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Mobile and VoIP Telephony: a Case Study of the Touchscreen Facilitation for Heavily Motor Impaired Users

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Université de Namur
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Mobile and VoIP Telephony: a Case Study of the Touchscreen Facilitation for Heavily Motor Impaired Users

Jonathan MAES

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Supervisor: ______________________ (Signed for Release Approval - Study Rules art. 40)
Pr. Bruno Dumas

A thesis submitted in the partial fulfillment of the requirements
for the degree of Master of Computer Science at the Université of Namur

Abstract

Nowadays, touchscreens are used everywhere and every time. However, numerous of the applications using a touchscreen are not accessible for heavily motor impaired users. This thesis provides a mobile and VoIP telephony solution designed to facilitate the touchscreen use for this kind of user. In order to do that, a VoIP application was implemented and validated by disabled user and experts. First, this thesis provides a description of this application and of the evaluations made. Then, a review of the scientific literature concerning the touchscreen use by motor impaired users was made and a summary of the observations was provided. Another review was conducted to highlight error rate reducing solution for disabled users. A third review was made, concerning the existing telephony touchscreen application for heavily motor impaired users. After that, some improvements of the application created were proposed in regard with the state of the art.
The proposed solution seems to be the first providing a mobile and VoIP telephony application designed to facilitate the use of the touchscreen by heavily motor impaired users.

Keywords: Touchscreen, heavy motor impairments, accessibility, mobile telephony, VoIP telephony, smartphone, tablet.

Résumé

De nos jours, les écrans tactiles sont utilisés tout le temps et partout. Cependant, de nombreuses applications utilisant l'écran tactile ne sont pas utilisables par les personnes ayant un lourd handicap moteur. Cette thèse fournit une solution de téléphonie mobile et VoIP conçue pour faciliter l'usage de l'écran tactile pour ce type d'utilisateur. Dans cette optique, une application de téléphonie VoIP a été implémentée et validée par un utilisateur ayant un lourd handicap moteur et par des experts. Premièrement, cette thèse fournit une description de cette application et des évaluations mises au point. Ensuite, une revue de la littérature scientifique concernant l'utilisation du touchscreen par les personnes ayant un handicap moteur a été réalisée et un résumé des observations faites a été créé. Une autre revue a été faite pour mettre en lumière les solutions reduisant le taux d'erreurs pour les personnes handicapées. Une troisième revue concernant les applications existantes de téléphonie conçues pour les personnes lourdement handicapées a été réalisée. Après cela, certaines améliorations issues des différentes revues ont été proposées pour l'application.
La solution proposée par cette thèse semble être la première à fournir une application de téléphonie mobile et VoIP conçue pour faciliter l'usage de l'écran tactile par les personnes ayant un lourd handicap moteur.

Mots-clés: Ecran tactile, lourd handicap moteur, accessibilité, téléphonie mobile, téléphonie VoIP, smartphone, tablette.

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I would like to thank the CRETH and the test user for giving me their time to improve my solution.
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Contents

Chapter 1

Introduction

"I suspect we will be seeing touch screens used fore more applications than ever before"(Shneiderman, 1991).

More than 25 years later, proof is everywhere that Shneiderman's prophecy is fulfilled. Touchscreen interfaces are massively used today for various purposes: to buy a train ticket a the station terminal, to withdraw money from an ATM, to communicate with people by means of a mobile phone, etc. However, as of today, not everyone uses them. There is indeed a category of users who struggles with touchscreen technologies, namely the heavily motor impaired people (Irwin et al., 2008, 2010; Irwin and Sesto, 2012; Chen et al., 2013; Chourasia et al., 2017).
The market of disabled people has thus a lot of needs for the use of technologies and their accessibility. Many companies are trying to answer those needs. Home Based (a startup born three years ago) is one of them.

The founders of Home Based were aware of the numerous difficulties faced by the disabled people who wish to continue to live at home. This is why they developed a home control system (called Soline) specially designed to improve the quality of life of disabled people and of their relatives. It is possible to interact with Soline thanks to speech recognition (e.g. if the impairments are too heavy to use a push button), a (or several) push button(s), a pointer,etc..
The users of Soline are mainly people with severe disabilities and/or degenerative diseases such as multiple sclerosis. Consequently, a major challenge for this system is to be usable by people with all kinds of disabilities.

One of these users had a video door entry. However, he could very hardly use it because there was not any compatible program or application which was designed for disabled users.

Thus, a missing feature of Soline was the communication with the video door entry. This is why Home Based recruited two interns. One worked on the PC version (Pierre Rousseau) and the other worked on a mobile version for the smartphone and the tablet (Jonathan Maes).

The scope of the application was extended to the telephony functionality, and more precisely to contacts management, history, favorite contacts features, and call management, but also the creation of an HTTP gateway to link Soline to the application.

As the features were very similar, some decisions in the design of the applications were taken in collaboration with Pierre Rousseau. The details of the work done in collaboration are explained at the Subsection 2.2.

1.1 Research Objectives and Approach

The objective of this thesis is to improve the use of touchscreen mobile platform for people with heavily motor impairments. The research question of this thesis is:

- How to modify a VoIP telephony application for touchscreen devices into a VoIP and mobile telephony solution designed to facilitate the use of the touchscreen by heavily motor impaired people ?

In order to answer this question, it is necessary to know:

- How disabled people interact with a touchscreen and which are the challenges they face?
- How to reduce the error rate of the use of a touchscreen on mobile devices by disabled users?

The answers to these two sub-questions will be provided by the state of the art.

In order to answer the research question, a three-step process is conducted: *research on existing solutions on the market*, *prototyping and interviews*, and *research on related works in the literature*.
The first part was a research on the existing solutions for disabled people in mobile platform. Home based has also explained us their requirements concerning the functionality they wanted, the kind of user they target, the different technologies they use, etc. We extended our research to fit the needs that Home Based expressed, by meeting two experts: the CRETH and Mr Dumas.
For the second part, a user of Soline was interviewed to better understand the problems faced and to highlight the different challenges to solve. We observed the interviewee using a working prototype (proof of concept). We conducted a last interview with the final solution to further consolidate the application we have developed.
The last part consisted of literature reading. The objective was to see how researchers answer the problematic.

1.2 Contributions

This thesis makes the following contributions:

- A modification of an existing VoIP telephony application for touchscreen devices into a complete mobile and VoIP telephony solution designed to facilitate the use of the touchscreen by heavily motor impaired people.
- A review of the scientific literature in order to understand the problems and highlight the challenges faced by users who suffer motor impairments when they use a touchscreen.
- A review of the scientific literature in order to highlight solutions to reduce the error rate in the use of a touchscreen by disabled people.

1.3 Organization

The next chapter of this thesis presents the work done during the internship at Home Based. The chapter 3 is a state of the art about the pure HCI solutions as well as more software solutions or haptic and tangible solutions. The chapter 4 details the modifications or the extensions brought to the solution of the internship, based on chapter 3. The chapter 5 concludes the thesis with an overview of the key points of this work.

Chapter 2

Adaptation of a Mobile Application for Disabled People

This chapter describes the problematic linked to the internship, the work done during this internship, the methodology used to implement the proposed solution and the different aspects explored.
This chapter answers partly the research question of this thesis.
It is important to add that some common parts of this internship were made in collaboration with Pierre Rousseau. This is why he intervenes in this chapter. But, the mobile aspect concerns only the internship of Jonathan Maes, and thus this aspect is specific to this thesis.

2.1 A Word about the Problematic

This thesis answers some questions about the interaction and the problematic linked to the use of a mobile touchscreen device by people with motor impairments.

As mentioned above, the disabled users have a lot of difficulties using a touchscreen. Because of their impairments, there are some gestures or actions they cannot make. In order to facilitate these movements and actions, some guidelines are provided for developers to improve the accessibility of their applications. However, considering the multiplicity of impairments, it is difficult to find a global solution which improves the use of touchscreen for all the impairments. This is why some research attempted to sort impairments according to a functional classification (Petrie, 2001).

They divided the impairments into two main classes: upper limbs impairments and lower limbs/trunk impairments. For both main classes they listed and classified the linked functional impairments and the proposed solution for each.

Another research tried to understand how disabled people use their touchscreen and what are the challenges they face in their daily life (Naftali and Findlater, 2014). They conducted a survey on 16 respondents and an in-person study on 4 users. They found that people with motor impairments have a more difficult time using a phone outside the home than using it inside the home. The multi-touch and the text entry seem to be difficult to use for half the respondents of the survey. Also, one redundant difficulty was tapping on a small target.

