KeyRoad: Intuitive and Predictive Customisation of Touch-Screen Keyboard for People with Hand Disabilities

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Abstract. This paper presents KeyRoad, a new virtual keyboard design method for such a hand-held multi-touch devices like smart phone, PDA, pad, etc. As the size of virtual keys are too small that makes inefficient text entry experience, the main aim of KeyRoad is to make text entry task easier, faster and more usable for people with motor coordination problems. Therefore, we propose predictively resizeable keyboard layout design, i.e. we propose solution that expands next most probable character just after inputting current one. Resizing is personalized and performed on the basis of several statistical analysis of users' previous entries. The prototype of KeyRoad was tested on a group of disabled people and compared with other solutions. The results appeared promising.

Keywords: HCI, Soft Keyboard, Accessibility, Assistive software, Motor hand disabilities.

1 Introduction

Due to recent advancements in Information and Communication Technology (ICT), ubiquitous computing has been advanced and evolved in different devices like smart phone, tablet etc. This makes possible to accomplish powerful computations on mobile devices. Current smartphones support running of complex applications which require powerful input system. Meanwhile, in these devices, it is not possible to locate hardware keyboard because of the limitations in size of devices. To avoid this problem, system designers are proposing virtual keyboards. The virtual keyboard (VK) is a soft graphics keyboard and is comparable with its hardware keyboard analog.

Virtual keyboards or on-screen keyboards in its classical meaning is a representation of a hardware keyboard in touch-screen environment. They are commonly used as a mechanism of augmentative communication by people with motion disability. Currently, a lot of mobile devices is equipped with virtual keyboard,

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while original purpose of it was an increasing communicational experience between graphically powered computing devices and people with disabilities.

Many researchers agree that the best solution for hardware keyboards that we associate with desktop computers, is the traditional QWERTY key arrangement [1] [2] [3], and that the other alphabetical arrangement of keys offers no specific advantages over it [4]. The background for designing layout for current Virtual Keyboards, was based on the design of hardware keyboards.

Most of these devices and virtual keyboards have been designed for the ordinary, typical users. Unfortunately, people with limited range of hand functionality cannot properly interact with small handheld device. This is the result of their limited ability to control their hands for effective communication. However, virtual keyboards are widely used to help people with motor disabilities to make interaction more productive.

Recently, major part of smartphones and handheld smart devices use small size virtual keyboard that are too small to be well used by people with limited range of hand functionality. Consequently, the usage of these systems often yields a poorer typing accuracy causing frustration and hindering interactivity in people with motor disabilities. Many of individuals suffering from that hand motorical limitations are heavily disabled to interact with entire environment around them. Computer devices are the best way to give them a feeling of autonomy.

Several ways for solving that problem were proposed, including target expansion methods [5] [6]. BigKey aims to expand four most probable key just after depressing current one. Fisheye keyboard allows to compact all keys on a small screen. It makes easier pointing experience for the user by expanding any given key as a function of its distance from the stylus.

Although, we think that target expansion notation can be employed to accelerate text input efficiency, existing methods still have some shortcomings in various significant aspects. Since they have no any option to cancel mistakenly predicted (expanded) letters. It might serve as contrast to its natural purpose. BigKey prediction system implements tables of single letter and diagram frequency [7]. Coming from language specifications it might be a reason for a poor prediction. While Fisheye implements quite interesting method, it is totally aimed to stylus based devices, therefore it is inefficient for thumb based interaction.

This paper proposes a new virtual keyboard, called KeyRoad, that solves some smartphone accessibility problems. We propose solution that expands next most probable character just after inputting current one. Our method is aimed to improve existing prediction system efficiency by adding extra prediction model that is based on most probable third letter expansion. Therefore resizing is personalized and done based on several statistical analysis of user's previous entries. The main contributions of this paper include:

- Augmented way of text-input process on multi-touch based smart phone devices.
- More efficient prediction system in comparison with existing ones.
- Possibility of prediction cancellation.

