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Designing Usable Touch screen Text Entry Interface for Visually Impaired People

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Visual impairments affect more than 2.2 billion people worldwide, significantly limiting essential daily activities such as reading and writing on touchscreen devices. This study introduces the EzAccess Keyboard, a specialized text-entry method designed to address interaction challenges for partially sighted and low-vision users. A mixed-method research approach was adopted, including a survey of 50 visually impaired smartphone users to identify design requirements and a comparative evaluation against 16 existing techniques. Quantitative performance analysis showed that the EzAccess Keyboard achieved a typing speed of 5.00 WPM and a mean accuracy rate of 95.20%, representing the highest reported accuracy among compared specialized QWERTY and several Braille-based interfaces. Numerical benchmarking indicates that while EzAccess maintains a competitive speed comparable to systems such as key-magnified keyboards (5.28 WPM) and TypeHap (5.96 WPM), it significantly outperforms established baselines such as Conventional Tap/TalkBack (2.97 WPM, 75.83% accuracy) and BrailleTouch (85.00% accuracy). Statistical validation via the Mann–Whitney U test confirmed performance parity with the state-of-the-art TypeHap system, revealing no significant difference in typing speed (p=0.287) or accuracy (p=0.909). Furthermore, Z-score standardization positions the proposed method above the mean reported in the literature for speed (Z=+0.31) and nearly one standard deviation above the mean for accuracy (Z=+0.99). Qualitative evaluation using the System Usability Scale (SUS) produced a score of 93.9 out of 100, indicating excellent usability and strong user satisfaction. These findings demonstrate that utilizing user-centric affordance principles can significantly enhance typing performance and digital inclusiveness for the visually impaired population.

Keywords: Touch Screen; Visually Impaired; Keyboard Layout and Interaction Techniques.

Introduction:

Visual impairments and eye diseases are a significant challenge for many people worldwide, affecting over 2.2 billion individuals according to the World Health Organization (WHO). These conditions can have a profound impact on daily life activities such as reading and writing, making it challenging for visually impaired individuals to lead independent and self-sufficient lives [1][2]. Furthermore, as smartphones have become the predominant computing device, the inability to master mobile text entry—the core skill required for digital interaction—can deepen existing social, cultural, and economic exclusion [3]. While assistive tools exist, many rely on audio feedback which compromises user privacy in public and fails in noisy environments [3]. This is particularly critical in low-income regions where the accessibility rate for assistive products is as low as 3%, leaving hundreds of millions at higher risk for depression and social isolation [3].

Assistive Technology for Visually Impaired Persons:

Assistive technologies (AT) are essential tools that enable visually impaired persons (VIPs) to access information, interact with their environment, and perform everyday tasks more independently. Defined as products that maintain, improve, or enhance functional capabilities, AT has evolved from conventional hardware solutions to smartphone-based applications, smart canes, wearable devices, and more advanced Intelligent Environments (IE) and Ambient Assisted Living (AAL) systems incorporating intelligent vision systems, smart wearables, and location-aware technologies such as RFID tags and Bluetooth beacons [4][5]. Despite these technological advances, nearly one billion people worldwide continue to face barriers in accessing these essential assistive products [5].

Among the many activities supported by AT, reading and writing remain among the most fundamental yet challenging tasks for visually impaired users. Although dedicated hardware solutions have been developed to facilitate text entry, the widespread adoption of smartphones and touchscreen devices has shifted the focus toward software-based mobile solutions. Existing Bluetooth-enabled assistive keyboards still require users to carry additional hardware and are often prohibitively expensive [6]. However, mobile text entry on touchscreen devices remains challenging because standard touchscreens lack tactile feedback, forcing users to rely primarily on audio feedback or speech-to-text technologies. These approaches can compromise privacy in public settings and reduce situational awareness by masking important environmental sounds [7][8]. Consequently, there is a growing need for efficient non-auditory text-entry techniques, including haptic feedback and gesture-based interaction, to improve accessibility and promote digital inclusiveness for visually impaired users [8].

Text-Entry Methods for Visually Impaired Persons:

To address the text-entry problem, screen readers for virtual keyboards on smartphones were introduced [9][3]. This text entry method was convenient but still did not resolve all the issues faced by the visually impaired in text entry; in order to enter a specific character, the user needs to place their finger on letters one by one to listen to them until they reach the required character, a process that is frequently slow, laborious, and frustrating [10]. Furthermore, this heavy reliance on audio feedback creates significant barriers, as it compromises user privacy in public spaces, carries a social stigma, and is often ineffective in noisy environments [3][8].

Researchers proposed many different solutions, but these solutions were mainly focused on completely blind people and not on people with less visual impairment [10][11][12]. Consequently, recent research has begun to shift toward addressing the specific functional needs of "low vision" users through innovations such as layout-magnified gesture typing and silent, phoneme-based haptic feedback systems [8][10]. These newer approaches aim to promote digital inclusiveness by providing accessible interfaces that leverage haptic or visual cues rather than sound, ensuring that text entry remains private and functional across diverse everyday contexts [13][14].

Usability in Text-Entry methods for Visually Impaired Persons:

Usability is a critical factor that determines how easy it is to complete a specific task on any software system, and its misalignment with user capabilities often leads to high abandonment rates [14]. Most of the proposed text-entry methods have been evaluated quantitatively in terms of words per minute (WPM) but lack qualitative testing in terms of usability [15]. To address this gap, modern research increasingly incorporates standardized qualitative frameworks such as the System Usability Scale (SUS) to evaluate user perceptions [10] and the USE (Usefulness, Satisfaction, Ease of Use) questionnaire to assess user-friendliness and satisfaction [7]. Furthermore, perceived cognitive workload is now frequently captured through the NASA-TLX scale to ensure that non-auditory interfaces do not impose excessive mental demand [8].

Khan and Khusro (2021) identified several issues regarding usability in mobile applications and text-entry methods for visually impaired persons and concluded that the usability of such software can be improved using different usability heuristics and guidelines [4]. Recent advancements have expanded these guidelines to include affordance theory to connect design features more explicitly with the functional capabilities of the user [14]. Additionally, new evaluation metrics such as mode-switching time and switch-key movement time have been introduced to more precisely measure usability when hands-free interaction or multi-mode keyboards are involved [16].

This research study makes the following key contributions:

Developed the EzAccess Keyboard, a user-centered smartphone text entry solution specifically designed for partially blind and low-vision users.

Identified user requirements through a comprehensive survey, ensuring the keyboard design was based on the real needs, challenges, and preferences of visually impaired users.

Proposed practical design guidelines for accessible smartphone text entry, emphasizing customizable interfaces, larger touch targets, multimodal feedback, and simplified interaction.

Improved smartphone text entry accessibility and usability by incorporating accessibility features such as adjustable keyboard size, high-contrast themes, customizable layouts, and enhanced text editing.

Validated the proposed keyboard through a standardized usability evaluation using the System Usability Scale (SUS) with visually impaired participants, providing reliable and comparable usability evidence.

Research Aim & Objectives:

This research aims to explore the existing text entry methods for people who are visually impaired and the work done in existing text entry methods regarding qualitative and quantitative testing. And to design a usable text entry method for visually impaired (VI) people. Research Aim To design a usable text-entry mechanism for visually impaired people to improve the user experience in touch screen interfaces [12][15][4]. Following research objectives are designed to achieve this aim.

To understand the needs and expectations of visually impaired (VI) people for text entry in touch screen interfaces.

To identify and extract guidelines to design usable text entry mechanisms for impaired (VI) people.

To design a usable text entry mechanism for visually impaired (VI) people in touch screen devices.

To evaluate the proposed text entry mechanism and compare it with existing text entry methods for visually impaired people using qualitative (usability/user experience) and quantitative (WPM and accuracy) measures.

Research Motivation:

The primary motivation or drive to conduct the research on the chosen subject was Assistive technology required to improve the daily activities of people with visual impairments due to the massive increase in eye diseases and visual impairments. Despite the many AT solutions that have been suggested, text entering is still difficult, especially for people with less severe visual impairments. Screen readers for Smartphone virtual keyboards have been introduced, but usability testing for these systems is lacking. The goal of this study is to quantitatively and qualitatively assess the text-entry techniques now in use and to provide a workable solution in terms of usability for those who are visually impaired. The goal of the study is to identify problems with text entry for people who are partially visually impaired and to create a more user-friendly solution that will increase their independence and self-sufficiency.

Research Process:

The research involved conducting a thorough literature review to gain insights into the available text entry methods for visually impaired individuals, their limitations, and the guidelines to design more user-friendly text entry mechanisms. The evaluation of existing text entry methods will be done by employing qualitative and quantitative measures, such as user experience, speed, and accuracy. Additionally, a survey will be conducted to identify the issues and requirements of visually impaired users. Based on the outcomes of the survey and literature review, a new text entry method will be developed. The effectiveness of the proposed method will be assessed by conducting user-based usability testing using both qualitative and quantitative methods.

Material and Methods:

Related Work:

This section presents the existing text entry methods available for visually impaired people. Text entry is a critical aspect of using smartphones, and it is even more challenging for visually impaired people who cannot completely rely on their sense of sight as there is only a touch screen display to enter text using a virtual keyboard and no physical buttons/keys to feel and identify. This limitation poses a significant challenge for visually impaired individuals to efficiently and effectively communicate through text-based messaging applications. To overcome this challenge, many different text entry methods on Smartphone and touch screen devices have been introduced for visually impaired people in the past literature. The proposed text entry methods differ in their level of complexity and suitability, and their effectiveness varies depending on the individual's level of visual impairment. A wide range of text entry methods have been studied and implemented, including speech recognition, Braille input, and touch-based interfaces. This literature review examines and analyzes the various text entry methods available for visually impaired people. Ultimately, this literature review aims to provide a comprehensive understanding of the various text entry methods that have been proposed for visually impaired individuals and to inform the development of future accessibility-focused technologies. To give a better idea about these text entry methods these methods are divided into two categories, 1. Braille text-entry methods, 2. QWERTY/Other text-entry methods.

Braille text-entry methods:

Oliveira et al. (2011) present a new approach to enabling visually impaired individuals to communicate through braille using touchscreen mobile phones [17]. BrailleType offers a promising solution to the challenges faced by blind individuals when using touchscreen devices. By incorporating the familiar Braille cell layout and leveraging the benefits of touch screens. This text entry method was mainly designed to avoid the multi-touch features used by some other techniques. Users can select a single braille dot with one touch and after selecting every braille dot it will give an audio confirmation to the user. It also includes gestures such as a double tap for confirming after selecting every braille dot and a swipe gesture to remove the selected braille dot [17]. Shaking the mobile changes languages and switches between entering numbers and alphabets. Too many operations put a high cognitive load.