With the multiplicity of existing impairments, the users came up with a lot of ways to use the touchscreen of their mobile device. One study collected and analyzed 187 YouTube videos showing people with motor impairments using a touchscreen mobile device (Anthony et al., 2013) to highlight the ways of using a touchscreen. This study was completed by a survey conducted on people featured in these videos. The different and most used ways to interact with a touchscreen found by this study are: the fingers, the (palm or side of the) hands, the nose, the feet, some head sticks, some mouth sticks or a stylus. However, even with these solutions the difficulties remain numerous (e.g. unintentional activation of the screen).

Home Based was aware of this problematic and, because of the diversity in disabilities faced by their users, they wanted a solution convenient for the most users possible.

2.2 Methods

The internship was composed of 4 milestones of research/development/creation:

- Review of the existing applications and libraries
- Review of the motor impairments and their existing software and hardware solutions
- Development of the application and creation of the protocol
- Interviews and tests

After the internship and with a little abstraction, a link can be made with the universal abstract activity cycle (Hartson and Pyla, 2012) shown in Figure 2.1. Two iterations of the abstract activity cycle were completed during the internship. The evaluation step of the first cycle was the analyze step of the second one.

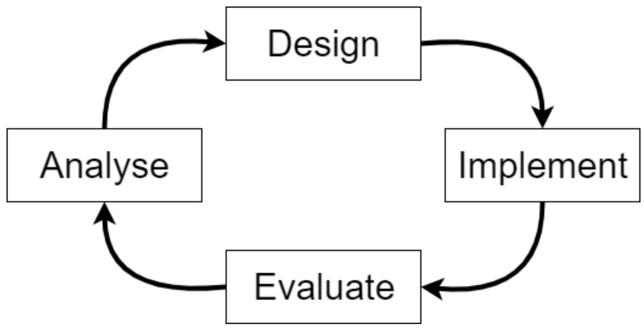

Figure 2.1: Universal abstract activity cycle (taken from (Hartson and Pyla, 2012))

2.2.1 Review of the Existing Applications and Libraries

The goals of this review were to be aware of the existing applications and libraries, to start with the right library/application and to avoid facing troublesome unknown elements at the end of the internship.
The research was limited by the constraints given by Home Based. The applications and the libraries had to use the SIP technology and had to be able to send a DTMF[1] during a call.

2.2.2 Review of the Motor Impairments and Their Existing Software and Hardware Solutions

The objectives of this review were to be immersed following the needs of Home Based, to understand the challenges faced by disabled users and to be aware of the existing solutions. These objectives were achieved by discussing with Home Based about the disabilities of their customers and the solutions they found. The research was extended by meeting the CRETH (the ”Centre de Ressource et d'Evaluation des Technologies pour les personnes Handicapées”) to get more information about the hardware solutions and some issues the disabled users face with mobile telephony.

[1]Dual-Tone Multi-Frequency. It is signal emitted with a tone by pushing on a touch of the dialer. It is often used by the call center.

A meeting was also organized with Mr. Dumas who provided a starting point for scientific literature review. The research was completed by looking at the software solutions developed by Samsung and Apple (overall the accessibility option).

2.2.3 Development of the Application and Creation of the Protocol

The development of the solution is divided into three parts: the technical choices made during the internship, the software architecture and the functionality.

Technical choices

The Android language was chosen because Home Based found more relevant to spend more time on thinking about the application rather than mastering Swift for iOS. Moreover, the Android devices are accessible to more people in terms of price: there are some Android devices under 70€ in comparison with IOS devices which start from 300€. Furthermore, the user of the beta-version had only Android devices. Also, Android doesn't require any graphical libraries, all can be done with the XML language. It is a saving on the potential purchase of a license required to use a graphical library.
The HTML and CSS languages were not chosen because Home Based was concerned about the difficulties to integrate the SIP technology and especially the video codec in HTML. Moreover, these languages don't allow the contact research, the contact management and the telephony functionality.

Concerning the VoIP technology, a choice had to be made between starting from scratch, starting from an existing VoIP application and starting from a VoIP library. Starting the project from scratch was clearly not appropriate, it would take a lot of time and it was totally out of the scope of the internship.

An existing VoIP application seemed to be the right starting point. It avoided the rewriting of many VoIP features that were not the core of the internship. It also allowed taking this time to focus on the application's design for disabled people and the implementation of additional features (e.g. telephony, favorite contact,..).
As mentioned above, the constraints fixed by Home Based were such that the application had to use video and VoIP (especially SIP technology) and had to be able

to send a DTMF.
Several applications matched the criteria: Doubango, Linphone, Zoiper,... After testing these applications, Linphone was chosen because it was the application temporarily used by Home Based. Thus, Linphone fulfilled with certainty all the required features.

Regarding the protocol, JSON was the format used for its flexibility and readability in comparison to XML. Moreover, JSON is faster than XML for the transmission because JSON needs to transfer less data.
For the way to transmit the messages, HTTP seemed to be the right choice. This is why a mini HTTP server was implemented on the Android device.
In order to do that, the use of a library was justified because doing it from scratch would have been long and tedious, and the libraries supplied by Android do not allow creating an HTTP server. Two libraries matched the criteria: NanoHttpd and AndroidAsync. AndroidAsync was used because it allowed a clearer and simpler code.

Software architecture

As shown in Figure 2.2, the mobile application can be connected to the video doorbell entry thanks to the SIP technology. The Windows program developed by Pierre Rousseau can be connected to it in the same way. When a call is established, the application can send a DTMF signal to the video doorbell entry. Once this signal is received, the video doorbell entry opens the door.
Both programs can also be connected to all devices and applications in the environment. This is possible thanks to the protocol (detailed further in this section) developed with Home Based and Pierre Rousseau during the internship.
Also, as both programs were going to be used by the same user, the choices concerning the design of the lists, the number of buttons on the screen, the symbols, the titles and the position of each button were made with Pierre Rousseau for consistency purposes.

Concerning the Android application, the Figure 2.3 represents a voluntarily simplified architecture of the application. The application is composed of activities. Each activity can use some fragments in order to change the interface on the screen.

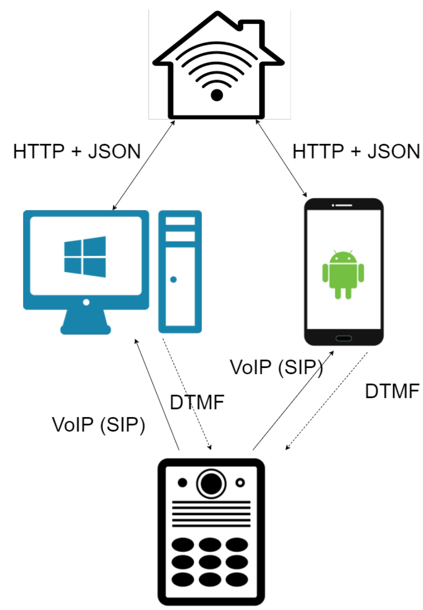

Figure 2.2: Software architecture of the solution

It also allows enabling some animations when an interface is replaced by another. In the schema, the green color represents the classes created during the internship, the yellow and orange color represents classes which have been largely modified for the needs of the internship. The dotted arrows represent a possible call to the target fragment/activity (only in the direction of the arrow). The solid arrows mean a possible call in both direction (call to a fragment/activity and then the user pushes on the back button). Some arrows are annotated to give further explanations on the link between two classes.

The large orange rectangle gives a good idea of the structure and the hierarchy between the fragments in LinphoneActivity. The SettingsFragment is an exception because it can be opened from each fragment in LinphoneActivity.

LinphoneLauncherActivity is the activity launched on the start of the application. LinphoneService is a background service called by RestartServiceReceiver to be sure that the application is never totally shut down.

The others activities, for their part, control the telephony and the VoIP calls thanks to LinphoneManager and some receivers (e.g. PhoneCallReceiver).

