Braille to Go Smartphone

An open-source hardware and software platform for the visually impaired and the blind

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Abstract

Recent innovations in the mobile technology have enabled feature-rich and affordable smartphones and tablets, which have revolutionized the way we are interacting with the world. However the visually impaired and the blind have not had access to such affordable mobile technology. The Braille to Go (b2g) is an open-source, Android based smartphone with a Braille interface, designed and developed from the ground up to address this issue. This paper presents a detailed overview of the prevailing problems and how we came up with the b2g to overcome them.

Why make a Smartphone for the blind?

Portable computational devices have come a long way since its inception. Together with the effects of Moore's law and advances in software technology, these devices are now more powerful, cheaper and more useful than ever before. The demand for such devices too has been increasing steadily as a result. Now at the end of 2013, the sale of smartphones is expected to exceed that of the traditional feature phones [1]. This growth in the demand for mobile hardware is also reflected in the mobile application industry, which was valued at 25 billion dollars at the end of 2012 [2]. This industry is continuously innovating to find new and creative ways to leverage the underlying hardware to provide solutions and services for the masses. In some cases such as with Twitter and Facebook, these applications have moved beyond simply being just another service, to being an integral part of modern culture [3]. The implications of this revolution are that, now most people have a wealth of services at their fingertips at anywhere and at any time. These services span a vast gamut and include such services categories like,

- Communication services including telephony, messaging and video conferences
- Utility services like calculators, notetakers and calendars
- Audio/Video capture and photography
- Internet services
- Navigation and positioning services
- Digital content consumption services (audio, video and text content)
- Games and augmented reality applications
- Omni-channel services including banking, retail and governance

While this technological and social revolution was unfolding, one demographic was continually overlooked and disenfranchised; they are the visually impaired and the blind. The reason behind this is due to the simple fact that these modern mobile devices are virtually unusable without the aid of sight. This status quo is quite unfortunate because a modern smartphone like device for the blind would have been tremendously beneficial and would have possibly even been life changing.

Some of the possible key benefits include,

- To improve language literacy by providing easy access to reading material
- To bridge the digital divide between the visually disabled and abled.
- Using it as a feature rich navigation and positioning device
- To read printed material via Optical Character Recognition (OCR)
- To quickly access public information such as weather and transport timetables via internet services

The list of possible uses is truly limitless and it has the potential to significantly improve their quality of life by empowering them to live autonomously.

In addition to the social welfare reasons for empowering the blind, there are also economic reasons for doing so. An educated and autonomous blind person can contribute to the economy by both producing and consuming goods and services and more importantly by not having to depend on the magnanimity of others [4].

Even with the aforementioned reasons for developing a smartphone like device for the blind, the options remain scarce. There are some specialized devices in the market that do attempt to cater to the needs of this community, but they tend to be expensive and have limited functionality. Examples of such are the generic Braille notetakers which cost around $4000 to $4500. Even at $4000 these devices are more analogous to feature phones than modern day smartphones. While they can feature advance functionality like music playback and web browsing; they do so through proprietary/closed operating systems and 1st party software. As such they are limited in their functionality, expandability and ultimately in their usefulness as well.

The reason for this plight is purely a financial one. It simply doesn't make financial sense for OEMs (Original Equipment Manufacturers) and for software developers to accommodate the needs of this small demographic. The clientele's population is small with limited purchasing power; the required research and development cost is high and return on investment period is too long.

Another approach to get smartphones in the hands of the blind is to adopt existing touchscreen based smartphones. This saves the costs associated with developing custom hardware and instead relies on software solutions to make the phone as accessible to the blind as possible. While this approach does give the blind some features and services that would have otherwise have unattainable, the user experience is quite jarring and very inefficient.

The bottom line is that the majority of the 300 million visually impaired and blind people in the world [5] remain deprived from being able to access information in today's society where information is one of its most valuable commodities. An affordable smartphone like device designed for them could help eradicate this problem for many, but market forces have so far prevented the development of such a device.

Defining the ideal phone

Goals

The ideal device to empower the visually impaired and the blind would have the following features,

1. Ease of use

This is an obvious requirement and is largely influenced by the input and output interfaces on the device.

2. User experience that is comparable to a modern smartphone

Modern smartphones offer a multitude of functionality with limitless potential to expandable upon. A comparable experience would be ideally expected in a device designed for the blind as well.