Mascetti et al. (2011) propose TypeInBraille, a new typing technique for blind users to input Braille characters. This typing method divides the screen into two rectangles per row of the Braille cell and defines intuitive gestures. The system optimizes commonly used characters, reducing the number of gestures required and enhancing typing speed. Flick gestures, such as the one-finger right flick for character completion and the one-finger left flick for undo/delete operations [18]. Too many gestures for entering and editing teoperations, difficult to remember all gestures for these operations making it complex for the user and can be considered a drawback of this typing method.

Frey et al. (2011) introduced BrailleTouch, a text entry method designed for the visually impaired. The authors state that conventional touchscreens and keyboards are inaccessible to individuals with visual impairments, and therefore, this project aimed to develop an alternative solution that would allow such individuals to send text messages efficiently and independently. The BrailleTouch application was developed using the standard six-dot braille code, which allowed users to input text by tapping on the touchscreen with a combination of fingers [6].

Nicolau et al. (2015) propose a system called "Holibraille" which uses multipoint vibrotactile feedback to simulate the sensation of Braille on the user's fingertips [19]. The input method relies on braille touch [6] and uses a vibrotactile motor to provide vibrotactile feedback [19]. Overall, BrailleTouch is an effective alternative to conventional hardware keyboards for individuals with visual impairments. However, BrailleTouch should be used by the users at a distance from their face while holding the screen away from the face makes it very uncomfortable for the users the evaluation of this method was performed with participants who were trained professionals and have good knowledge of braille code that might affect the results.

Azenkot et al. (2012) aimed to improve non-visual text entry for users with visual impairments [20]. The authors proposed a system called "Perkinput", which uses touch screens to enable text entry without visual feedback. Perkinput adopts the dot-to-finger mapping as Perkins Braillers for two- handed input, where fingers 1, 2, and 3 correspond to dots 1, 2, and 3 on the left hand, and dots 4, 5, and 6 on the right hand. For one-handed input on small screens, two touches are required to enter a Braille character. Reference points are established through long presses, and Perkinput employs a Gaussian touch point distribution for ML detection. Swipes are used to represent characters like spaces and backspaces, while a one-finger swipe indicates a blank Braille column. Perkinput also introduces the concept of two-device input, where two Bluetooth-connected touchscreen devices are used simultaneously to input Braille characters into a primary device. The left-hand inputs dots 1, 2, and 3 on one device, while the right-hand inputs dots 4, 5, and 6 on the second device. The primary device decodes the multi-point touch information received from the secondary device to determine the entered character. Reference points are registered on each phone, and character decoding follows the same principles as standard Perkinput. Learning and mastering the Perkinput method may require a significant amount of time and effort. Users need to become familiar with the Braille encoding system, IFD mapping, and the various gestures associated with the input method. This can be challenging for individuals who are new to Braille or have limited prior experience with tactile input methods the cognitive load associated with remembering gestures can impact accuracy and user experience. Additionally, the lack of standardization across platforms may affect interoperability [20].

Sˇepic´ et al. (2015) present a novel solution for individuals who are blind or visually impaired to input text on their smartphones using only one hand. Traditional braille keyboards require the use of both hands, which can be cumbersome for individuals with limited mobility. The proposed BrailleEasy keyboard allows users to input text using a one-handed, chord-based input method. But the main challenge in this technique is that it has some specific reference points that can identify the user's finger location and in order to type using this method user first need to locate the reference points and this makes it difficult to use [21]. Only some specific reference points can identify the user's finger location and in order to type using this method user first needs to locate these reference points.

Mattheiss et al. (2015) present a novel technique that utilizes the edges of a touch screen to create virtual Braille keys for users to input text [22]. The method involves the use of swipe gestures to simulate Braille key presses, allowing users to input text without having to rely on an external keyboard or a physical Braille display. To evaluate the proposed method authors compared it with braille type and perkinput and other braille text input methods. However, different problems and limitations like not being able to edit text and not being possible to draw the lines for characters as it can only be used to type alphabets and numbers and deactivating dots decreases the input speed of the input method [22].

Alnfiai et al. (2016) introduced SingleTapBraille [23]. User selects the dots on the keyboard in sequence 1-4-2-5-3-6. And when the user stops entering dots, it will enter the letter. Users can do swipe operations to add space or the next line. No fixed locations were defined in this method which might make it difficult to use for blind people as they won't be able to remember where they tapped for the first dot and No evaluation with real-time users raises questions about the usability of the method [23]. The user must enter dots at fixed coordinates after entering the first dot in order to enter a character. It also limits the characters that can be entered by the braille method as a single tap anywhere on-screen will always add the letter 'A'.

Siqueira et al. (2016) Introduced BrailleEcran [24]. The application is designed with three columns to facilitate vertical finger sliding without the need for horizontal sliding. It provides feedback through vibrotactile and audio cues. The "Text box" displays the typed message and serves the purpose of assisting visually impaired users in communication with sighted individuals. The "Confirm" button has multiple functions, including confirming letters typed in the braille cells, inserting spaces, and deactivating the keypad. The "Send Message" button allows sending messages or canceling the sending process. The "Delete" button can delete letters or clear the display. Each point in the braille cells can be activated individually, and multiple points can be activated simultaneously [24]. Dividing the screen into multiple columns takes too much of the screen leaving a small area for the input fields and making it very difficult to use while holding the phone vertically.

Soonyong et al. (2018) Introduced SBraille a mobile braille input method that utilizes both tap and swipe gestures on the touch screen of mobile devices. It is designed to be operated with one hand, using the thumb for input. SBraille allows users to create their own baseline by swiping from the bottom of the screen to a diagonal direction, adapting to individual thumb positions. Four types of input methods are supported: touching the left or right side of the area divided by the baseline, swiping up, or swiping down. Each input method corresponds to different combinations of braille dots. On average, it takes three gestures to input six dots of braille [25]. The reliance on swipe gestures and the need for multiple gestures to input each braille character may slow down the typing speed and make it difficult to use for visually impaired people.

Alnfiai et al. (2017) Introduced BrailleEnter text entry method that addresses navigation challenges and promotes one-finger interaction. The keyboard offers functions for typing small and capital letters, numbers, and punctuation, as well as editing options such as adding spaces and using backspace. To type using BrailleEnter, users employ braille shapes with one hand. Each character is represented by a combination of activated and inactivated dots, organized in two columns and numbered from one to six. Users can distinguish between characters based on the number and order of activated and inactivated dots. BrailleEnter utilizes two types of gestures: a press gesture (long tap) to represent active dots and a tap gesture (brief tap) to represent inactive dots. Users need to perform six taps or presses on the touchscreen to input a letter. The specific location of the interactions is not crucial, as users can tap anywhere on the screen for inactivated dots and press the activated dots at any position [26]. However, the user must enter all Braille dots for each pattern, even when only one dot is needed and Complex operations to insert raised and unraised dots.

Li et al. (2017) introduced the BrailleSketch text input method. It enables individuals with visual impairments to sketch Braille codes on a touchscreen. Users input a Braille code by performing a gesture that connects the desired dots. For example, to input the letter 'N', the user would place their finger anywhere on the screen to input the top left dot, drag their finger to the right for the top right dot, drag downwards for the dot on the right side of the middle row, and drag diagonally downwards for the dot on the left side of the bottom row. Once the finger is lifted, the letter 'N' is recognized. BrailleSketch allows users to sketch the code in a way that feels most natural to them, provided that all the intended dots are included in the drawn path. To assist users in perceiving their sketches accurately, BrailleSketch provides audio feedback. A 1000 Hz sine-wave sound is played when a new dot is adjacent to the previously added dot in a horizontal or vertical direction, while a 200 Hz sine-wave sound is played for dots in a diagonal direction. This feedback helps users identify incorrect inputs. The system reads aloud the entire word after the user completes it with a space, following the idea that providing feedback after typing a word, rather than after each letter, can increase typing speed. Immediate audio feedback ("no") is provided if the sketched gesture cannot be recognized as a letter [27]. However, the system does not support real-time correction while drawing the gesture, requiring the user to delete and retype the incorrect gesture.

Subash et al. (2012) Introduced BrailleKey. BrailleKey uses a mapping system that assigns specific functions to the four discernible corners of the screen. The lower two keys are used for deleting and entering individual characters, while the upper two keys serve as dot-marking buttons for the left and right dots of a braille character. Tapping a button activates the first dot, double tapping activates the second dot, and a long press activates the third dot. This mapping allows for all six dot combinations to be created using single taps, double taps, and long presses. Once the necessary taps are performed, pressing the enter button inputs the letter onto the screen. A double tap of the enter button inputs a space character, and a single tap of the delete button deletes the last entered character. To replay the typed content, the user can press the volume key on the top of the phone, and the application will read out everything that has been typed [28]. However, only four keys on the whole screen and the use of multiple gestures increase the cognitive load on the user and may affect the performance.

Guerreiro et al. (2008) introduced BrailleTap. BrailleTap is a text-entry method designed for blind users, which utilizes the familiar Braille alphabet. The method transforms the functionalities of a mobile phone keypad to align with the Braille alphabet's structure. In the Braille alphabet, letters are formed using groups of six dots arranged in a 3x2 cell. By mapping this cell onto the keypad of a mobile phone, specific keys are assigned to represent each dot. [29]. However, due to the multi-step process of entering each letter, pressing multiple keys to represent the dots in a Braille cell and then confirming the letter with another key requires a lot of steps, potentially impacting the overall efficiency of text entry.

Voutsakelis et al., (2024) introduced a "Haptic Braille Keyboard" that allows users to customize their experience by dragging and dropping virtual buttons to create personalized layouts [7]. The researchers compared a traditional Perkins Brailler layout (horizontal) with a modern two-group layout where the device faces away from the user. The traditional layout was found to be difficult to operate while standing or moving, while the modern layout presented a steep learning curve. Furthermore, the evaluation primarily used blindfolded sighted participants, which may not fully represent the qualitative experiences of visually impaired persons (VIP). While this study offers a specialized keypad, its reliance on simulated blindness fails to address the unique usability requirements and authentic user experience (UX) of actual VIPs in everyday mobile contexts.