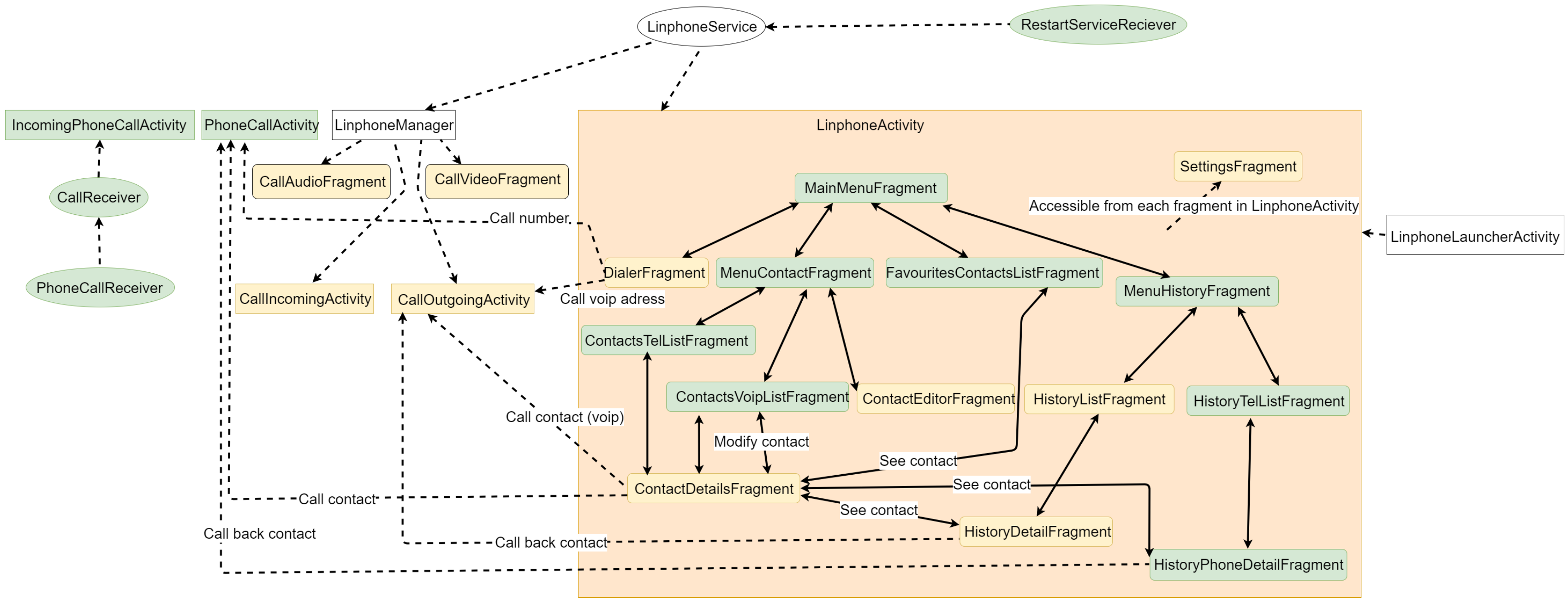

Figure 2.3: Architecture of the application

Solution's choices

In order to improve the application, the methodology used during the internship was composed of iterations. A meeting was organized each week with the internship mentors. Other meetings with the supervisor of the internship were also organized. Thanks to this methodology, the solutions were refined and improved.

It is important to explain how these iterations were integrated in the abstract activity cycle shown in Figure 2.1. The wheel illustrated at Figure 2.4 was created in order to explain the different steps for making a good UX project (Hartson and Pyla, 2012) and to explain the iterations needed to make these steps.
For this internship, the iterations were particularly comprised in the prototyping step.
After the first evaluation based on a high fidelity prototype, explained in Subsection 2.2.4 (which marks the end of the first cycle), Home Based decided to modify the prototype to a beta application more purified (starting point of the second cycle).

Concerning the protocol, it was not completed because some changes had to be made by Home Based in order to fulfill their own requirements for the future of Soline. Thus, an explanation of the ideas and of the solutions found will be described here but these solutions were only partially implemented.

Before explaining the protocol, it is important to give further details about the vocabulary used. For this protocol, an application is a program which provides one or several features by using zero, one or several devices. A device is an object which is used to provide a feature (e.g. the connected lamps, the speakers, the microphones, the voice over, the remote controller, a push button,etc.)

In order to link all the devices to all the applications, the creation of a master which manages the connections and disconnections between the devices and the applications seemed to be appropriate. The big issue was to be compatible with all the existing devices and the all the existing applications. In order to achieve that, it is the protocol (thanks to the master) that manages the connections between the applications and the devices. The devices and the applications just have to follow the steps described in the next paragraph. If it is not the case, a little "driver" can be implemented for the device/application in order to follow the required steps.

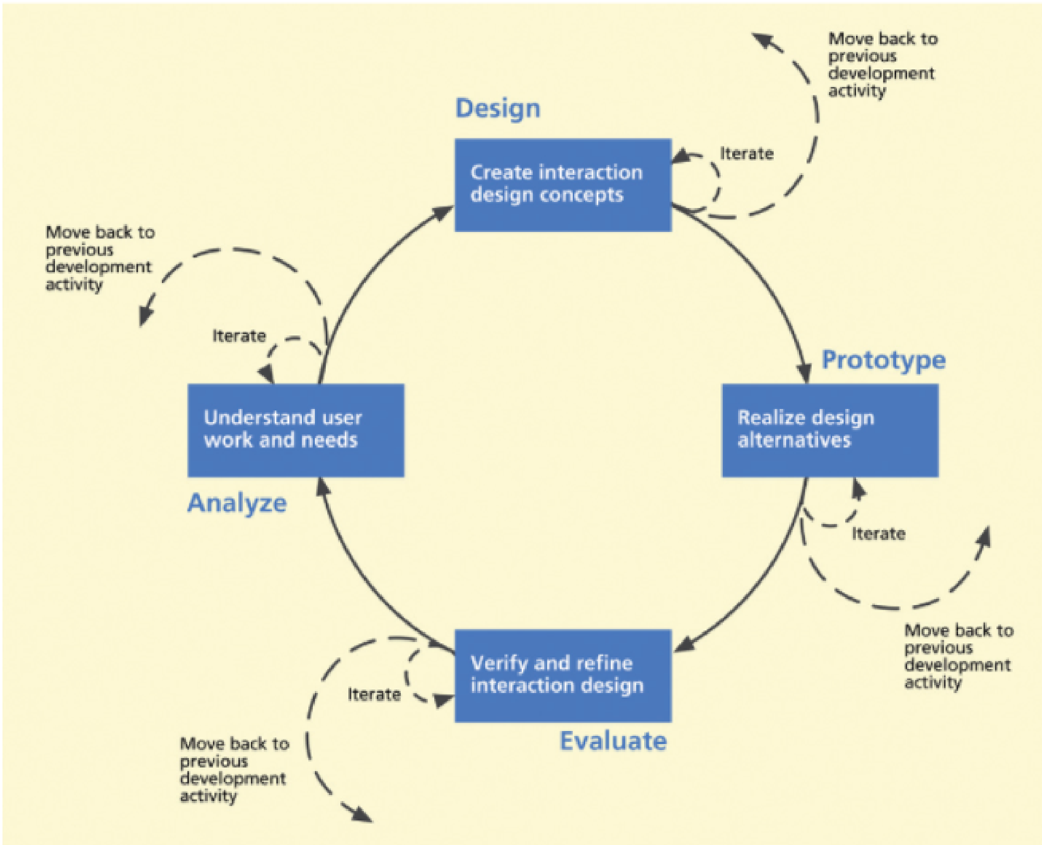

Figure 2.4: The wheel: a lifecycle template illustrating the process part (taken from The UX Book (Hartson and Pyla, 2012))

When an application is connected to one/several device(s), the communication does not pass anymore through the master but directly between the application and the device(s) in order to avoid an overloading of the master.
In order to be compatible with different devices, 12 modes of use were created. These modes allow the devices and the applications to agree on the action followed by pressing a button or by expressing a command (e.g. voice command). Each kind of pressure on a button (e.g. simple click, double-click, triple-click) is linked to zero or one action. The user can also change the links between action and button/command in the settings part of the application to use it in his own way.

The connection works in the following way:

First, the device/app sends a message to the master to inform it is available. Then the master links an application to one or several device(s). The application and the device(s) send to each other their compatible modes. Once the device(s) and the application are synchronized, each time the user presses a button (or expresses a command) included in the configuration (i.e. the links between action and button/command), the device sends a command directly to the app (e.g. up, down, select, call X,...). As mentioned before, this way allows all the applications to be controllable by all the devices.
The main step is the configuration. For that, a default configuration is used if the device(s) is(are) connected for the first time to the app (e.g. button 1 sends the command select, button 2 sends the command next,...). Thus, the device(s) use(s) the default configuration and, if the user want to change the configuration (e.g. press button 5 to go up and not the button 3), he can do it in the application.

Concerning the disconnection, when the master detects that one of the devices is no longer connected (e.g. when the device doesn't reply to the ping), it sends a message to all the applications which were connected to this device.

Concerning the application, it was clearly impossible to create an application which is directly adapted to all the existing motor impairments. This is why some settings were created to enable the users to dynamically adapt the application to their needs. Since the needs of the users can change over time (degenerative disease, ageing of the user,..), this dynamical adaptation was very advantageous. They just need to reconfigure the settings to their current needs and buy another application.
In order to avoid that the user opens the settings accidentally, the option menu is hidden and for displaying it, a slide movement is necessary (see Figure 2.5). Thus, it is impossible for the disabled user to open the settings unintentionally.
The settings were separated in several parts following their categories (see Figure 2.6). Figure 2.7 and 2.8 show the accessibility part of the settings. The following paragraph describes all the solutions proposed in the accessibility settings.