This paper is organized as follows. The next section overviews the most frequent motor disabilities. Third section overviews works related to proposed solutions. Fourth section introduces and explains the proposed method of virtual keyboard enhancement. Fifth section summarises the results of experiments. The last Section concludes the paper.

2 Motor Disabilities

Motor disabilities are disorders that influence capacity of a person to perform motor tasks that typical person is well used to and trained to do. Those limitations most commonly are associated with lack of ability to perform object manipulation, such as walking, running, tying shoes and others. To be classified as a disability, one should have notable low motor coordination performance comparing with his age, and the problem must interrupt with the activities of daily living [8]. There exist several kinds of motor disabilities which leaves individuals out of fully coordinated control.

Cerebral Palsy. Cerebral palsy is an injury to the brain, resulting in decreased muscle control (palsy). Common characteristics of cerebral palsy include muscle tightness or spasm, involuntary movement, and impaired speech [9].

Muscular Dystrophy (MD). MD is a genetic disorder in which the genes for muscle proteins are damaged. It is characterized by the progressive degeneration of the muscles. Muscular dystrophy can affect people at any age, but is most common in children [10].

Rheumatoid Arthritis (RA). RA causes premature mortality, disability and compromised quality of life in the industrialized and developing world. Rheumatoid arthritis is a systemic inflammatory disease which manifests itself in multiple joints of the body. Arthritis occurs most often in the elderly, but can occur in younger individuals as well. Many people with arthritis are able to use a keyboard and mouse, but they do not always have the fine motor control sufficient to click accurately [11].

3 Related Work

With a world wide development of smartphone devices, the text input methods have become a topic of thorough research. Consequently new constraints have been raised. e.g. minimized display or one hand interaction. Currently, various directions of research in this field have been advanced like speech recognition, eye-tracking system, scanning method [12] [13] and virtual keyboards.

NavTap [14] is a method which provides audio feedback to the users suffering from motor disabilities, while pressing certain key. Parakeet [15] is a touch-screen system for continuous speech recognition on mobile devices. It shows significant improvement in sense of Word Per Minute (wpm) accuracy.

Few of scanning systems were proposed by researchers. Scanning system is a representation of several options to user by providing them with a visual cursor advice. Cursor location is changed during a specified time span. User just

touches the screen while intended option is highlighted by visual cursor. One option can be container for another set of options [16] [13]. EasyWrite [17] is a touch-based entry method for mobile devices inspired by the notion of scanning group systems. It proposes a small virtual keyboard having less keys of bigger size. It provides an important advantage over other scanning methods proposed elsewhere. It allows users to navigate directly through groups and subgroups of characters by tapping on directional keys in order to find the way for the desired character rather than waiting for a visual cursor to advance through the options.

Various methods for stylus-based touch devices have been investigated in purpose of increasing accessibility of soft keyboards. Their specifications, based on usability testing, are wide enough to be applied for multi-touch devices. EdgeWrite [17] is a unistroke text-entry method, which is based on the recognition of formerly defined gestures resembling alphabetical signs. The method increases text typing accuracy by providing square hole imposed over the usual text input area. The gesture recognition is accomplished in the intended square.

Approaches above have been well covered by researches. However, methods based on target (user interface element) expansion were less investigated, but still there are few proposed methods in this direction. McGuffin and Balakrishnan's proposition is a design approach of one-dimensional sequence of User Interface elements [18]. The main aim of proposed interface design method is the facilitation of typical discrete target selection task by targets width expansion dynamically after the onset is moved towards intended target [19]. Fisheye Keyboard [6] is one more method which realizes target based expansion on touch screen mobile devices. Main aim of Fisheye Keyboard is displaying all keys on a small screen while making pointing easier for the user by expanding any given key as a function of its distance from the stylus.