De Carvalho et al., (2026) addressed the "app-silo" limitation of previous Braille prototypes by redesigning Braille Écran as a native Android Input Method Service (IME) [13]. This allows VIPs to use Braille input across all system applications rather than being restricted to a single app. The study remains a technical proof-of-concept for its dual-mode interaction model, with the research into its hybrid tactile-digital interface still in its very early foundational stages. Although it improves efficiency through system-wide access, the study prioritizes technical architecture over the qualitative usability testing needed to ensure the keypad is truly user-friendly for diverse VIP profiles.

QWERTY/Other Text-Entry Methods:

Bonner et al. (2010) proposed a multi-touch keyboard and No-look Notes. It was designed similarly to the keypad of old mobile phones, dividing the screen into 8 sections and each section contains a set of multiple characters. First, the user selects the section that contains the desired character, then all the characters are displayed to the user then the user can select the desired character from the list of characters [30]. The results show a significant increase in typing speed over voice-over; however, the users complained about fatigue as the users need to locate the character in 8 sectioned menus and the double operation to enter a character.

Tinwala et al. (2010) proposed a gesture-based keyboard for visually impaired people. The user can draw a character or alphabet using a finger on the touch screen device when the user finishes drawing the character on screen the keyboard then identifies the character if it is identified successfully the character is added to the text after audio feedback and if the character is not valid user is alerted with a short vibration. For the purpose of error correction algorithms for exact or approximate text matching were used. The keyboard was evaluated based on text-entry speed based on words per minute [31]. Mainly the gestures defined by developers can be substantially different from the gestures drawn by blind or visually impaired people [15][32]. Audio feedback at the word level raises some privacy issues.

Guerreiro et al. (2008) introduced NavTap. The NavTap text-entry method is a mobile phone keypad-based approach that enables users to navigate through the alphabet and input text. The alphabet is divided into five lines, each starting with a different vowel, and the keypad's number 'key '5' serves as a reference point, and a cursor can be mapped on the keypad using keys '2', '4', '6', and '8'. Users can navigate in all these rows using multiple vertical or horizontal gestures on the keyboard for top, left, bottom, and right navigation. In addition to these navigation gestures audio feedback is also provided to the user [29]. However, multiple gestures for navigation make it difficult to use for visually impaired users.

To support low-vision users, Zhang et al, (2024) designed layout-magnified and key-magnified keyboards. They utilized a kinematics-based decoder to accommodate unique VIP input behaviors, such as "wiggling" and inaccurate starting positions. The study focused exclusively on users who can see keys with a magnifier, thereby excluding those with severe impairments who require non-visual solutions. Additionally, the lack of support for multi-segment gestures means users must delete and restart a word if they lift their finger prematurely. This method fails to provide a fully "accessibility-inclusive" solution for the entire spectrum of visual impairment and does not yet optimize long-term UX for users who struggle with spatial context on magnified screens.

Yim et al., 2025 developed a TypeHap system that delivers phoneme-based haptic cues via piezo actuators on the smartphone's sides, paired with a tactile screen overlay to help users identify QWERTY rows without audio. Evaluation showed that the mental demand was initially high, and the system lacks support for essential characters such as punctuation, symbols, and numeric inputs. Despite proposing a specialized keypad aimed at privacy, the high cognitive load and incomplete character support represent significant usability barriers that hinder the overall user experience and efficiency in complex textual interactions.

Wan et al., (2024) explored hands-free multi-type character entry in Virtual Reality (VR) using eye blinks and dwell times for selection, combined with head-crossing for mode switching [16]. The study did not evaluate common mobile text entry scenarios like emoji use or "all-caps" word strings. Additionally, device ergonomics (such as key size and distance) were not fully explored as independent variables. The complexity of head-crossing and blink selection may impede usability compared to a dedicated physical or virtual keypad, as the cognitive effort required to manage four different modes can diminish text entry efficiency.

Komninos, (2023) developed a simulator named, RoboType, that evaluates keyboard layouts using synthetic participants modeled on human finger kinematics, allowing researchers to simulate user archetypes like those with tremors [11]. The current version is limited to index finger entry and does not simulate the visual attention switching or error observation behaviours characteristic of real-world users. This research demonstrates that even modern theoretical models fail to fully capture the qualitative UX and usability factors required to design a specialized keypad for actual visually impaired users.

Research Gap:

Despite the existence of numerous text entry methods introduced in the past, a significant research gap persists in the field. Specifically, there is a pressing need for a better-designed layout that caters to the text entry needs of visually impaired individuals. While substantial work has been conducted on text entry methods for blind people, there is a lack of corresponding methods tailored specifically to individuals with lesser visual impairments. Unlike blind people who heavily rely on audio feedback, individuals with lesser visual impairments often prefer alternative approaches due to inherent drawbacks associated with audio feedback, including reduced privacy and difficulties operating in noisy environments. The accuracy of text entry holds more importance than its speed. Additionally, users should be made aware of any automatic actions performed by the text entry method to maintain a sense of control and prevent potential errors [12]. This research gap highlights the need to develop novel and improved text entry methods that address the unique requirements of visually impaired individuals, thereby enhancing their overall user experience and efficiency in textual interactions. An overview of existing literature is given in Table 1.

Table 1. Overview of Related Work on Text Entry Methods for VIP

Reference	Aim	Research Design	Contributions	Limitations
[7]	To assess the usability of two Braille layouts (Perkins vs. modern two-group) for smartphone applications.	Developed a "Haptic Braille Keyboard" app with customizable drag-and-drop buttons; tested with 47 sighted (blindfolded) and 11 blind participants using the USE questionnaire.	Proved that blind users prefer the classic desktop-style layout for stability, while blindfolded users preferred the modern two-group layout.	Relied heavily on simulated blindness; small blind sample size (N=11). Reliance on blindfolded sighted users fails to capture authentic user experience (UX) for real VIP in mobile contexts.
[13]	To enable system-wide Braille input on Android devices	Redesigned "Braille Écran" as a native Android Input Method Service	Established an extensible, open-source framework for hybrid tactile-	Research into the hybrid interface is still foundational and proof-of-concept.

	beyond individual application "silos".	(IME); introduced a "Connect" mode using heuristic algorithms.	digital interfaces and system-wide Braille accessibility.	Prioritizes technical architecture over the qualitative usability testing required for diverse user profiles.
[10]	To make gesture typing accessible for low-vision users who use screen magnifiers.	Designed layout-magnified and key-magnified keyboards with a kinematics-based decoder to handle "wiggling" and inaccurate starts.	Key-magnified keyboard improved typing speed by 27.5% over conventional gesture typing for low-vision users.	Excludes users with severe impairments who cannot use magnification; decoder lacks multi-segment gesture support. Not fully accessibility-inclusive for the entire VIP spectrum; users struggled with spatial context maintenance.
[8]	To enable private, non-auditory text entry using phoneme-based haptic cues delivered via phone sides.	Created "TypeHap," a hardware add-on with piezo actuators and tactile screen overlays; evaluated via 4-day training with 11 BLV participants.	Achieved speeds and accuracies comparable to standard audio feedback; participants reported increased confidence in public spaces.	High initial mental demand to interpret haptic patterns; lacks support for punctuation, symbols, and numbers. Significant cognitive load and incomplete character support hinder broad usability in complex interactions.
[16]	To explore hands-free multi-type character entry (letters, symbols, numbers) in Virtual Reality (VR).	Evaluated eye blinks, dwell selection, and head-crossing for mode-switching across four layouts using 24 participants.	First hands-free multi-type VR keyboard; introduced new metrics for mode-switching and switch-key movement time.	Complexity of head/eye actions may increase workload; did not account for device ergonomics (e.g., key size). High cognitive effort to manage four keyboard modes diminishes overall text entry efficiency.
[11]	To provide an open-source simulator (RoboType) for evaluating keyboard layouts using synthetic users.	Python-based simulator using Fitts' Law and stochastic touch modelling to simulate diverse user archetypes (e.g., those with tremors).	Allows rapid traversal of the design space and reproducible benchmarking without the cost of physical recruitment.	Currently limited to index-finger entry only; does not simulate visual attention switching or error observation. Theoretical models still fail to fully capture the

				qualitative UX factors required for specialized keypad design.
[33]	Tont physical tactile graphics with location-specific AI audio feedback for VIP children.	Developed "TactileGuide AI", using smartphone cameras to track pointing gestures over tactile materials.	Demonstrated higher short-term learning gains for children compared to static Braille descriptions.	Specific to image-based exploration; semantics are pre-defined by the recognized graphic regions. Not designed for active text entry; highlights the need for broader semantic support in assistive tools.
[14]	To provide design principles for digital inclusiveness using affordance theory.	Synthesis of AIT prescribes through a systematic review and the application of affordance theory.	Developed an affordance-cantered framework connecting technological features (modality selection, minimalist actions) to user capabilities.	Theoretical principles require further broad empirical verification across multiple devices. Directly supports your goal by identifying "minimalist reusable actions" as a core usability principle.

Problem Statement:

Despite the proliferation of diverse mobile text-entry methods for visually impaired persons (VIPs), recent studies reveal a systemic lack of focus on qualitative usability and authentic user experience in their design and evaluation [3]. Most existing solutions are assessed primarily through quantitative metrics, such as words per minute (WPM), but fail to adequately address the high cognitive workload and privacy barriers inherent in current audio-reliant interfaces [3][8]. This misalignment between assistive design features and the actual functional capabilities of VIPs often results in high technology abandonment rates [14]. Consequently, there is a critical need for a specialized, accessibility-inclusive keypad that integrates usability heuristics and affordance principles to optimize textual interaction efficiency and enhance the digital inclusion of the visually impaired population [14][7].

Overview of the Proposed Solution:

This section provides an overview of the proposed solution to address the identified problem in the field of text entry methods for visually impaired individuals. The problem statement indicates that while numerous text entry methods have been introduced for this population, recent studies have highlighted a lack of emphasis on usability within these methods. Recognizing the need for an effective and user-friendly text entry mechanism for visually impaired individuals, the proposed solution aims to design a specialized keypad tailored specifically to the needs of this user group. The goal is to enhance the overall user experience, improve usability, and optimize text entry efficiency for visually impaired individuals.

Research Questions:

RQ1: What are the needs, expectations, and challenges of visually impaired people when performing text entry on touchscreen devices?