In order to meet the requirements of the users who can only use one/several push button(s) or a remote controller, a cursor was created (see Figure 2.9). This cursor can change of button itself if the user checks the option. The time the cursor stays on each button is adjustable between 1 and 10 seconds (see bottom of Figure

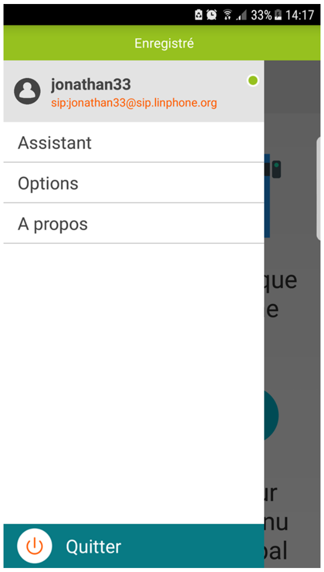

Figure 2.5: Options menu displayed

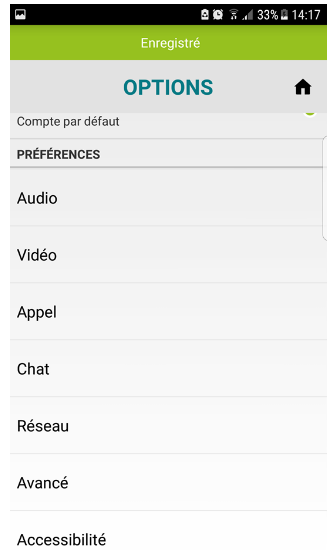

Figure 2.6: Settings

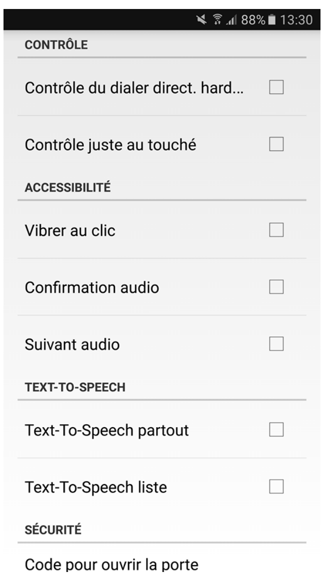

Figure 2.7: Top of accessibility settings

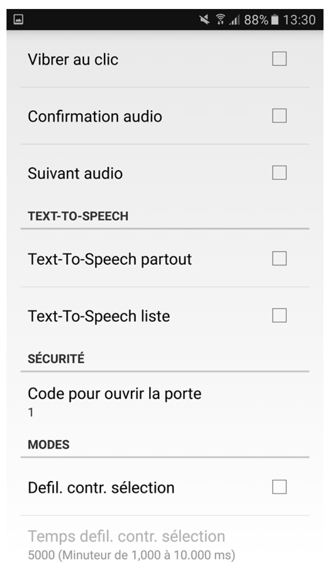

Figure 2.8: Bottom of accessibility settings

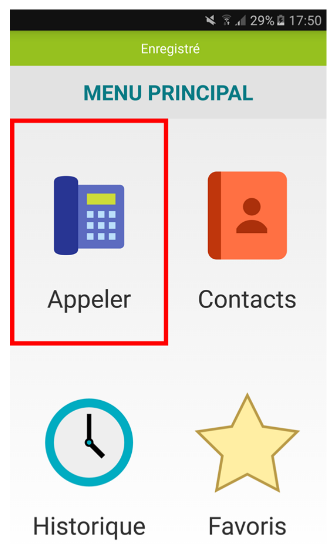

Figure 2.9: Main menu

2.8). If the user doesn't use a push button but an entire keyboard, he can check the option "Contrôle du dialer direct. hardware", the behavior of the cursor will

change and pass on editable areas and then the user can directly enter input with the keyboard. Another option is the control of the application with touch only. If this option is checked, the cursor disappears to avoid that the user have to click twice on the button he wants(one to bring the cursor on the desired button, and the second to confirm the click).
The user can also check the option ”vibrer au clic”. It allows the user to have a physical feedback when he presses a button. This option is especially useful for deaf users.
The application had to be developed also for blind people. This is why, ”confirmation audio” (when a button is pressed) and ”suivant audio” (which emits a beep when the cursor goes to the next button) options were added.
The redundant multimodality (Dumas et al., 2009) provided by these three options (”vibrer au clic”, confirmation audio”, ”suivant audio”) in addition to the fact that the button turns orange when it is pressed, is very useful because the user does not always know if its touch was sensed by the device.
As the communication protocol was not finished, a text-to-speech (TTS) system was created in the application. There are two options, the TTS for the whole application or the TTS only for the lists. If the user chooses the TTS for the whole application, the TTS will say on which button the cursor is and the TTS for the lists will be activated. If the user chooses the TTS only for the lists, the TTS will say the number of the first and the last visible item as well as the total of items present in the list (e.g. item 4 to 9 on a total of 75) and then, it will enumerate all the visible items of the list.

As shown in Figure 2.8, some settings are already preconfigured (such as the code to open the door) to facilitate the installation of the application.

There are other settings categories like the network settings where the user can decide to be reachable by VoIP call only when he is connected on his home's Wi-Fi for security reasons.
There are also the call settings, the user can enable or disable some options like the vibration of the device when there is a missed call, the coloration of the history button to orange when there is a missed call or the possibility to add a call back button on the missed call push notification (see Figure 2.10). In addition, when there is a missed call, an icon is added to the top bar. In that way, the user can see it if he is not on the main menu.(see Figure 2.11).

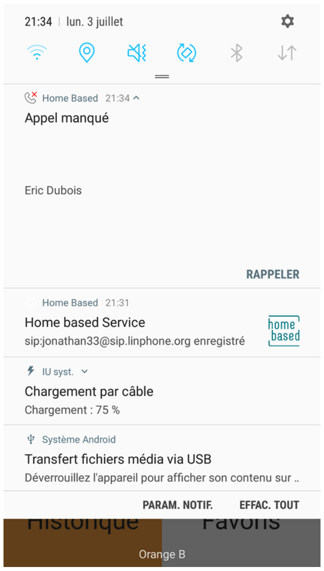

Figure 2.10: Call back button on the notification

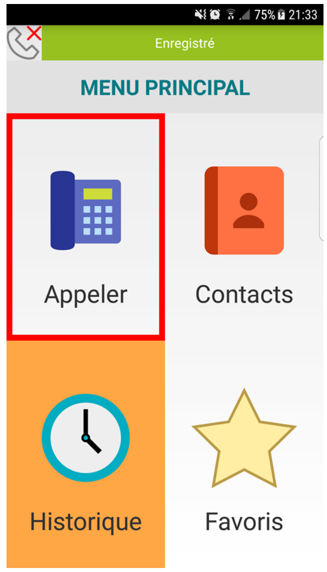

Figure 2.11: Icon and colored button when missed call

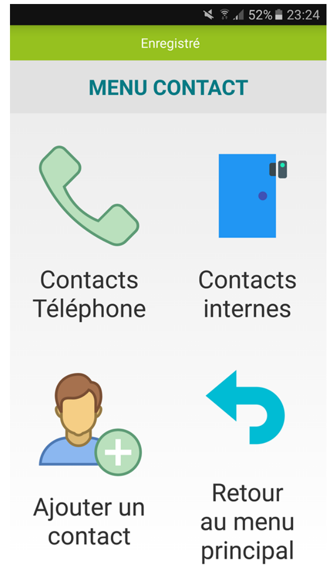

Figure 2.12: Menu Contact

In the audio settings, the user can enable the loudspeaker to listen to the correspondent even if his device is on his knee (like the user of the beta-version).

Since the application has to be as simple as possible, the interface consists of four buttons (when it is possible, for the dialer there are more buttons). Each button is composed of a clear symbol and a text which describes the action of the button (as shown in Figure 2.9). There is also a title in order not to lose the user. Figure 2.12 shows the back button with the title which mentions where the user goes if he presses it.
In the same idea, some animations were created for navigating in the application. When the user clicks on a button, the page where he is, goes to the left followed by the next page which comes from the right (and conversely for the back button). In addition to these animations, the application always displays a message when it loads something (see Figure2.13).
An important requirement of this project was to be usable by all kind of users, this is why it is also available in English. The text on each button and the Text-to-speech are directly available in the right language if the language of the device is English.