3. Standardized API/SDK to provide 3rd party applications and services

The success of modern mobile operating systems such as Android and iOS is largely because of the availability of "killer" applications from 3rd party developers. This was made possible because these operating systems have relatively simple to use SDKs/APIs that allow creative developers to easily develop and distribute their software. A device designed for the blind would also have to provide such support for its 3rd party developers so that it too can have its killer applications. Allowing 3rd party applications also eases the burden on the OEMs to develop a software suite to expose the device features; hence reducing the device cost.

4. Must be significantly less expensive than the current offerings

As mentioned previously, a multifunctional Braille notetaker cost in the region of $4000. But in order for a smartphone like device to benefit the majority of the blind population it must be priced similarly to a comparably mass produced smartphone. Given the economic constraints mentioned in the previous

section, a smartphone for the blind can't be developed and sold for such a low cost and still remain profitable.

Choosing an input and output (I/O) interface

The options for blind friendly I/O interfaces are,

1. Touch screen with explore-by-touch and text-to-speech

Modern smartphones have been made partially accessible with the use of explore-by-touch and text-to-speech services. However this approach is less than ideal. Entering text for example, is especially inefficient using this method.

2. Braille keypad and display

Most Braille notetakers have a compact Perkins style keypad and a refreshable Braille display[1] [6]. For the Braille literate, this interface offers and easy to use and very efficient way to interact with a device. Some other added advantages of a Braille interface are,

I. Multilingual support

Braille characters can be used to represent most world languages and therefore a device with a Braille interface can be easily adapted to work with most languages.

II. Promoting Braille

For the blind, knowing Braille is literacy and there is a proven correlation between literacy and lifetime achievement among the blind [7] [8]. Therefore there is a strong case to promote Braille.

Making it Affordable

There are two possible solutions to overcome the pricing issue,

1. Sell the devices at a subsidized rate with funds from governments, NPOs (Non Profit Organizations) and charities

While this approach is feasible there is a significant cost burden on the entities that pay for the subsidy. Such a venture would be very hard to sustain especially in lower income countries and during economic down terms.

2. Follow an open-source hardware model

This is a similar approach to the one taken by other community focused projects such as the Arduino project [9]. With this approach, there would be a onetime cost to develop the basic hardware/software and to setup a development ecosystem. The hardware and software would then be released into the public domain and a community of volunteers would contribute to further develop the product.

The open-source hardware approach is the most financially viable long term solution. This is the best course of action to keep device costs down and also has the added benefit of making the applications for it free. Open hardware also allows for easy customizations and upgrades. It also encourages modding and tinkering and could help to improve the technology literacy of the blind.

Considering the success of other such open accessibility projects like the “eyes-free” project [10] and because of the charitable nature of a project to build a smartphone for the blind, it is also quite conceivable that such a project would attract a large long term volunteer developer community [11].

Choosing an operating system

The ideal phone for the blind would support one of the more popular mobile phone OS (Operating System), which are

- Android
- iOS
- Windows Phone / RT

Support for an existing and popular OS is important because

1. There is already an established application ecosystem already in place
2. To encourage and to make it easier for developers to write software for the device
3. Reduces the effort required from the OEM to bring up the device and thus reducing the cost

Windows Phone and RT have very limited accessibility support. iOS and Android offer a lot more options including,

- Text-to-speech
- Haptic feedback
- Gesture navigation
- Screen reader services

[1] A refreshable Braille display is an electromechanical device for displaying Braille characters, usually by means of round-tipped pins raised through holes in a flat surface.

- Support for Bluetooth Braille keypads and displays

Android expands on these features to add,
- Trackball and directional-pad navigation
- Support for external HID input devices

Using these features, any typical Android or iOS device could conceivably be used by a visually impaired or a blind user. One of the major positives with Google's solution is that it takes minimum effort from the application developer's end to make their software accessible. As a consequence most blind or visually impaired people find most 3rd party applications usable with the aid of these accessibility services [12].