RQ2: What usability and accessibility guidelines should be considered for designing an effective text entry mechanism for visually impaired people on touchscreen devices?
RQ3: How do existing text entry methods for visually impaired people compare in terms of qualitative measures (e.g., usability and user experience) and quantitative performance metrics (e.g., text entry speed in words per minute (WPM) and accuracy)?
RQ4: How does the proposed text entry mechanism compare with existing text entry methods for visually impaired people in terms of qualitative measures (e.g., usability and user experience) and quantitative performance metrics (e.g., text entry speed in words per minute (WPM) and accuracy)?

Proposed Methodology:

Different text entry methods were compared using both quantitative and qualitative measures as shown in Figure 1. A comparative analysis between the proposed technique and existing techniques will also be conducted. First, the problems and limitations of current text entry methods for visually impaired people will be identified through a comprehensive literature review. Subsequently, a cross-sectional survey of visually impaired smartphone users will be conducted to investigate their text entry practices, usability challenges, privacy concerns, and expectations regarding touchscreen text entry. The findings of the survey were analyzed to identify user requirements and derive design guidelines that will complement the findings from the literature review. Next, comparative testing of existing text entry methods will be performed using both qualitative and quantitative evaluation metrics to establish a baseline for comparison. Based on the findings from the literature review, survey, and comparative analysis, a new text entry technique will be designed and implemented. The proposed text entry method will then be evaluated through qualitative and quantitative testing with visually impaired users. The results obtained from testing the proposed method will be compared with those of the existing text entry methods to determine its effectiveness. Quantitative evaluation will be conducted with visually impaired participants to assess improvements in text entry performance, including speed and accuracy. Additionally, usability testing of the proposed method will be carried out in three iterative design cycles, with each iteration involving three to five visually impaired users, to progressively refine and improve the design based on user feedback before the final comparative evaluation was conducted.

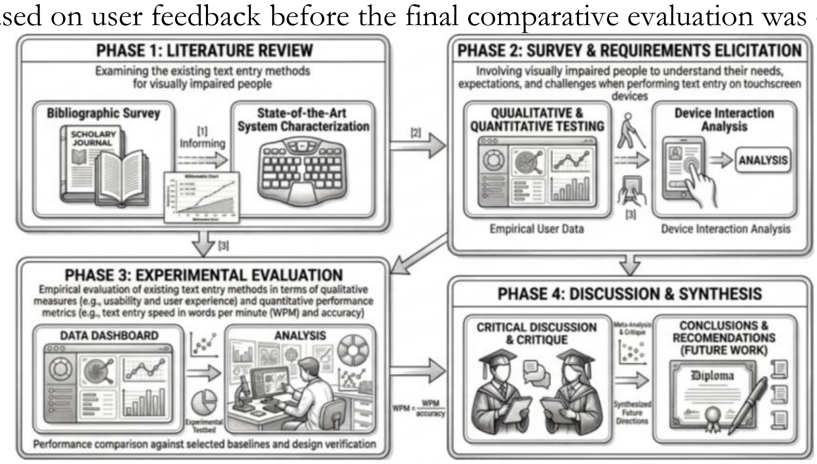


Figure 1. Research Flow

Survey for Visually Impaired People:

This section aims to present the rationale and methodology behind conducting a survey on text entry methods among visually impaired and low-vision individuals. This population uses a variety of text entry methods, and people frequently look for one that closely matches their own requirements and is easy to learn and easy to use. The lack of direct user feedback in the development of such text entry methods, however, highlights a significant research gap, according to the body of existing literature. Past studies have primarily relied on previous research to propose text entry methods, without explicitly consulting the users to ascertain their preferences and requirements. Consequently, to address this limitation, we undertook a comprehensive survey to gather insights directly from visually impaired and low-vision individuals. The survey aimed to uncover their needs and desires pertaining to a text entry method that would better accommodate their unique circumstances. By directly involving the target users in this study, we sought to bridge the gap between theoretical proposals and the practice of user-centered design in the realm of text entry methods for visually impaired and low-vision individuals.

Type of Survey:

A cross-sectional survey design was adopted to collect data from visually impaired (VI) smartphone users at a single point in time. This design was considered appropriate because the study aimed to investigate the existing text entry practices, usability challenges, privacy concerns, and user expectations regarding touchscreen text entry mechanisms without examining changes over time. The cross-sectional approach also provided an efficient and economical means of gathering data from a diverse population of visually impaired users.

Target Population and Sampling:

The target population consisted of blind and low-vision individuals aged 15 years and above who regularly used touchscreen smartphones for communication and text entry. Participants had prior experience using at least one smartphone text entry method, such as a QWERTY keyboard, speech-to-text, Braille keyboard, or gesture-based typing.

A purposive sampling technique was employed to recruit participants who satisfied the predefined inclusion criteria. Since visually impaired smartphone users represented a specialized and relatively difficult-to-reach population, snowball sampling was also adopted by requesting participants and organizations serving visually impaired individuals to refer other eligible participants. A total of 50 visually impaired participants successfully completed the survey and were included in the final analysis.

Inclusion and Exclusion Criteria:

The inclusion criteria required participants to be diagnosed with blindness or low vision, be at least 15 years of age, regularly use a touchscreen smartphone, possess prior experience with smartphone text entry, and voluntarily agree to participate in the study.

Participants without visual impairment, individuals who had never used touchscreen smartphones, respondents unable to provide informed consent, and incomplete survey responses were excluded from the analysis.

Questionnaire Design:

A structured questionnaire was developed following an extensive review of the literature on assistive technologies, smartphone accessibility, and text entry methods for visually impaired users. The questionnaire was designed to gather information on the text entry practices of visually impaired smartphone users, the usability challenges they encounter, their privacy concerns regarding speech-to-text, and their expectations for improved text entry mechanisms.

The questionnaire comprised seven sections covering demographic information, smartphone usage patterns, existing text entry methods, usability challenges, privacy concerns, desired keyboard features, and participant suggestions. Demographic questions collected information such as age, education, type, and severity of visual impairment, while the remaining sections explored participants' smartphone usage, current text entry techniques, typing difficulties, preferred keyboard features, and design recommendations.

To obtain a comprehensive understanding of user needs, the questionnaire incorporated multiple question formats, including categorical, multiple-choice, frequency-based, five-point Likert-scale, and open-ended questions. This combination enabled the collection of both quantitative and qualitative data, allowing the identification of user requirements and design guidelines that subsequently informed the development of the proposed accessible text entry mechanism. The questionnaire link is provided in Appendix A.

Instrument Validation and Reliability:

The questionnaire was reviewed by experts in Human–Computer Interaction (HCI), accessibility, and assistive technologies to establish content validity. Based on the experts' feedback, ambiguous questions were revised and the overall structure of the questionnaire was improved.

A pilot study was subsequently conducted with a small group of visually impaired users to evaluate the clarity, readability, completion time, and usability of the questionnaire. Minor modifications were made before administering the final survey.

Data Collection Procedure:

Data were collected using a questionnaire-based interview approach. During each interview session, the moderator (researcher) verbally presented the structured questionnaire to the participants, explained any questions when necessary, and recorded their responses directly on the questionnaire. This approach was adopted to ensure that visually impaired participants could fully participate in the study. The survey link was distributed through educational institutions and organizations supporting visually impaired individuals. Participation was voluntary, and informed consent was obtained from all participants before data collection commenced. No personally identifiable information was collected to ensure participant anonymity and confidentiality.

Data Analysis:

The findings obtained from both quantitative and qualitative analyses were subsequently synthesized to derive a comprehensive set of user requirements and design guidelines that directly informed the design and development of the proposed text entry mechanism.

Ethical Considerations:

At the start of the survey, participants were informed about the purpose of the survey, its objectives, the voluntary nature of their participation, and the intended use of the collected data. Informed consent was obtained from all participants before they completed the survey. No personally identifiable information, such as names, email addresses, or contact details, was collected to preserve participant anonymity and privacy. All survey responses were treated as confidential, securely stored, and used exclusively for academic research purposes. The data collected were analyzed and reported only in aggregated form to ensure that no individual participant could be identified.

Survey Execution:

The survey was initially designed to be administered online using Google Forms to facilitate broad participation through organizations and online communities supporting visually impaired individuals. However, during the initial stage of data collection, it became evident that the online approach yielded a limited response rate, primarily because many potential participants preferred not to use smartphones for extended activities beyond essential communication, while others were reluctant to provide information through an online platform.

To improve accessibility and participant engagement, the data collection strategy was subsequently adapted to a questionnaire-based face-to-face interview approach. During these sessions, the moderator verbally presented each questionnaire item to the participants, clarified questions where necessary, and recorded their responses directly on the questionnaire. This approach ensured that participants could comfortably complete the survey irrespective of their level of visual impairment and maintained consistency in data collection across all respondents.

The questionnaire-based interview approach resulted in a higher response rate and provided comprehensive insights into the text entry methods currently used by visually impaired individuals, the challenges they encounter, their privacy concerns, and their expectations for improved smartphone keyboard features. These findings subsequently informed user requirements and design guidelines for the proposed accessible text entry mechanism.

Analysis & Results of Survey:

This section presents the results and key findings of the survey conducted to investigate the text entry experiences of visually impaired individuals using smartphone devices. A total of 50 participants with diverse educational backgrounds, age groups, and levels of visual impairment participated in the study. The majority of the participants (68.42%) were college or university students or graduates, while the remaining 31.58% were high school students or graduates. Participants ranged in age from 15 to 55 years. Regarding the severity of visual impairment, most participants (57.9%) reported a high level of visual impairment, followed by 26.3% with moderate impairment and 15.8% with low impairment, as illustrated in Figure 2.

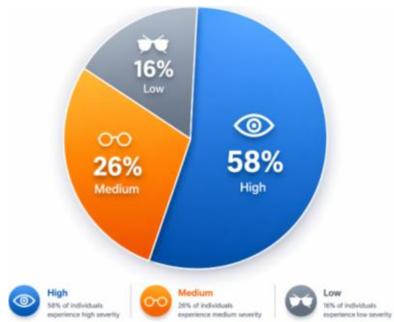


Figure 2. Severity of Visual Impairment

The smartphone usage pattern among the participants indicated that 47% were high-frequency users, followed by 32% who reported moderate usage and 21% who reported low usage, as illustrated in Figure 3.

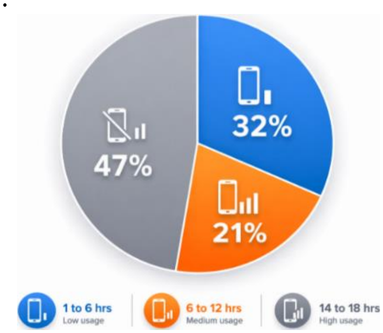


Figure 3. Smartphone Usage

The frequency of typing text messages and emails using smartphones among the participants is presented in Figure 4.