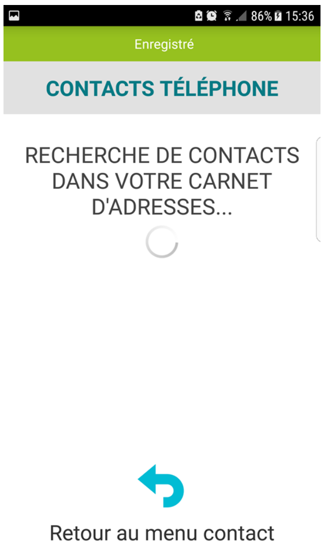

Figure 2.13: Loading the contacts

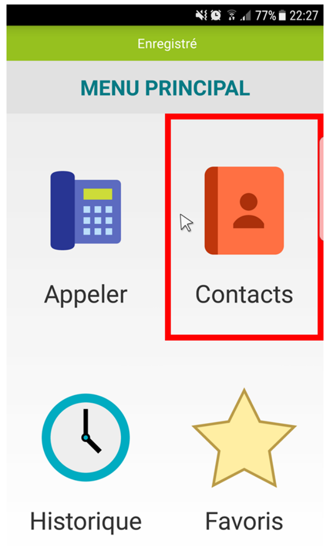

Figure 2.14: Pointer followed by the cursor

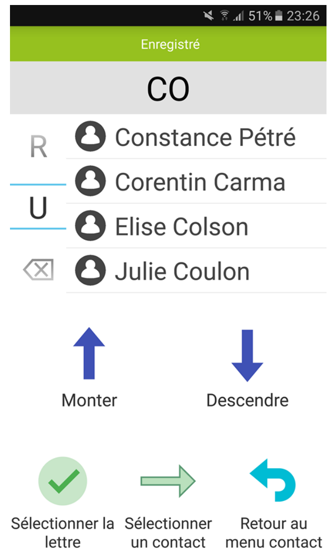

Figure 2.15: Research of a contact

After the evaluation of the first cycle, some features had to be added because the device of the user was used also by other members of his family (his children). Thus, to be sure the user can use the application even after another user clears all background applications, a feature was created to restart the application when it is totally shut down. In that way, the user doesn't need someone else for restarting the application.
In addition, thanks to this feature, the user could (with the use of the protocol) display the application at any time with a voice command.

Another feature added was the possibility to use a pointer (such as a mouse) to interact with the application. The interviewed user controls the pointer with the joystick of her wheelchair. This is why the cursor follows the movement of the pointer and highlights the button where the pointer is (see Figure 2.14). It provides more comfort of use to the user, especially for the interviewed user who attaches the Android device on her knee (a pointer can be very little to that distance).

For disabled people, the encoding of a string is very difficult with a classic Android software keyboard. To improve their comfort, a predictive alphabet was created as shown in Figure 2.15. This predictive alphabet proposes only the next letter of the

contacts' name which matches the letters already entered. With this solution, the user can find a contact in a few clicks. The user navigates in the alphabet with the arrows and when he found the contact, he pushes on the "select a contact" button. Once he has done that, he is in the situation of Figure 2.16 where the focused contact is highlighted. Then, the user navigates in the list of names with the arrows. Once he has selected the contact (by pushing the "select contact" button), he sees the details of this contact, he can call the contact, modify or delete it (see Figures 2.17, 2.18 and 2.19).
The contact modification was not redesigned for disabled users because this task is done rarely and the user's relatives can do it for him if needed. For the deletion, the application displays a message to make sure that the user really wants to delete the contact.

Figure 2.16: Selection of a contact

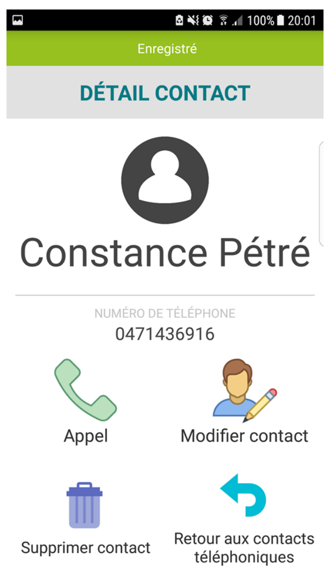

Figure 2.17: Details of a contact

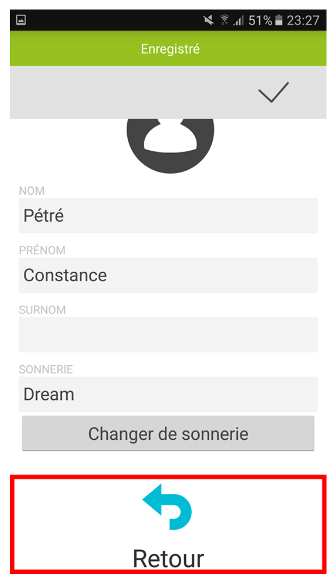

Figure 2.18: Modify a contact

During the review of the motor impairments, some difficulties for the disabled user were highlighted. The disabled user can not make (or with difficulties) the swipe gestures. This is why an elevator system was created to navigate in the lists (like shown in Figures 2.20, 2.21 and 2.22). For the history list, the user navigates in the list 5 items by 5 (see Figure 2.20) and when he found the line he searched, he can navigate one item by one (see Figure 2.21).

Some important information was added on each item of the list such as the time of the call.

The dialer was also rethought to require the fewest clicks possible for any operation.

Figure 2.19: Deletion of a contact

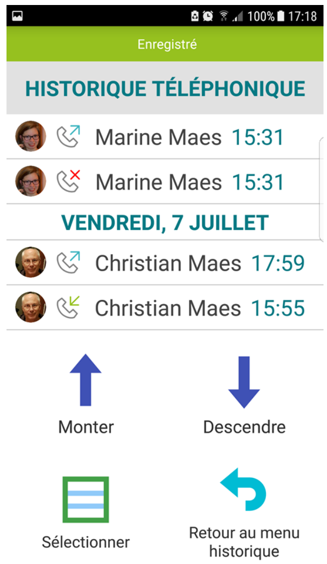

Figure 2.20: History list

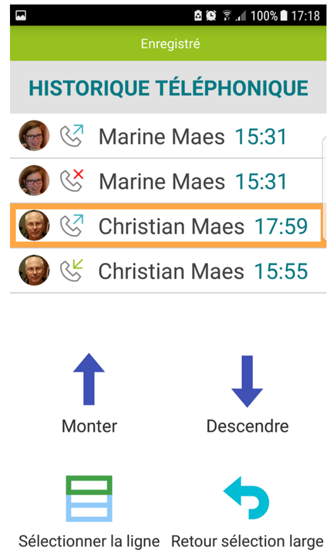

Figure 2.21: Selection of a history

The cursor first went on each line (see Figure 2.23) and after a click on a line went on each number of the line (see Figure 2.24). If the user selects a number or if the user makes a mistake and doesn't want to select a number, the cursor will go at the end of the line and surround the line of numbers in dotted lines. At this time the user has to push on the button to come back at the line selection (see Figure 2.25). The special characters line was hidden to avoid passing each time on it, given the rare use of these characters. The user just has to click on the special characters button to display this line. When the special characters line is displayed, the behavior of the cursor is modified: it is blocked between '+','#','*' and special characters button. The user has to click a second time on the special characters button to hide the special characters line, the behavior of the cursor is than restored to its normal behavior as explained above.

The erase button is disabled and is shaded for more clarity when there is no number or special character entered.