4 KeyRoad: A New Virtual Keyboard

Due to small size of mobile devices, major part of text-entry facilitation methods yields inefficient usability experience for people with motor disabilities. Those individuals are usually accompanied by extra limitations like low vision and inability of holding device properly. That can be an additional reason for frustration caused by mistakenly overshooting. Taking those difficulties into account we have developed virtual keyboard, named KeyRoad, mainly addressed to smartphone devices. However, potential of the method is great enough to be implemented on variety of handheld devices supporting soft keyboard based text-entry environment.

The idea behind KeyRoad is as follows: Expansion of the next most probable buttons are done respectively to its character, just after a user releases finger from the current key. The crucial aspect is that well predicted character will serve as a tool for augmented visual scanning as well as way of increasing probability to be easy clicked, since size and color gamma of intended buttons are increased.

The notable aspect is that not all characters can be predicted correctly. This can result in target key overlapping, and the user has to focus on the target key in order to depress it. For the purpose of solving that problem one extra key was

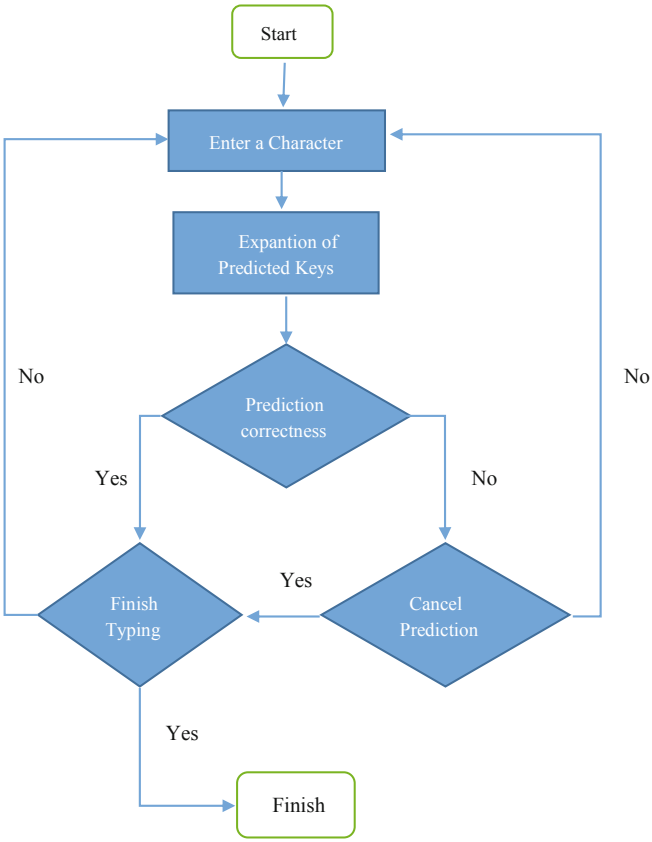


Fig. 1. A block diagram of a procedure of character input in KeyRoad including next predicted key size expansion with the possibility of prediction cancelling.

added to the Keyboard layout, which underlies cancellation of prediction and gives natural layout view to the interface (see Fig 1).

It is noteworthy that no key rearrangement was implemented in KeyRoad and it is fully based on traditional QWERTY layout. However, some researchers tryed to increase text-input efficiency based on changing character arrangement [20].

4.1 Inspitration

We have derived our inspiration from two different sources: (1) BigKey [5] a virtual keyboard for stylus based mobile devices and (2) responsive, animative and rich User Interface concept. The method behind proposed on-screen keyboard in BigKey solution (1) is to expand four most probable characters just after inputing current one. For building prediction system, authors have employed tables of single letter and diagram frequency Counts proposed by Mayzner and Tresselt [7]. Researches have shown that a four key prediction soft keyboard has an

advantage comparing with one key prediction and against an ordinary keyboard. Since BigKey was intended for senior people, participants for experiment were selected from an old aged persons. No user research was done for people with motor coordination problems. However, those individuals were mentioned as a probable target users. In some sense, one can think of this interaction method as a kind of self-customised text input system, in which the various keys are expanded just after current one is depressed.