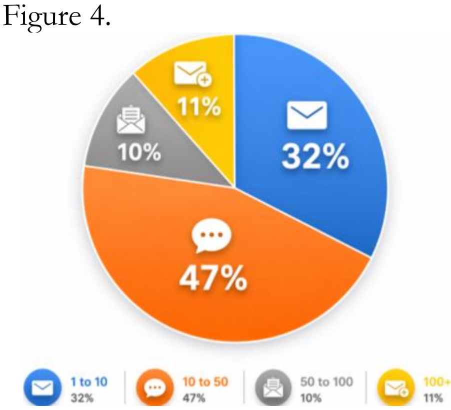


Figure 4. Email/Messages per Day

All participants who reported using speech-to-text as their primary text entry method expressed privacy concerns regarding its use. The most frequently reported concerns included the possibility of other people overhearing sensitive information, such as passwords and account details; exposure of private conversations with family and friends; and the risk of speech being misinterpreted due to background noise in public environments. Several participants also indicated that they preferred using text-based input methods instead of speech-to-text when communicating in public places.

The survey results further revealed that the QWERTY keyboard was the most commonly used soft keyboard among the participants, whereas only a small proportion reported using Braille keyboards or alternative text entry methods, such as character-drawing techniques. These findings indicate that QWERTY-based keyboards were the most commonly used among the surveyed participants. The distribution of the keyboard types used by the participants is presented in Figure 5. Regarding usability, 42% of the participants reported experiencing some difficulty while using their current text entry method, whereas the remaining participants indicated that they experienced little or no difficulty during text entry.

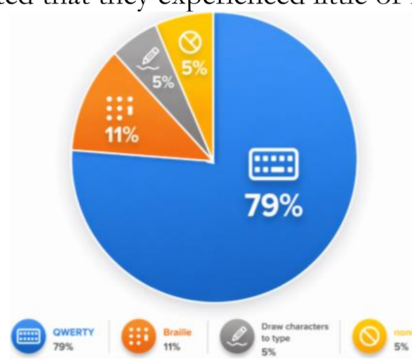


Figure 5. Keyboards Used.

The majority of respondents (73.68%) reported experiencing one or more difficulties while typing text on smartphones. The most frequently reported problems included editing previously entered characters, keyboard latency, poor text clarity, and general difficulties in operating the keyboard. Most participants (68.42%) identified several positive aspects of their current keyboards. The most appreciated features were ease of use and swipe typing. Other commonly preferred features included keyboard customization (e.g., changing colors and backgrounds), emoji support, responsive typing, and audio feedback on key presses. However, 10% of the participants indicated that they did not find any feature of their current keyboard particularly useful. Participants were also asked to identify features that should be incorporated into future smartphone text entry methods for visually impaired users. Their responses highlighted several recurring design requirements. Participants emphasized the need for a more user-friendly interface with larger keys, a more intuitive keyboard layout, easier text editing (e.g., an undo function), improved language-switching capabilities, and greater customization options, including configurable colors, backgrounds, and audio feedback. Several participants also recommended incorporating haptic feedback, increasing the contrast between the keyboard background and text, and providing greater spacing between keys to improve typing accuracy and accessibility. These findings were subsequently translated into the design requirements for the proposed accessible text entry mechanism.

Design and Implementation of the EzAccess Keyboard:

Visually impaired and low-vision users often encounter significant challenges when using conventional touchscreen keyboards due to the lack of tactile feedback and accessibility features. To address these challenges, a user needs assessment survey was conducted to understand their text entry practices, usability issues, privacy concerns, and expectations for an accessible text entry mechanism. This chapter presents the design and implementation of the proposed EzAccess Keyboard, which was developed by incorporating the requirements and preferences identified through the survey.

Design Considerations:

The design of the EzAccess Keyboard was guided by the findings of the user survey and supported by evidence from the literature on accessible text entry for visually impaired users. The survey identified several recurring user requirements that directly influenced the keyboard design. Participants emphasized the need for a more intuitive and user-friendly interface, larger keys to improve touch accuracy, simplified text editing, and greater customization options. Participants also highlighted the importance of configurable visual themes, including adjustable colours and backgrounds, as well as multimodal feedback through configurable sound and vibration on key presses. In addition, participants recommended improved key spacing, high-contrast visual elements, and a more intuitive keyboard layout to facilitate faster and more accurate text entry. These user requirements were systematically translated into the design features of the EzAccess Keyboard, ensuring that the proposed solution addressed the usability challenges identified during the survey while improving accessibility, efficiency, and the overall user experience for visually impaired smartphone users.

Implementation:

Based on the survey findings and the derived design requirements, the EzAccess Keyboard was developed to address the usability challenges experienced by visually impaired and low-vision smartphone users. The implementation focused on improving accessibility, typing efficiency, and user experience by incorporating the features most frequently requested by the participants.

Haptic Feedback and Audio Confirmation:

To provide non-visual confirmation of key presses, configurable haptic feedback and audio cues were incorporated. Both features can be enabled or disabled through the keyboard settings, allowing users to customize the feedback according to their preferences.

Adjustable Keyboard Size:

To improve touch accuracy and accommodate users with different levels of visual impairment, the keyboard size can be adjusted to occupy up to 75% of the screen, providing larger touch targets and reducing typing errors.

High-Contrast Themes: Two high-contrast themes were implemented to enhance readability for low-vision users: a dark theme with white characters on a black background and a light theme with black characters on a white background.

Customizable Key Shapes: The keyboard provides both oval and square key layouts. Changing the key shape also increases the spacing between adjacent keys, making them easier to distinguish and reducing accidental key presses.

Multiple Keyboard Layouts: To accommodate different user preferences and minimize the learning curve, three alternative keyboard layouts were implemented, allowing users to select the layout they found most familiar and comfortable.

Enhanced Text Navigation and Editing: Dedicated navigation controls were incorporated to simplify text editing. Users can move the cursor in all directions, select text, and perform copy, cut, and paste operations without relying on complex gestures.

Integrated Speech-to-Text: Although many participants expressed privacy concerns regarding voice input, speech-to-text functionality was retained as an optional feature to provide flexibility in situations where voice interaction is appropriate. Users can activate speech input by pressing and holding the dedicated microphone button.

Quick Access Features: Frequently used functions, including emoji input and commonly used editing controls, were placed directly on the keyboard header bar. This design minimized the need for multiple gestures and menu navigation, enabling users to access essential functions with a single tap.

Overall, the implementation of the EzAccess Keyboard was guided by the survey findings, ensuring that the proposed features directly addressed the needs and preferences expressed by visually impaired users. Particular emphasis was placed on improving touch accuracy, simplifying text editing, enhancing customization, and reducing interaction complexity while maintaining compatibility with familiar smartphone typing practices. Figures 6(a)–6(c) illustrate the alphabetic and numeric keyboard layouts in the high-contrast dark theme with different keyboard sizes. The keyboard size can be increased or decreased using the controls located on the header bar, as shown in Figure 7.

a).SquaredKeypad. b).RoundKeypad. c).NumberKeypad.

Figure 6. Buttons for controlling size of keyboard

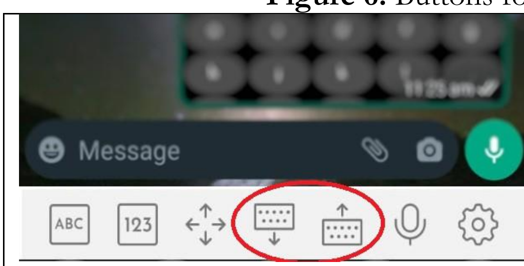


Figure 7. Buttons for controlling size of keyboard

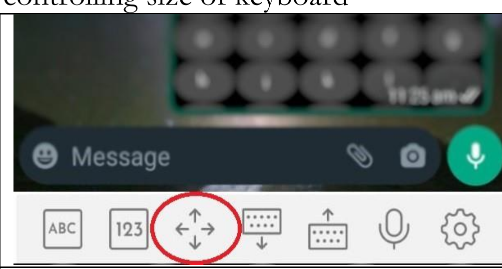
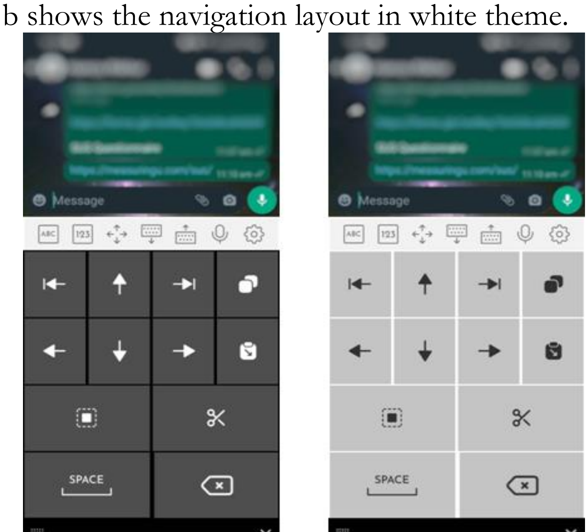


Figure 8. Button for Navigation Layout of keyboard

The user can navigate on the typed text using the navigation key on the navigation Layout. The navigation layout can be opened using the button on the top bar as shown in Figure 8. The navigation layout can be seen in Figure 9. Figure 9 shows the navigation layout in black theme, and 9 b shows the navigation layout in white theme.



a).NavigationKeypad b).NavigationKeypad.

Figure 9. Navigation Layout of keyboard

Speech-to-text functionality can be accessed through the dedicated microphone button located on the keyboard's header bar, as shown in Figure 10. To use this feature, the user presses and holds the microphone button while speaking. Upon releasing the button, the spoken input is automatically converted into text and inserted into the active text input field.

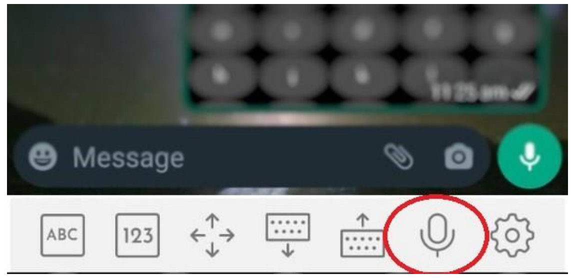


Figure 10. Button for Navigation Layout of keyboard

The keyboard settings can be accessed either by tapping the Settings button located on the right side of the keyboard's header bar, as shown in Figure 11, or by launching the EzAccess application from the device's app menu. When the application is opened for the first time, or if the EzAccess Keyboard has not yet been enabled as the default input method, the user is guided through the setup process, as illustrated in Figures 12(a) and 12(b).