For the call (VoIP call or phone call), the important information is displayed in

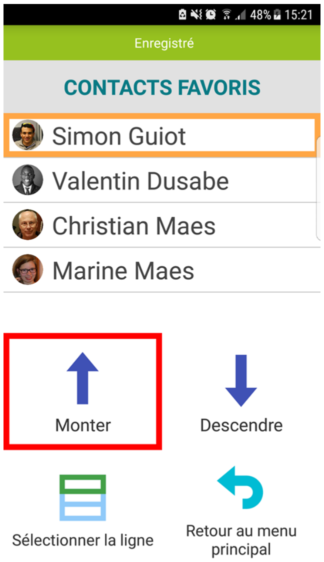

Figure 2.22: Favorite contacts

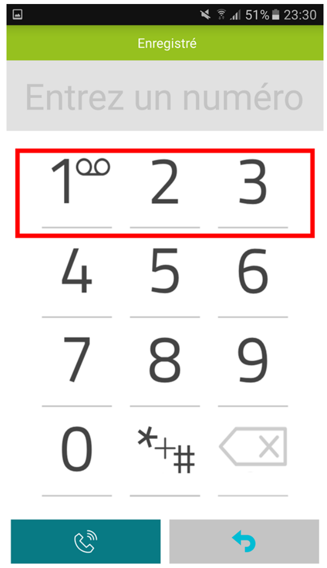

Figure 2.23: Dialer with the cursor on a line

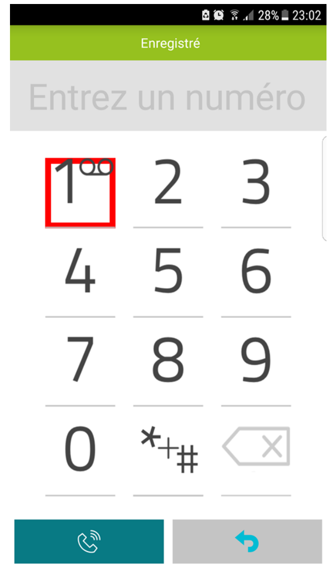

Figure 2.24: Dialer with the cursor on a number

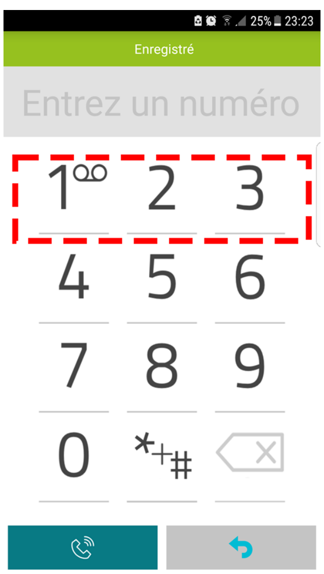

Figure 2.25: Dialer with the cursor on 'come back to line selection'

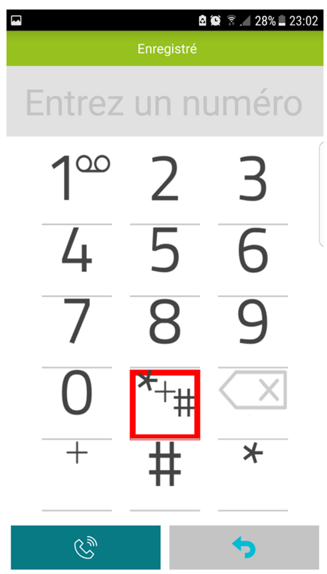

Figure 2.26: Dialer with the cursor on a the special line displayer button

Figure 2.27: VoIP call from the door

large font, in that way the user can see it easily (see Figures 2.27, 2.28 and 2.30). The buttons were colored differently to quickly distinct them and their actions from

Figure 2.28: VoIP call to the door (similar for the phone call)

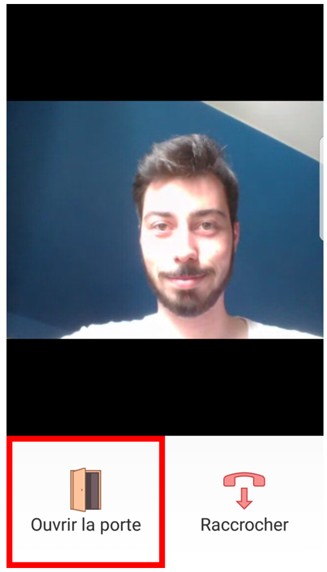

Figure 2.29: Ongoing VoIP call with the door

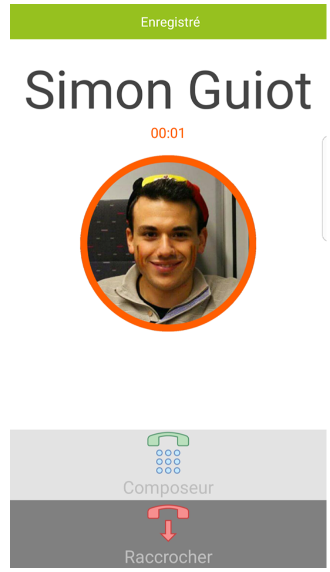

Figure 2.30: Ongoing phone call

the other. Concerning the ongoing VoIP call, when the user press on the "open the door" button, the application sends the DTMF and waits a few seconds before ending the call. It allows the user to push only one time on a button, the rest is automatic.

A view of the purified beta-version's main menu is shown in Figure 2.31. The beta-version was adapted for the tablets and for horizontal orientation, as shown in Figure 2.32. The first button is for calling the door. The second one is the VoIP history. The last one is for opening "Theia" (the previous name of Soline). The usability of the beta-version was also rethink to take advantage of the horizontal orientation as showed at Figure 2.33.
Moreover, for the beta-version some settings were added such as the possibility lock the application on vertical or on horizontal. It allows avoiding the change of orientation during the use (especially if the user uses his smartphone on his knees which is not very stable). Another settings are the possibility to add the Theia IP address and the SIP address of the door in order to configure the application once for all and after this configuration, to only require one click.

As many screens are shown in this chapter, Figure 2.34 (resp. 2.35) represents the different screens visible during the navigation on the beta-version (resp. complete version). The dotted arrows are used when the occurrence of a screen is uncertain (such as when there is no VoIP history). The solid arrows are used when the occurrence is sure.

Figure 2.31: Main menu beta-version (English version)

