot be separated from the range of intertwined social concerns that must be recognized simultaneously.

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