4.2 Prediction System

There exists several word completion and prediction methods including learning ones [21] [22]. Although, such systems are complex enough to be easy scanned visually, they require significant amount of time to read all presented predictions and chose intended one. Coming from that, we have decided to focus on latter in our method.

Prediction is done by two kind of statistical analysis of the user input. Authors of the paper think that combination of several prediction methods can be an efficient solution and can serve as a complementing tool:

- Most probable next letter after current one.
- Most probable third letter after previous one.

System is intended to be flexible enough to store user text input data in such a manner that it would be easy to retrieve it for the late use. For that purpose we implemented three dimensional array (see Figure 2) containing 27 elements in each dimension that correspond to the letters amount in latin alphabet. That kind of implementation is efficient to store and access information in the above mentioned array.

4.3 KeyRoad Prototype Evolution

The development of KeyRoad virtual keyboard text entry method was covered by several evaluation and redesign cycles. First working release of our keyboard was a prototype of Windows Phone 8.1 on-screen keyboard (Figure 3(a)) with elements of three predicted keys, increased by 44% (Figure 3(b)) and a final prototype (Figure 3(c)).

A further user research has been performed on our first prototype in order to evaluate and assess usability of the layout design. Experiment indicated that people with hand coordination problems had several notable remarks regarding the layout and device design. The contribution of this user research was huge as we have redesigned our prototype based on the users feedback. The final design implements 35% of target expansion coefficient. The color of highlighted keys was changed according to uncomfortable visual flashes caused by higher animation experience (Figure 3(c)).

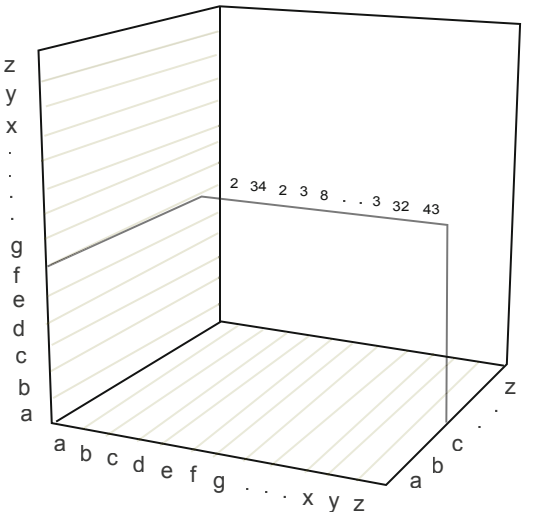


Fig. 2. Prototype of three dimensional matrix with elements of integers, that is used to store/retrieve information about third most probable letter. Y axis is assumed to correspond to the first letter, X axis corresponds to the second letter. While cross field of them is matched to the Z axis and presents values for the number of times the given letter appeared after the combination of precedent two in the previous text, written by the user letter after previous two. In the presented example, 'z' is going to be the most probable letter after combination of 'c' and 'f'.