Selecting the Enable Keyboard button directs the user to the device's accessibility and keyboard settings, where the EzAccess Keyboard can be enabled as an available input method. Subsequently, selecting the Select Keyboard button opens the system keyboard selection menu, allowing the user to choose EzAccess as the default text input method. Once the keyboard has been enabled and selected, the main settings panel is displayed, as shown in Figure 12(c).

The settings panel allows users to customize various aspects of the keyboard according to their preferences. Users can select different keyboard layouts, switch between available themes, and choose the preferred key shape. In addition, haptic feedback and audio feedback on key presses can be enabled or disabled, providing a personalized typing experience tailored to individual accessibility needs.

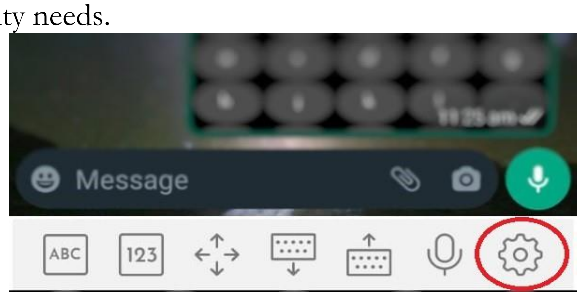
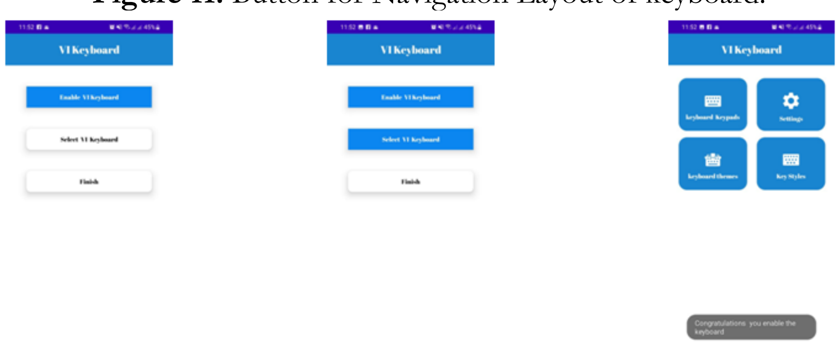


Figure 11. Button for Navigation Layout of keyboard.



a).keyboard Enabled. b).Select the keyboard. c).Settings Panel.

Figure 12. Selecting the keyboard as input method

Overall, the EzAccess Keyboard was designed and implemented to provide visually impaired and low-vision users with an accessible, user-friendly, adaptable, and efficient text entry mechanism. By incorporating the user requirements and preferences identified through the survey, the proposed keyboard improves typing accuracy, usability, accessibility, and the overall user experience. The customizable interface, enhanced feedback mechanisms, and simplified interaction feature collectively facilitate more effective and inclusive smartphone-based text entry for visually impaired users.

Experiment Design – Comparative Evaluation:

Following the design and implementation of the EzAccess Keyboard based on the user requirements identified through the survey, an experimental research method was adopted to evaluate its effectiveness by comparing it with existing smartphone text entry methods for visually impaired users, as illustrated in Figure 13. The purpose of the experiment was to determine whether the proposed keyboard provides improvements in both quantitative and qualitative performance measures.

The independent variable in the experiment was the text entry method used on touchscreen devices, while the dependent variables included quantitative measures, such as text entry speed (words per minute; WPM) and accuracy, and qualitative measures, including usability and user experience. The control variables included participant characteristics, such as age group and visual impairment profile, to minimize potential confounding effects. The treatments consisted of the different text entry methods evaluated during the experiment, and the experimental objects were the corresponding mobile keyboard applications.

The experiment was conducted to test the following hypotheses:

Null Hypothesis (H_0): There is no statistically significant difference between the proposed EzAccess Keyboard and the existing text entry methods in terms of quantitative and qualitative performance measures.

Alternative Hypothesis (H_1): The proposed EzAccess Keyboard performs significantly better than the existing text entry methods with respect to quantitative and qualitative performance measures.

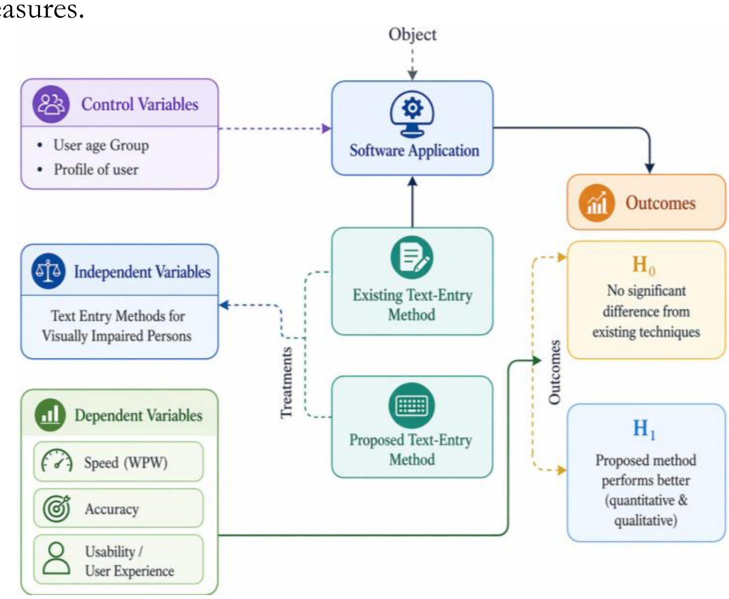


Figure 13. Experiment Design

The evaluation procedure assessed the proposed keyboard using both quantitative and qualitative measures. Quantitative performance was evaluated in terms of text entry speed, measured in Words Per Minute (WPM), and text entry accuracy, measured as a percentage. In addition, the usability of the keyboard was assessed using the System Usability Scale (SUS) questionnaire. The evaluation was conducted with nine visually impaired participants representing different age groups and varying levels of visual impairment. All participants were familiar with QWERTY keyboards prior to the study. The demographic characteristics of the participants are presented in Table 2.

Table 2. Demographic Information & Visual Impairment level of the Participants

No.	Age	Visual impairment	Qualification
P1	55	Cataract	D. Pharmacy
P2	51	Retinal Damage due to brain tumor	MA
P3	38	Chornial Dystrophy	MA. Special Education
P4	32	VI due to Genetical Issue	Matric
P5	21	Low Vision due to Genetical Issue	BS hons.
P6	26	Retinal Pigmentosa	Mphil Special Education
P7	25	Partially Blind	BS Islamic Studies
P8	21	Partially Blind	BS Islamic Studies
P9	22	Partially Blind	BS Urdu

Result and Discussion:

This section presents the results of the evaluation conducted to assess the performance and usability of the keyboard.

Quantitative Evaluation:

Before the experiment, each participant was given five minutes to familiarize themselves with the keyboard layout and the positions of the keys. Once participants indicated that they were comfortable using the keyboard, they were instructed to type the sentence: "The Quick Brown Fox Jumps Over the Lazy Dog."

The participants' screens were recorded throughout the typing task to enable subsequent measurement of typing speed and accuracy. The quantitative evaluation comprised two performance measures: (i) typing speed (WPM) and (ii) text entry accuracy.

Typing Speed (WPM):

Typing speed was calculated by measuring the time elapsed from entering the first character to entering the final character of the sentence. Following the standard text entry evaluation methodology, a word was defined as five characters, including spaces, to provide a consistent measure of typing performance irrespective of the actual word lengths. Since the evaluation sentence contained 34 characters, it corresponded to approximately 7 standard words. Therefore, if a participant completed the sentence in one minute, the resulting typing speed would be 7 WPM.

The typing speed was calculated using Equation (1). The text entry speed obtained for each participant is presented in Table 4.

$$\mathbf{WPW} = \frac{\left(\frac{\text{Total typed Characters}}{5}\right)}{\text{Time(min)}} \quad (1)$$

Accuracy: Participants were instructed to type the given sentence without correcting any typing errors. Once the typing task was completed, the accuracy of the entered text was calculated by comparing the typed sentence with the reference sentence.

The Levenshtein Distance (Edit Distance) was used to measure the number of editing operations required to transform the typed text into the reference text. This metric was selected because it accurately compares strings of different lengths by counting the minimum number of insertions, deletions, and substitutions required to make the two strings identical. Consequently, it provides a reliable measure of typing errors even when participants omitted or inserted additional characters.

After computing the edit distance, the error rate and text entry accuracy (%) were calculated using Equation (2). For example, if the target word was *"JUMPS"* and a participant typed *"JUNP"*, the edit distance would be 2, corresponding to one substitution ($M \rightarrow N$) and one deletion of the character *S*. The edit distance can be computed using the dynamic programming matrix approach, where the value in the bottom-right cell of the matrix represents the final edit distance between the two strings. An illustrative example is presented in Table 3.

Table 3. Edit Distance

		J	U	M	P	S
	0	1	2	3	4	5
J	1	0	1	2	3	4
U	2	1	0	1	2	3
N	3	2	1	1	2	3
P	4	3	2	2	1	2

The text entry accuracy and error rate for each participant are presented in Table 4. The results indicate that the proposed keyboard achieved an average typing speed of 5 WPM, with an average error rate of 4.8% and an overall text entry accuracy of 95.2% across all participants. Since previous studies have reported quantitative performance using different evaluation metrics, two separate comparison tables were prepared: one for text entry accuracy and another for error rate. While most existing text entry methods reported error rates, some reported accuracy (%), while several studies did not report accuracy or both speed and accuracy as part of their quantitative evaluation.

Table 4. Text Entry Speed and Accuracy using EzAccess

No.	Age	Speed (WPM)	Error Rate (%)	Accuracy (%)
P1	55	9.77	0	100
P2	51	2.86	8.9	91.1
P3	38	3.25	2.3	97.7
P4	32	4.3	0	100
P5	21	8.6	2.3	97.7
P6	26	3.49	9.3	90.7
P7	25	1.47	18.1	81.9
P8	21	6.3	0	100
P9	22	4.8	2.3	97.7

Table 5 presents a comparative analysis of the quantitative performance of the proposed EzAccess Keyboard and existing text entry methods. The results indicate that the EzAccess Keyboard achieved the highest text entry accuracy and the lowest error rate among the compared methods. Although its typing speed was slightly lower than that of a few existing methods, it outperformed the majority of the reported techniques in terms of text entry speed while maintaining superior accuracy.