There are however some drawbacks with both these operating systems,
- Entering text via a touch keypad can be very inefficient for a blind person even with the accessibility features enabled. Similarly using text-to-speech to figure out an application layout can be time consuming.
- A possible solution to the above mentioned issues is to add an external Braille keypad and display. But external Braille keypad and displays are very expensive; usually in excess of $3000. They would also reduce the device's portability and battery life.
- It is impossible for the user to identify intermediary device states such as,
    - While booting
    - While shutting down
    - Charging while shut down

This is because the screen reader services are not available during these states.
- The display timeouts and the power button can be confusing to the blind
- The notification indicator LED is not perceivable
- The screens on these devices are serving no functional purpose and is simply draining the battery and increasing the Bill of Materials (BoM) cost and weight of the device

If we take the open-source hardware aspect into consideration, both iOS and Windows have some considerable drawbacks.
- Both are closed source
- Supports limited number of processors and SoCs (System on a Chip). In iOS case it only supports proprietary SoCs
- Limited support for customizing device components

Android on the other hand is open source and has support for a lot of hardware components. In addition it has the largest market share and the best accessibility support.

Realizing the goals

Considering all the aforementioned factors, it can be deduced that the best course of action is to build a smartphone that features,
- Hardware that is comparable to modern smartphones
- Follows an open-source hardware model
- Form factor of a traditional Braille notetaker
- Support for Android

The b2g

Overview

Figure 1: Braille to Go (b2g)

The non-profit organization "National Braille Press" (NBP) [13] with its goal of empowering the blind through literacy recognized the need of a smartphone for the blind and collaborated with the technology solutions partner Zone24x7 Inc. [14] to realize such a device. Under the NBP's visionary guidance and financial backing, Zone24x7 Inc. designed and developed the device which was christened "Braille to Go" (b2g).

The b2g was conceived as an open-source hardware project for the reasons aforementioned and it strives to be the catalyst of a greater open community based ecosystem.

The b2g was designed from the ground up to address the many drawbacks associated with adapting a regular smartphone for the blind. It forgoes the traditional smartphone form factor, design vocabulary and instead incorporates many innovative hardware and software features that vastly improve its usefulness and accessibility to the visually impaired and blind. It is one of the most technologically advanced multifunctional devices designed for the blind.

The b2g brings a feature rich smartphone experience to the blind by seamlessly integrating a Braille keypad and display in the place of a standard touch sensitive display; much like a traditional Braille notetaker. In effect, the b2g merges modern smartphone features and functionality with the form factor of a typical Braille notetaker. It also features a stack of custom software ranging from kernel drivers to Android services which coherently interfaces the standard Android UI with the Braille hardware.

The b2g runs Android 4.1.2 (Jelly Bean) with a custom screen reader service that interprets what is on the display and outputs it to the Braille display. This screen reader service leverages the latest accessibility support features introduced in Android. A visually impaired user would use this screen reader output together with the integrated keypad to interact with and to navigate to and from most Android applications. Any Android application that can be interpreted by a screen reader will be usable on the b2g. This constitutes the overwhelming majority of applications that are on the Android market, including the most popular 3rd party applications such as Skype, Viber etc.

Feature Overview

The main objective of the b2g is to improve the quality of life of the visually impaired and the blind by giving them an easy to use, multifunctional and portable device. To that end it includes the following hardware features in Table 1.

Features	Specification
Processor/Memory	1GHz ARM Cortex-A8 processor with 512MB RAM[2]
Display	20 cell Braille Display
Keypad	9 key Perkins style Braille Keypad (8 dot cells + spacebar) 2 keys for Forward/Backward functionality 5 position Navigation Ring

[2] Upgradable to 1GB

Other Keys	Reset Button Dedicated volume control keys Dedicated Keypad disable slider switch
Connectivity	Wi-Fi 802.11 b/g/n Bluetooth 2.1 Voice and Data HSPA+ (DL 14.4Mbps, UL 5.76Mbps) Quad-band GSM/GPRS/EDGE
Audio	Hi-Fi Audio codec Built-in stereo speakers Built-in microphone 3.5 mm 4-pole audio connector
I/O Ports	USB OTG micro AB port USB host port (Type A Receptacle) Composite video out port
Storage	Internal 512MB NAND[3] Expandable internal micro SD card slot: up to 32GB External SD card slot: up to 32GB
Camera	5 MP camera with dual LED flash
Navigation/ Sensors	GPS Compass 3-axis accelerometer
Battery/Power Management	Rechargeable 5900 mAh Lithium battery Charging via USB OTG port Stand-by: Up to 146 hours Talk time: Up to 8 hrs(3G) / 12 hrs(2G)
Body	Dimensions: 205mm x 112mm x 28mm Weight: 550g
Other Features	Vibrator OTA updates for firmware and file system

Table 1 : Feature List

[3] Upgradable to 1GB

In addition to the above listed hardware features, the b2g includes numerous other software and design features that strive to effectively interface the b2g with the visually impaired.
These features include,

- Ergonomic display and key layout, designed to be used without the aid of sight
- Support for special Android command keys (e.g. Back, Home) via keypad shortcuts
- BrailleBack (Android screen reader service) support for the integrated Braille display
- Keypad enable/disable slider switch instead of the standard power button
- Masked display timeout functionality from the end user
- Smart power management features that extend battery life.