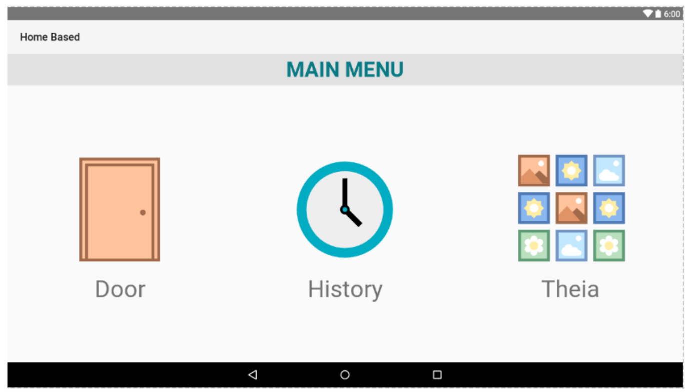

Figure 2.32: Adaptation of the beta version for the tablets

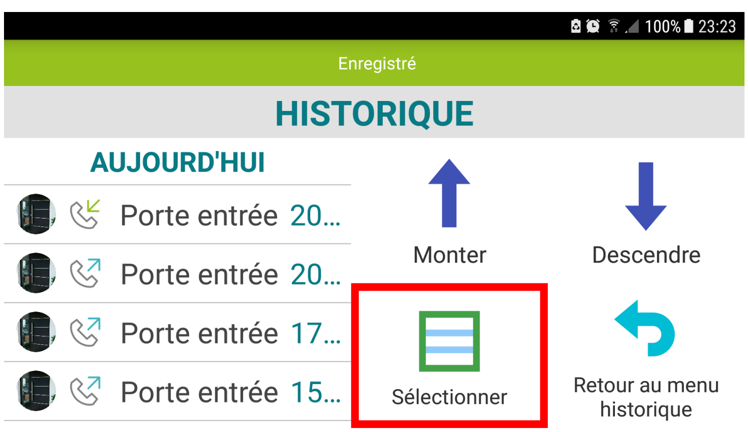

Figure 2.33: Adapted list for horizontal use of the beta-version

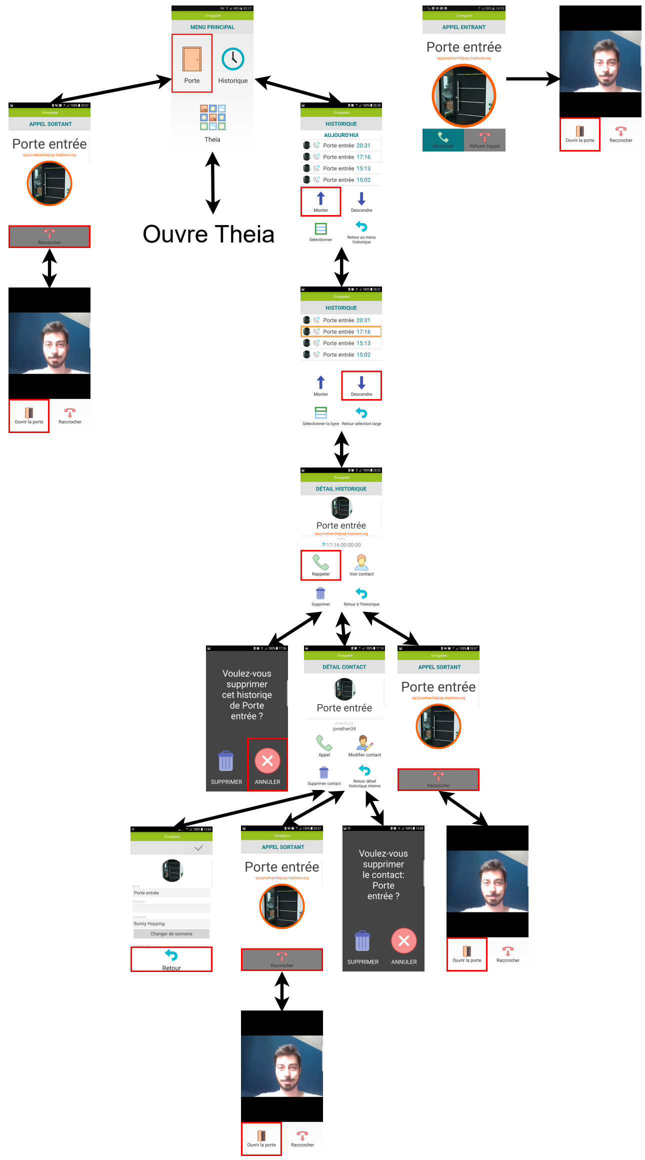

Figure 2.34: Tree representing the navigation on the beta-version application

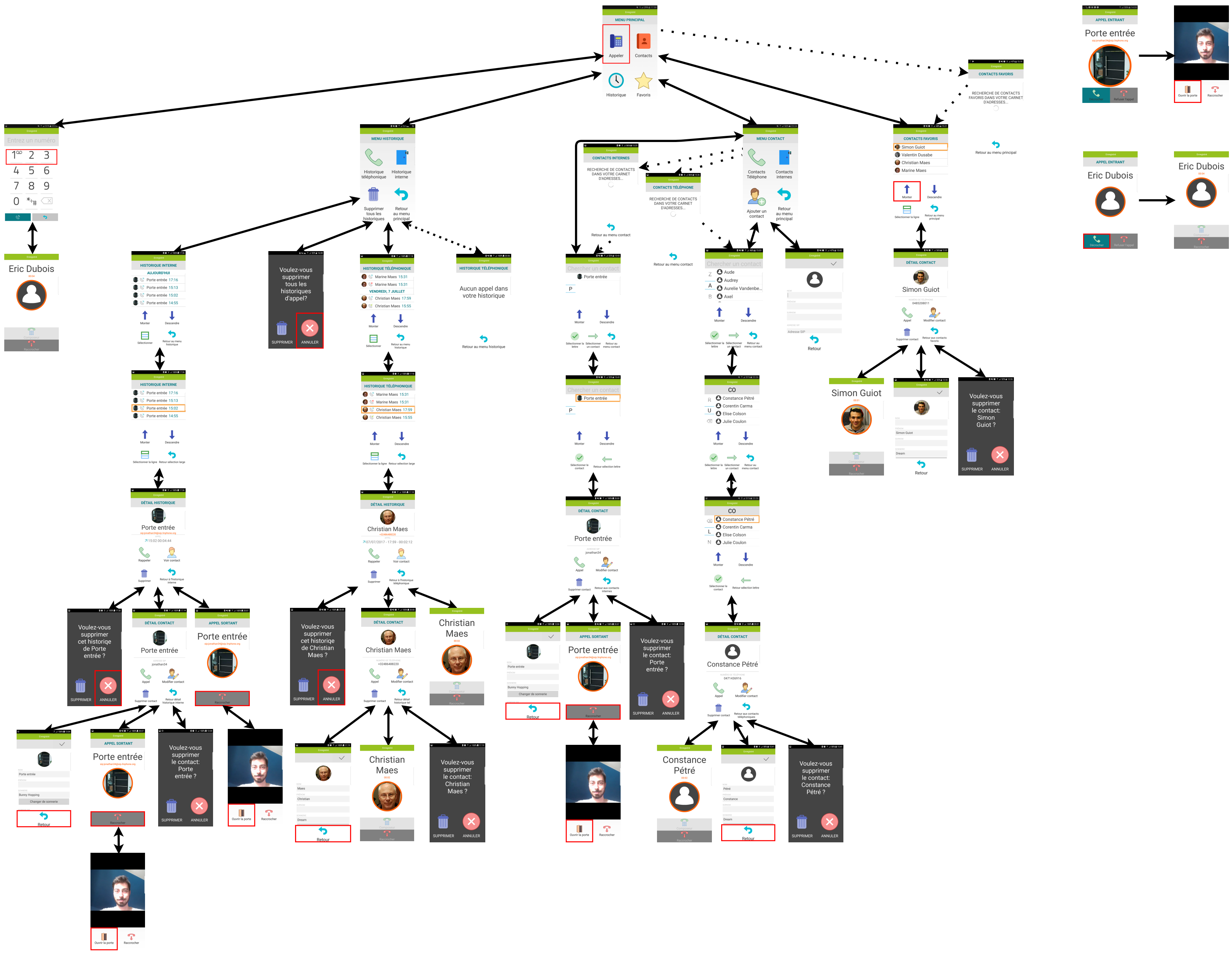

Figure 2.35: Tree representing the navigation on the application

2.2.4 Interviews and Tests

It was decided that a potential user will be interviewed only when a high fidelity prototype will be designed. For this reason, experts such as Home Based, the CRETH[2] and Mr. Dumas were first interviewed. Once the high fidelity prototype was designed, two interviews were made with a potential user who already had the Soline system at his house.
The interviews detailed here are those made with the potential user because these interviews help validating this work.

The test user is a woman who is about forty years old. She lives with her family in an adapted house. She suffers from amyotrophic lateral sclerosis. This illness leads her to lose the use of her legs and also to experience difficulties to use her hands. She has the Soline solution in her house to improve her comfort. She also has a video door entry for which she has to use a software for her PC or an Android application, both being not adapted for her needs (see figure 2.36).

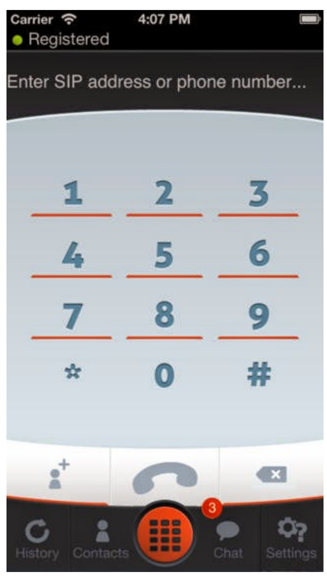

Figure 2.36: Application used by the test user

Two meetings were organized with the test user. The first one marked both the

[2]As a reminder, the CRETH is the "Centre de Ressource et d'Evaluation des Technologies pour les personnes Handicapées".

end of the first cycle and the start of the second cycle (as mentioned in Subsection 2.2).
During the first meeting, the occupational therapist (who is also member of the CRETH) was present. Thus, it was a double evaluation: one made with the test user and the other made with an expert who is used to work and to give advice to disabled people.

The level of fidelity of the prototype can be considered as high-fidelity (real working application). For this evaluation, the entire application was shown (there were some less important features which were not yet implemented) on a PC for Pierre Rousseau and on an Android device for Jonathan Maes.
After having briefly explained the objectives of the applications, the test user was left alone to perform tasks with the application (first on PC and then on Android) in order to see if the applications were intuitive and simple for the user. Finally, she gave her advice on the applications globally and made remarks about several features.

The feedback made by the test user was very positive. She found the applications very intuitive, simple and had no problem to execute the tasks. She made several remarks: the interface should be simplified by putting more options in the settings (adjusted once and for all) and less in the interface. She noted and appreciated the solution used for the keyboard (line selection and then number selection) because it requires less clicks for the same task. She also appreciated the navigation in the lists (5 by 5 and then one by one) because it requires less clicks. The test user preferred by far the new application in comparison with the app she used because (among others) it needed less clicks and required no swipe for hanging on the call. She also found the new application clearer and simpler.

The evaluation made by the occupational therapist was excellent. She found the application very clear and simple to use. She even suggested to target also the elderly people with the application. The occupational therapist was very enthusiastic about the future use of the application.

As mentioned in Subsection 2.2.3, following this interview and the very positive feedback received, Home Based decided to create a more purified prototype called beta-version. The features of the beta-version are: call the door, receive a call from the door, display the history of the calls and open the Theia menu.

Regarding the second interview (which marked the end of the second cycle), after installing and configuring the Android beta-version application on the test user's Android device and the windows beta-version application on her PC, a brief explanation of the applications was given together with Pierre Rousseau. Once again, the test user was also left alone to perform tasks (e.g. call the door). She was very satisfied with the applications. She noted that far less clicks were required to perform the same tasks in comparison with the older version she had.