Table 5. Comparison of Qualitative Results

No.	Text Entry Method	Target Users	Speed (WPM)	Error Rate (%)	Accuracy (%)
1	EzAccess Keyboard (Proposed)	**PB/LV**	**5.00**	**4.80 (ER)**	**95.20**
2	TypeHap (Haptic Phonemes)	BLV	5.96	3.37 (UER)	96.63*
3	Key-Magnified Keyboard	LV	5.28	5.08 (WER)	94.92*
4	Layout-Magnified Keyboard	LV	4.58	7.08 (WER)	92.92*
5	BrailleEasy	VI	**8.30**	–	–
6	Perkinput	VI	**9.46**	12.23 (ER)	–
7	BrailleTouch	VI	6.30	–	85.00
8	SingleTapBraille	VI	4.71	11.23 (ER)	–

9	Conventional Gesture (Voice)	LV	4.14	11.00 (WER)	89.00*
10	EdgeBraille	VI	3.97	8.43 (ER)	–
11	BrailleTap	VI	3.36	6.55 (ER)	–
12	Conventional Tap (TalkBack)	LV	2.97	24.17 (WER)	75.83*
13	BrailleKey	VI	2.50	5.80 (ER)	–
14	BrailleEnter	VI	2.30	14.12 (ER)	–
15	BrailleType	VI	1.45	–	91.09
16	NavTap	VI	1.32	9.87 (ER)	–
17	No-LookNotes	VI	1.32	–	–

Abbreviations: PB/LV = Partially Blind and Low Vision; VI = Visually Impaired; BLV = Blind and Low Vision; WPM = Words per Minute; ER = Error Rate; WER = Word Error Rate; UER = Uncorrected Error Rate; "–" = Not Reported; *Accuracy calculated as 100 − reported error rate**.**

Metric Variations: Error rates are reported using different standards based on the source study: ER (General Error Rate) as seen in the case of EzAccess and Alnfiai and Sampalli (2016), WER (Word Error Rate) utilized by [10], and UER (Uncorrected Error Rate) reported by [8].

(*) Calculated Accuracy: Where accuracy was not explicitly reported as a percentage, it has been calculated as (100−Error Rate) to provide a standard basis for comparison across different reporting styles, a method applied to data from studies including [10] and [8].

Performance Insight: The EzAccess Keyboard maintains a competitive position by offering the highest reported accuracy (95.20%) among specialized QWERTY and several Braille-based methods such as BrailleTouch (Frey et al., 2012) and BrailleType (Oliveira et al., 2011), while its typing speed (5.00 WPM) is on par with the latest Key-magnified system [10] and TypeHap [8].

Qualitative Evaluation:

The qualitative evaluation of the EzAccess Keyboard was conducted using the System Usability Scale (SUS), a widely used and reliable instrument introduced by John Brooke (1986) for assessing the perceived usability of interactive systems. The SUS questionnaire consists of 10 statements, each rated on a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The questionnaire is presented in Table 6.

Unlike task-specific usability questionnaires, the SUS provides an overall measure of perceived usability rather than identifying individual usability problems. The resulting score ranges from 0 to 100, with higher scores indicating better perceived usability. In general, SUS scores above 80 are considered to represent excellent usability, whereas scores below 50 indicate poor usability and suggest that substantial improvements are required.

The SUS score was calculated following the standard scoring procedure. For the positively worded items (Questions 1, 3, 5, 7, and 9), 1 was subtracted from each participant's response. For the negatively worded items (Questions 2, 4, 6, 8, and 10), each response was subtracted from 5. The adjusted scores were then summed and multiplied by 2.5 to obtain the final SUS score out of 100. The average participant responses for each questionnaire item are presented in Table 7, while Figure 6.4 illustrates the mean score for each SUS statement. The proposed EzAccess Keyboard achieved an overall SUS score of 93.9, indicating excellent perceived usability. Furthermore, a review of the existing literature revealed that most previously proposed text entry methods for visually impaired users did not evaluate usability using a standardized instrument such as the SUS, making a direct comparison of qualitative usability scores difficult.

Table 6. SUS Questionnaire

No.	Questions
1	Name
2	Age
3	Qualification
4	I think that I would like to use this keyboard more frequently.
5	The keyboard was complex to use.
6	It was very easy to type using this keyboard.
7	I think that I would need the support of a technical person to be able to use this keyboard.
8	Editing text was very easy using navigation keys.
9	It was quite easy to type text using speech to text.
10	I thought there was too much ambiguity in this keyboard.
11	I would learn to use this keyboard very quickly.
12	I found this keyboard very challenging to learn.
13	I needed to learn a lot of things before I could start typing with this keyboard.

Table 7. SUS Questionnaire.

No.	Question	Avg. Response
Q1	I think that I would like to use this keyboard more frequently.	4.8
Q2	It was very easy to type using this keyboard.	4.9
Q3	Editing the text was very easy using navigation keys.	4.9
Q4	It was quite easy to type text using speech to text.	5
Q5	I would learn to use this keyboard very quickly.	4.8
Q6	The keyboard was complex to use.	1.3
Q7	I would need the support of a technical person to be able to use this keyboard.	1.1
Q8	I thought there was too much ambiguity in this keyboard.	1.7
Q9	I found the keyboard very challenging to learn.	1.3
Q10	I needed to learn a lot of things before I could start typing with this keyboard.	1.4

Analysis & Discussion:

Statistical Analysis:

To perform a statistical analysis for Speed and Accuracy, we require the raw participant data for each keyboard being compared, as the Mann–Whitney U test is a non-parametric test that relies on the ranking of individual scores rather than aggregate means [16][8]. Based on the sources and updated results in Table 5, we can perform this analysis for the EzAccess Keyboard versus TypeHap [8], as individual data points are available for both. However, we cannot perform it for other methods like the Key-magnified Keyboard [10] or [20] because the sources only report their final mean results and standard deviations.

Comparative Statistical Analysis: EzAccess vs. TypeHap:

To further validate the performance of the proposed EzAccess Keyboard, a Mann-Whitney U test was conducted to compare its quantitative outcomes against the TypeHap system [8], a recent haptic-based text-entry method. The Mann-Whitney U test, a non-parametric alternative to the independent t-test, was selected due to the relatively small and independent sample sizes (N=9 for EzAccess and N=11 for TypeHap) and the inherent non-normality of text-entry data in visually impaired populations [16][8].

Typing Speed (WPM):

The descriptive analysis indicates that while TypeHap achieved a slightly higher mean typing speed of 5.96 WPM [8] compared to 5.00 WPM for the EzAccess Keyboard, the statistical analysis revealed no significant difference between the two methods

(U=35.0,p=0.287,p>0.05). This result demonstrates that the EzAccess Keyboard is performance-competitive with cutting-edge haptic phoneme systems, successfully bridging the gap between existing specialized keypads and experimental non-auditory interfaces.

Typing Accuracy (%):

In terms of accuracy, the EzAccess Keyboard achieved a mean accuracy of 95.20%, while the TypeHap system recorded a mean of 96.63% [8]. Statistical testing confirmed that this difference is not significant (U=48.0, p=0.909, p>0.05). The lack of a statistically significant difference supports the claim that the EzAccess Keyboard provides a level of precision that is on par with high-end hardware-augmented solutions, even while maintaining a software-centric, accessibility-inclusive approach.

Comparative Benchmarking via Z-Score Standardisation:

In text-entry research for visually impaired persons (VIP), identifying significant differences is often restricted by the availability of only aggregate mean scores in secondary sources. To overcome this, we employed a Z-score standardisation approach to position the EzAccess Keyboard within the performance hierarchy of current state-of-the-art methods. The Z-score represents the number of standard deviations the proposed method's performance lies from the mean of the compared studies, where a positive score (Z>0) indicates above-average performance.

Standardization of Typing Speed (WPM):

The typing speed data from Table 5, encompassing 17 distinct specialised interfaces tested with VIP/BLV populations, yielded a literature-wide mean (μ) of 4.29 WPM with a standard deviation (σ) of 2.26. The proposed EzAccess Keyboard, with a mean speed of 5.00 WPM, achieved a Z-score of +0.31. This standardisation indicates that the EzAccess Keyboard performs above the established mean of contemporary assistive keyboards, maintaining competitive efficiency while avoiding the hardware complexities of systems like TypeHap [8] or the high cognitive load of chording methods like Perkinput [20].

Standardisation of Typing Accuracy (%):

The analysis of accuracy was conducted across the subset of studies in Table 5 that reported percentage-based accuracy or error rates for VIP/BLV users. This comparative set yielded a mean accuracy (μ) of 90.16% (σ=5.08). The EzAccess Keyboard achieved an accuracy of 95.20%, resulting in a Z-score of +0.99. This high positive Z-score demonstrates that the EzAccess Keyboard is performed above the average assistive interface in the comparison set currently available, approaching one full standard deviation above the literature mean.

Discussion of Ranking and Favourability:

Based on the derivation of Z-scores, the EzAccess Keyboard is positioned as a highly favourable member of the current text-entry ecosystem for the visually impaired. While specialised Braille layouts like BrailleEasy or BrailleTouch may offer higher raw speeds for trained users, they often suffer from lower accuracy or steep learning curves.

The positive Z-scores for both speed (+0.31) and accuracy (+0.99) statistically validate that the EzAccess Keyboard successfully addresses the identified usability gap by providing a balanced, user-friendly interface that does not sacrifice precision for speed. These findings support the alternative hypothesis (H1), confirming that a specialised, accessibility-inclusive keypad designed with user-centric affordance principles can significantly enhance the mobile interaction experience for the visually impaired population.

Comparison with Prior Studies:

When contrasted with TypeHap [8], which utilizes piezo actuators for haptic phonemes, EzAccess achieves statistical parity in speed and accuracy. However, EzAccess offers a significant usability advantage as it is a software-only solution, removing the "burden to carry external devices" identified as a major challenge in recent formative interviews [8].

Compared to Braille-based methods like Perkinput [20] or EdgeBraille [22], EzAccess demonstrates superior reliability. Braille literacy is globally declining, making QWERTY-based layouts like the one proposed here more accessible to the broader VIP population who may not be trained in Braille [8]. Furthermore, the accuracy of EzAccess (95.2%) significantly outperforms BrailleTouch (85%) and Conventional Tap/TalkBack (75.83%), addressing the "frustration with screen readers" noted in existing literature [10].