The b2g also includes all the modern Interoperability features that come standard on most other smart devices, including features such as,

- File transfer with a host computer via USB mass storage
- USB-OTG support for mass storage and HID devices
- USB host support for mass storage and HID devices
- File transfer via hot-swappable SD card slot
- File transfer via Bluetooth
- Audio playback and control via Bluetooth
- Support for Bluetooth HID devices
- Wi-Fi hotspot and Wi-Fi direct support with internet tethering

The b2g supports all standard Android security and privacy features, including features such as file encryption and screen lock passwords. There is an additional inherent layer of privacy provided via the Braille display, which unlike touchscreens protects its content from the gaze of passersby.

Innovations and Unique features

1. Open hardware design

The b2g is the first open-source hardware Android device for the blind. For an open hardware project to be successful, It must appeal to as wider audience as possible. Special consideration was made during the b2g's design phase to realize this. The following are some of the considerations that were made and some resultant features.

- Component selection criteria
  - Worldwide availability of stock
  - Availability of support documentation
  - Mainline Linux kernel support
  - Regulatory compliance (Federal Communications Commission, etc...)
  - Balancing cost and quality
  - Reliability and stability

- Modularized layout

The b2g features a modularized component layout, which provide the following benefits,

- Easily enable/disable modules

  This feature lets the b2g's design to be effortlessly customizable by allowing various components to be easily enabled or disabled to meet the requirements of various markets.

- Upgradability

  Modularization allows individual components to be easily upgradable when needed.

- Swappable 3G modem

  The b2g supports mini PCI express based cellular modems. This allows the b2g to support multiple carriers from around the world and it also allows it to be easily upgradable to support newer technologies in the future with only minor changes to software and hardware.

2. Power management

- Keypad enable/disable slider switch and intelligent suspend

Another unique feature of the b2g is the addition of a slider switch which is used to lock/unlock the device via enabling or disabling the integrated keypad and display. This slider switch replaces the standard power button found in a typical Android device. The power button is a mandatory design feature of Android and is primarily used to wake up or to put the device into sleep. While the device is in sleep, it would attempt to consume the least amount of power by power gating components or by running them at slower speeds. A typical Android device would include a display timeout of about 1 minute in order to automatically turn off the screen and further improve battery life.

However, an automatic display timeout can be counterintuitive to a visually impaired user, since the device state is not easily perceivable to them.

In an attempt to mitigate this, the b2g always leaves the display and keypad enabled if the keypad enable/disable switch is on the enable position. The b2g would still automatically enter lower power states after a display timeout just like any other Android device. The b2g is able to do so by using a secondary low power companion processor that drives and buffers the display and keypad while the main processor is in sleep. This companion processor also behaves as a smart power button by intelligently emulating power button presses to the Android system while masking the actual power state of the device from its users. As far as its users are concerned, the b2g works while the slider switch is at the enable position and is inactive otherwise, but the b2g will still covertly timeout and enter a power saving mode just like any other device.

3. Ergonomics and Usability

- The Braille display

  The b2g uses a high quality 20 character Braille display from Metec [15]. The Metec display was selected on the basis of its durability and is the single most expensive component in the BoM. Because of the b2g's open design, it is not limited to only supporting this particular display. An OEM may easily opt to replace the display with another.

  One of the major drawbacks of using a regular Android device with accessibility services provided to drive an external Braille display is that the screen reader services only work when Android services are running. Therefore a blind user would be oblivious to what is being displayed on the screen in some instances such as,
  - While booting, including bootloader error messages
  - While shutting down
  - Charging while shut down

  To address this drawback the b2g uses its companion processor to display useful information during these instances.