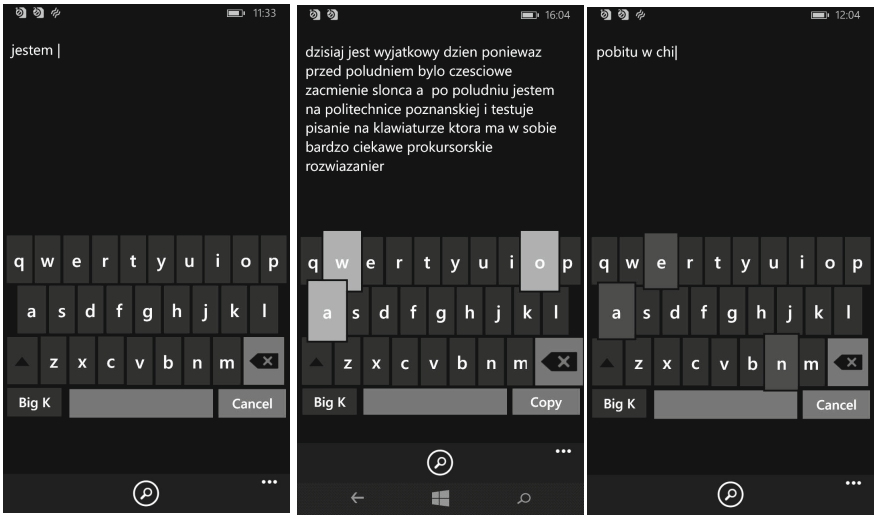
5 Experiment

The goal of the experiments was to evaluate efficiency of our proposed method and prove that it has significant improvement in text input process. Two well known methods were employed to estimate input speed and error accuracy: The text entry speed expressed in words per minute (wpm), and an average error accuracy count during the text entry task.

5.1 Participants

Six volunteers with different hand disabilities and no disabilities participated in our experiment. The initial KeyRoad prototype usability tests were run on 6 users only according to Jacob Nielsen rule [23], saying, that "only 5 users can find 85% of usability problems." All of them were using right hand for interaction. Almost all of them were in senior age. Some participants where novice users of multi-touch devices and none of them had an experience of using virtual keyboard on Nokia Lumia 730. The characteristics of users is following:

- I - age: 30+, Rheumatoid arthrithis, severe state, using smatphone daily but with difficulties.
- II - age: 40+, Muscular dystrophy, recovering from severe state, never before used a smartphone.



(a) Default (b) The first prototype (c) The final prototype

Fig. 3. Prototypes of KeyRoad.

- III - age: 50+, no disabilities, does not use a smartphone daily.
- IV - age: 50+, no disabilities, uses a smartphone daily.
- V - age: 30+, no disabilities, uses a smartphone daily.
- VI - age: 40+, Cerebral palsy, uses a smartphone daily.

5.2 Apparatus

The experiments were conducted on Nokia Lumia 730 having four core of 1.2GHz processor, screen resolution 1280x720, running under Windows Phone 8.1 mobile operation system. Three prototypes were implemented for the experiment: (1) The analog of the default Windows Phone virtual keyboard i.e. keyboard without key resizing, (2) BigKey method implementation in multi-touch environment, and (3) KeyRoad - a target expansion virtual keyboard proposed by us. All of those three virtual keyboards were built in Silverlight for Windows Phone.

5.3 Results

The experiment consisted of three parts: (1) Information Retrieval about user previous texting data in order to analyze it. Due to personality of most of conversational threads, personalization was achieved by analyzing Blog post of one of the participants. (2) Preliminary access to the Virtual keyboards, for the purpose of giving possibilities to the participant to familiarize with them. (3) Those two parts were followed by conduction of the main text entry experiment running on three random sentences created with the words used in previously analyzed blog. As the blog analyzed by the system was written in Polish using latin alphabet,