Addressing the Usability and Privacy Gaps:

A deeper discussion of the findings reveals that EzAccess successfully addresses the privacy gap identified by [3]. Most current solutions rely on audio feedback, which participants find "socially conspicuous" or "disturbing to others" [8]. By providing a usable, high-accuracy interface that does not mandate loud audio cues, EzAccess provides a liberating alternative for use in public or noisy settings.

Finally, the iterative design approach used in this study—moving from user surveys to prototype development—directly counters the "designer-led" trend where 80.7% of studies fail to prioritize qualitative feedback [3]. This alignment between Affordance Principles and user requirements is likely the reason for the negligible technology abandonment indicated by the high satisfaction scores [14].

Mapping results with research objectives:

Objective 1: Understand needs and expectations of VI people for touchscreen text entry:

The study achieved this through a cross-sectional survey of 50 visually impaired (VI) smartphone users. Key findings regarding user needs and expectations included:

Privacy vs. Accessibility: While many users utilize speech-to-text, 100% expressed privacy concerns regarding sensitive information (e.g., passwords) and overhearing in public. Users explicitly expect text-based input methods that maintain privacy.

Layout Preference: 79% of participants currently use and prefer familiar QWERTY-based layouts over specialized Braille keyboards, suggesting an expectation for interfaces that do not require extensive retraining.

Primary Challenges: 73.68% reported difficulties with mobile typing, specifically citing text editing, keyboard latency, and poor visual clarity as major barriers.

Desired Features: Users expect user-friendly interfaces with larger keys, high-contrast elements, simplified navigation (like an undo function), and multimodal feedback (haptic/audio).

Objective 2: Identify and extract guidelines for usable text entry mechanisms

Findings from the survey and literature review were synthesized into a set of user requirements and design guidelines that directly informed the development of the proposed solution. These guidelines include:

Touch Accuracy: Utilizing larger touch targets and adjustable keyboard sizes to accommodate varying levels of visual impairment.

Multimodal Feedback: Integrating both haptic feedback and audio confirmation to provide non-visual validation of user actions.

Visual Optimization: Providing high-contrast themes (e.g., dark vs. light) and customizable key shapes to improve legibility.

Reduced Interaction Complexity: Implementing "minimalist reusable actions" and dedicated navigation controls to simplify text editing without complex gestures.

Objective 3: Design a usable text entry mechanism for VI people:

The study successfully translated the extracted guidelines into the EzAccess Keyboard, a specialized, software-based Android input method. Key design features include:

Adaptive Sizing: A keyboard that can be adjusted to occupy up to 75% of the screen for easier targeting.

Dedicated Navigation Keypad: A specific layout for cursor movement and text editing (copy, cut, paste) to replace difficult multi-touch gestures.

Customization: Three alternative layouts and various high-contrast themes to allow users to personalize their experience based on their functional vision.

Quick Access Header Bar: Frequently used functions (emojis, size controls, settings) are placed in a header bar to minimize menu navigation.

Objective 4: Evaluate and compare the proposed mechanism with existing methods

The EzAccess Keyboard was evaluated through user-based testing (N=9) and compared against 16 existing methods using both qualitative and quantitative measures.

Quantitative Results (WPM & Accuracy):

Accuracy: Achieved a mean accuracy of 95.20%, which was the highest reported accuracy among all compared specialized QWERTY and Braille-based methods.

Speed: Achieved an average typing speed of 5.00 WPM, which is competitive with the latest systems like TypeHap (5.96 WPM) and Key-magnified keyboards (5.28 WPM).

Qualitative Results (SUS/UX):

Achieved an overall System Usability Scale (SUS) score of 93.9, indicating "Excellent" perceived usability and strong user satisfaction.

Statistical Comparison:

Mann-Whitney U tests confirmed that EzAccess achieves performance parity with cutting-edge haptic systems (p=0.287 for speed; p=0.909 for accuracy) while offering the advantage of being a software-only solution.

Z-score analysis positioned EzAccess nearly one standard deviation above the literature mean for accuracy (Z=+0.99), statistically validating its efficacy in addressing the identified usability gaps.

Practical and real-world implications & applications:

The findings of this research extend beyond theoretical validation, offering several significant practical implications for the visually impaired (VI) community, developers of assistive technology (AT), and the broader field of digital accessibility. The EzAccess Keyboard is designed to be a functional, daily-use tool that addresses several systemic barriers identified in current mobile interaction research [3].

Enhancement of Personal Privacy and Autonomy:

A primary real-world application of the EzAccess Keyboard is providing a secure, non-auditory text-entry method for sensitive digital interactions. Current reliance on speech-to-text or audio-based screen readers often forces users to expose private information, such as passwords or account details, in public settings. By achieving high accuracy (95.20%) through a customizable visual and haptic interface, EzAccess enables users to communicate privately in public or noisy environments where audio feedback is either socially conspicuous or technically ineffective [8][10].

System-Wide Digital Inclusiveness:

Unlike many previous "app-silo" prototypes, the proposed system is implemented as a native Android Input Method Service (IME) [13]. This allows for immediate real-world application across the entire mobile ecosystem, enabling visually impaired users to use the specialized keypad for diverse tasks—ranging from professional emailing and social media engagement to navigating location-aware technologies and RFID-tagged environments [5]. This system-wide accessibility is critical for reducing the social and economic exclusion often experienced by those unable to master standard mobile text entry [3].

Economic and Functional Accessibility:

As a software-only solution, the EzAccess Keyboard removes the financial and physical barriers associated with carrying additional Bluetooth-enabled hardware, which is often prohibitively expensive and difficult to access in low-income regions [3]. This provides a practical path toward independence and self-sufficiency for the hundreds of millions of visually impaired individuals who currently have less than a 3% accessibility rate for essential assistive products [3][5].

Guidelines for Inclusive Design and Development:

Finally, this research contributes a validated framework of practical design guidelines for future assistive technologies. By demonstrating the success of "minimalist reusable actions," larger touch targets, and high-contrast customizable themes, this study provides a blueprint for developers seeking to reduce technology abandonment rates among the VI population [14]. These guidelines ensure that future mobile interfaces are designed with Affordance Principles that directly align with the functional capabilities of diverse user profiles [14].

Conclusion:

Previous research on smartphone text entry for visually impaired users has predominantly focused on individuals who are completely blind, whereas the needs of partially blind and low-vision users have received comparatively limited attention. This research addressed this gap by investigating the specific text entry requirements of partially blind and visually impaired users and developing an accessible keyboard tailored to their needs. The study aimed to identify user requirements, evaluate existing text entry methods, and design and assess a more usable smartphone text entry solution.

A comprehensive review of the literature revealed that most existing text entry methods are based on Braille and primarily target users with complete blindness. Furthermore, many of these solutions were developed without systematically eliciting user requirements, and relatively few studies employed standardized usability evaluation methods. These findings highlighted the need for a user-centered text entry mechanism specifically designed for partially blind and low-vision users. To address this gap, a user requirements survey was conducted to understand the text entry practices, challenges, preferences, and expectations of visually impaired users. The survey findings guided the design and implementation of the proposed EzAccess Keyboard, which incorporated several accessibility features, including customizable keyboard layouts, adjustable key sizes, high-contrast themes, configurable audio and haptic feedback, enhanced text editing capabilities, and simplified interaction mechanisms.

The proposed keyboard was evaluated using both quantitative and qualitative measures. Quantitative evaluation assessed text entry speed (Words Per Minute), accuracy, and error rate, while qualitative evaluation employed the System Usability Scale (SUS) to measure perceived usability. The evaluation demonstrated that the EzAccess Keyboard achieved high text entry accuracy (95.2%), a low error rate (4.8%), and an excellent usability score (SUS = 93.9). Comparative analysis further indicated that the proposed keyboard outperformed most existing text entry methods in terms of accuracy and usability while maintaining competitive typing speed.

Overall, this research contributes a user-centered and empirically evaluated text entry solution for partially blind and low-vision smartphone users. The study demonstrates the importance of incorporating user requirements into the design process and highlights the value of standardized usability evaluation when developing accessible mobile interfaces. It also provides practical design guidelines that can assist researchers and developers in creating more inclusive smartphone text entry technologies for visually impaired users.

Although the proposed keyboard demonstrated promising performance, further research is required to evaluate its effectiveness with a larger and more diverse participant population, investigate its long-term learnability, and explore the integration of emerging technologies such as adaptive interfaces, personalized interaction techniques, and artificial intelligence to further enhance accessibility and text entry performance for visually impaired users.

Future Directions: Although the proposed EzAccess Keyboard demonstrated promising results in terms of text entry accuracy and usability, there remain several opportunities for further improvement and investigation.

Keyboard Layouts: The current implementation includes three alternative keyboard layouts. Future research may explore additional layout designs based on key usage frequency, ergonomic principles, and user preferences to further improve typing efficiency and reduce input errors. Moreover, allowing users to create and save personalized keyboard layouts could provide a higher level of customization and better accommodate individual accessibility needs.

Cross-Platform Support: The EzAccess Keyboard was developed and evaluated on the Android platform. Future work should focus on extending the implementation to other mobile operating systems, particularly iOS, to improve accessibility and broaden the applicability of the proposed solution.

Larger and More Diverse User Studies: The experimental evaluation was conducted with a relatively small number of visually impaired participants. Future studies should involve a larger and more diverse participant population representing different age groups, levels of visual impairment, and technological experience to improve the generalizability and statistical validity of the findings.

Longitudinal Evaluation: The present study evaluated the keyboard during controlled experimental sessions. Future research could investigate the long-term usability, learnability, and user satisfaction of the EzAccess Keyboard through longitudinal studies involving regular real-world use.

Intelligent Personalization: Emerging technologies, including artificial intelligence and adaptive user interfaces, could be integrated to personalize the keyboard according to individual typing behavior, preferred layouts, and accessibility requirements. Such adaptive mechanisms may further enhance typing efficiency, usability, and the overall user experience.

By pursuing these research directions, future studies can further improve the usability, accessibility, and adaptability of smartphone text entry methods, ultimately supporting greater digital inclusion and independence for visually impaired and low-vision users.

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All authors reviewed, revised, and approved the final manuscript.

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Appendix A – Questionnaire for Visually Impaired People: Text Entry Practices, Preferences, Usability & Privacy Concerns

https://drive.google.com/file/d/1nXbqpmbAnBLyl1n3rE7zqDuUs0mGZL73/view?usp=sharing