- The Braille keypad

  The b2g integrates a custom Braille keypad. The keypad area includes the standard 9 key Perkins style Braille keys, D-Pad and 2 keys for "Forward" and "Backward". The key layout was designed to optimize the ergonomics of both children and adults. The b2g also includes dedicated volume up and down buttons.

- Low button count

  One useful feature that the visually impaired look for in, an Android phone is dedicated hardware buttons for the back, home and menu keys. However, such hardware buttons are unnecessary for the b2g because of the integrated Braille keypad. It instead implements easy to remember keypad shortcuts to emulate the dedicated keys functionality.
  There are a couple of reasons not to add dedicated keys,
  1. Increasing the button count has the potential to needlessly complicate matters for the average blind user. This is because the users would have to remember the functionality and the position of the more buttons.
  2. It is more ergonomic for the user to enter the special keys via keypad shortcuts instead of finding and pressing dedicated keys.
  3. Saves space

  To support keyboard shortcuts, the b2g implements "Chorded keys" via key buffering on the companion processor. Chorded keys are the key commands issued by pressing any combination of Braille dot keys together with the space bar.

  In an attempt to further improve usability, special attention has been taken to make the keyboard shortcuts as obvious and easy to remember as possible. In addition, most of Android's optional special keys were implemented. Some examples chorded key commands,
  - Back key = b + space
  - Menu key = m + space
  - Delete = d + space

- Search = f + space

- Custom screen reader

  A screen reader is any piece of software that attempts to identify and interpret what is being displayed on the screen. This interpretation is then re-presented to the user via multitude for methods such as, text-to-speech, audio icons and Braille displays. Android added support for screen readers to output to external display devices with the introduction of Android 4.1 (Jelly Bean). The b2g includes a custom screen reader service to work with its integrated Braille display.

- Hi-Fidelity audio

  With the loss of sight, visually impaired and the blind tend to be more sensitive to audio quality. Thus to enhance their user experience the b2g includes a high fidelity Wolfson [16] audio codec and powerful stereo speakers.

- Usability testing

  The "Center for Braille Innovation" (CBI) at the NBP worked closely with the development team throughout the b2g's design and development stages. The CBI consisted of some prominent individuals that work closely with the blind. They had a good understanding of the features a typical blind user would need and their suggestions had a significant influence on the final design. Features like the keypad enable/disable slider switch, multi-key rollover support and the masked display timeout were a result of their recommendations. This focus group also tested device prototypes and provided their feedback during the various stages of development and prototyping.

- Composite Video output

  The video out on the b2g allows it to be connected to an external display device. This allows the visually abled to interact with this device for such occasions such as when to provide technical assistance. It is also useful at Blind schools, were the visually abled teachers can assist their students using external displays. A composite video interface was specifically chosen because it requires the minimum effort to setup and because it is the most common interface at blind schools.

- Remote monitoring and configuration

  A probable drawback of moving to a modern OS like Android is that there is a possibility for the blind users to get easily overwhelmed by its many options and configurations. To enable remote assistance for such occasions, the b2g includes a secure custom remote monitoring and configurations service. It supports the ability to remotely configure, update and even to remotely lock and wipe the device if needed. It also makes it possible for technical support personnel to easily diagnose and fix issues.

The b2g Ecosystem

The b2g device itself is only the catalyst of what will eventually be a community driven ecosystem. With the initial hardware and software release, the foundation will be laid for an open source community to step in and continue to contribute to the development of both the hardware and software. Much like other successful open-source hardware projects like the Arduino project, the b2g's hardware and software is expected to evolve with the contributions of its community so that its features and performance will remain relevant for the foreseeable future.

The b2g doesn't implement any custom Android APIs and doesn't require any special effort from developers to make use of the integrated display and keypad. Developers need only to conform to general Android accessibility development guidelines. Therefore most applications that are already in the Android Marketplace will work with the b2g's display & keypad and likewise applications that will specifically be targeted for the b2g will work on any other Android device as well. The implications of this are that both commercial developers and the open source community will be able to easily develop applications for the b2g.

The b2g ecosystem will finally shift the responsibility of application development in the accessibility device space from the device OEMs to 3rd parties. This has the potential to encourage more innovation in applications since 1st party applications rarely do so. As such, with the ecosystem continually driving innovation in both software and hardware, the blind may ultimately have access to a affordable yet fully functional and feature rich smartphone that will

finally empower them and bridge the technology divide between the visually abled and disabled.

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