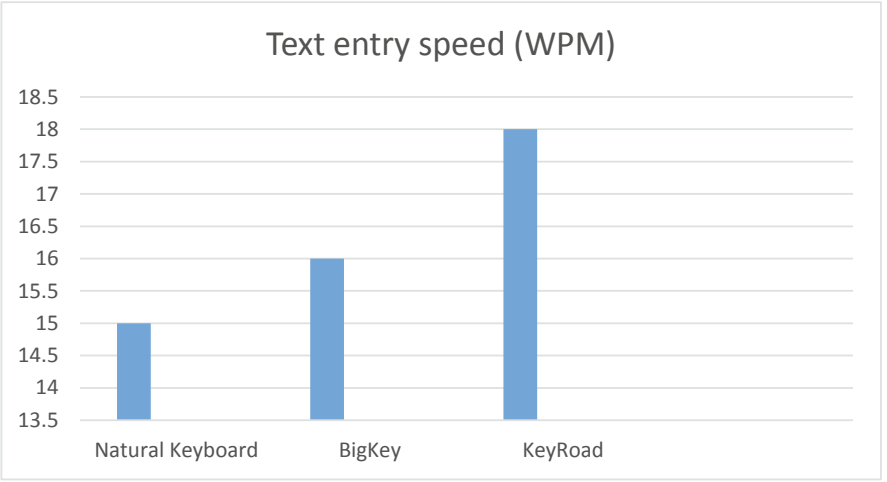


Fig. 4. Text entry speed based on Word Per Minute technique averaged for six users.

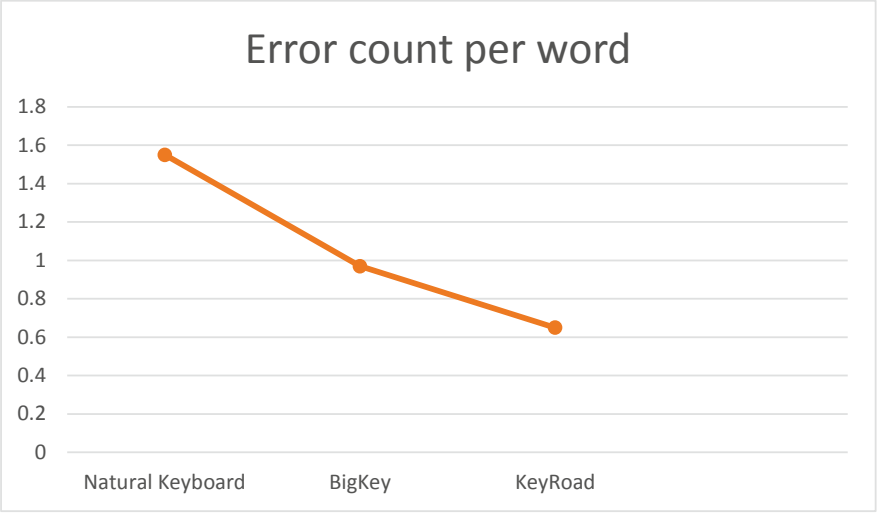


Fig. 5. Average error count per word for given Virtual keyboards.

we decided to construct sentences in Polish. All of them were the same for each participant. Average length of each sentence was 60 characters including spaces and around 11 words per each one. The study indicated that higher text entry speed was produced by KeyRoad (see Figure 4). Also the number of corrected errors while testing KeyRoad was much smaller comparing with an ordinary and Bigkey Virtual Keyboards (Figure 5).

Summarizing, the usability tests showed that most of participants had better performance on the the KeyRoad virtual keyboard. The subject suffering from

motor disability preferred usage of KeyRoad comparing with default and BigKey. Also it is notable that almost all participants reported problems caused by small size of the default keyboard.

6 Conclusions and Future Work

In this paper we have presented KeyRoad, a prototype of new virtual keyboard layout design for handheld mobile devices. Presented method is mainly aimed to people with motor coordination problems. Comparing with other assistive on-screen keyboards KeyRoad has bigger keys raised at correct time in the right place. The main idea behind the proposed method is inspired by target expansion notation. We have exercised an idea of key expansion, based on the user's previous input. Usability tests in which six persons were involved, have shown that KeyRoad can be an effective solution for the text entry task. Based on the user research results KeyRoad surpasses an ordinary virtual keyboard.

Based on the user feedback received during the experiments with the prototype KeyRoad, for a future work we plan to expand and complement our method. Our primary plan is to perform user research on a large group of disabled users. Also we are planning to employ a timer in order to cancel prediction after certain amount of time to facilitate choosing right key if the prediction was not accurate and to give a default view to the layout design after some time span. That can help avoiding an extra time caused by manual revocation of prediction. Word complement or word predictive modeling can be added to the method in order to accelerate the writing process.

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