Indeed, calling the door with the beta-version requires one click. With the application the user had before it requires more than 5 clicks. Another big plus was the possibility to open Theia in one click. Before, it was almost impossible for her: she had to open the browser, enter the local IP address of Theia and the push on "Enter". She can also hang up a call from the door in one click. It previously requires a swipe movement that she can not make. Finally, the beta-user can consult the call history and navigate in it by clicking, using the elevator system explained earlier. Before, she had to use swipe movements to move up and down the list of calls. The same comparison can be made between the entire developed application and the application used before by the test user.

However, one issue was encountered: in order to activate the video, the installation of the codec H264 on the device is required. This codec is automatically installed on Android devices running the version 5.0 (API 21) or later. For the other devices, the installation of this codec was not possible by the actual beta-version application. The devices with version 5.0 or later represents 71,5% of devices running on Android OS[3]. Thus, the majority of the devices can use the video during the call with the beta-version application.
The test user owned a smartphone with a recent version of Android (5.0) and a phablet. Unfortunately, her phablet was too old and did not have the codec H264 installed. Thus, it was not possible to establish a VoIP call with the video on her phablet.

[3] `https://developer.android.com/about/dashboards/index.html#Platform` consulted on July 3,2017.

Finally, Home Based was so satisfied with the application that they installed it on 2 other users' device who use it daily.

2.3 Outlook on the Development

With hindsight, some choices need to be rediscussed. The next paragraph discusses the choices made during the internship from a new perspective: the actual application and its future use.

Even now, the choice of the Android language is still appropriate. Some features such as mobile telephony would be totally impossible to develop for IOS (which is more restrictive at this level). However, Google doesn't give the permission to hang up a call. It is possible to emit a phone call, to refuse it but hang up a call is not permitted. After research, a solution was found which addressed the issue by exploiting a weakness on the Android OS. Nonetheless, with the last update of Android, the solution does not work anymore. The solution of the problem is discussed in Chapter 4.

Another considered solution was the use of a hybrid language (e.g. Xamarin). It allows reaching more potential users (Android, IOS and Windows mobile users). Nonetheless, the problem was the same as for IOS, the mobile telephony functionality could not be developed.

The use of web development seems still not appropriate. Indeed, Android OS allows a lot of different browsers. For the majority (and for the default browser), there is a top bar displayed with the web address and different options. This top bar can lead to a lot of mishandling and can be very unpleasant for a disabled user. Moreover, it requires a hosting service. Thus, for the potential user who owns only a Guinaz and not Soline, it is not possible to have the application because the hosting service is Soline.

For VoIP technology, Liblinphone could have been a good choice because, with regards to the beta-version, the Linphone application provides a lot of features which are unused (e.g. contact management, the chat,...) and linked to a complex internal

architecture. Moreover, the licence's price for Liblinphone is lower than for Linphone.
Nonetheless, Liblinphone for Android is a precompiled library in C, which make the modification very difficult. It was very convenient to already have an overlay to avoid writing it especially as it was not the core of the internship. Ultimately, the decision about this choice is mitigated.

Concerning the application in itself, the feedback is very positive and a lot of extension for the application have been emitted by Home Based such as the control of the home automation directly in the Android application. Other future developments are discussed in Chapter 4.

However, some aspects of the application can still be improved. Knowing that, a review of the scientific literature concerning the use of the touchscreen by heavily motor impaired users and the solutions proposed, is made in the next chapter. It allows finding other solutions to complete and improve the application.

Chapter 3

State of the Art

After the practical approach taken with the internship, a more theoretical approach is detailed in this chapter. This chapter describes the literature review made in order to find solutions to improve the application developed during the internship. It is possible by using some of the solutions proposed by experts in this literature and by taking account of the observations made by researchers.
This review is divided into three parts:

1. Understanding the use of the touchscreen and its challenges
2. Reducing error rate solutions
3. Mobile telephony solutions

These parts answer the first subquestion cited in Section 1.1 (1), the second subquestion (2) and the research question (3).
The structure of this chapter follows these three parts.

It is important to note that this thesis focuses on motor impaired people. Therefore, the scientific literature review is directed towards this kind of users with the awareness that potentially relevant solutions will be missed in the process. However, some solutions or analysis concerning not only motor impaired users were added when they can easily be adapted to the user category of interest.

3.1 Understanding the Use of the Touchscreen and its Challenges

According to Schneiderman (Shneiderman, 1991), the touchscreen clearly provides advantages in comparison with other pointing devices, such as the fact that:

- The touch directly on a target requires less thinking and is a more direct manipulation
- Touching devices are faster than every other pointing devices
- The coordination between the hand and the eye is easier with the touchscreen

However, still according to Schneiderman the touchscreen also has disadvantages such as the fact that:

- The screen can be obscured by the hand during the use
- The position of the touchscreen has to change in comparison with the other devices in order to reduce arm fatigue

Thus, it is clear that the touchscreen inherently provides some solutions for the motor impaired people[1].
However, the use of a touchscreen for motor impaired users still remains problematic (Wobbrock, 2006). Wobbrock listed different factors that make the use of a touchscreen difficult for elderly people suffering from impairments of fine motor skills. It is clear that the consequences of these factors are the same if not worse for more heavily motor impaired people.

Thus, it is very important to understand these problems to give better and more adapted solutions (Newell, 2003).

This is why this section details different studies which tried to understand the use of the touchscreen by heavily motor impaired users and the challenges they encountered. It allows designing more adapted solutions by being aware of the difficulties faced by the users and by taking into account the observations made in these studies for the design of the solutions.
The work of researchers in this regard can be organized into three categories. They tried to understand:

[1] `http://www.nytimes.com/2010/10/31/nyregion/31owen.html` consulted on July 25,2017.

- the disabilities and the linked capacities
- the use of the touchscreen by motor impaired people and the difficulties encountered
- the use of the touchscreen in context and its effects

The first category is not detailed here because it goes beyond the scope of this thesis. However, Cook and Hussey can be cited here because their evaluation method to highlight the capabilities of tetraplegics (Cook and Hussey, 2001) will be used later in this document. The aforementioned research of (Petrie, 2001) can also be included in this category.
The following subsections describe the results achieved for the second and the third categories.

In order to be the clearest possible, Figure 3.1 presents the exact structure of this section.

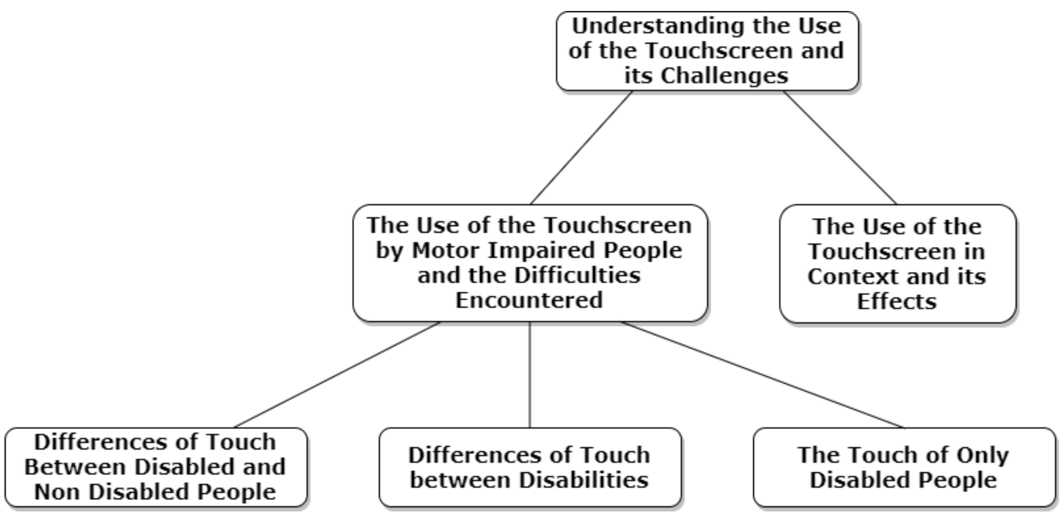

Figure 3.1: Detailed structure of Section 3.1

3.1.1 The Use of the Touchscreen by Motor Impaired People and the Difficulties Encountered

Scientists have used several ways to study the use of the touchscreen by motor impaired people. The researches focused on:

- the difference of touch between disabled and non disabled people.
- the difference of touch between the disabilities
- the touch of only disabled people

The structure of this subsection follows these three categories.

It is important to note that some studies detailed here were not made on mobile device touchscreen. However, "the performance data derived from the interaction with the touch screen is expected to be applicable to a wide range of configurations" (Duff et al., 2010).

Also, in order to be as clear as possible the focus is put on the objectives of the study. Thus, for example, when a comparative study between disabled and non disabled users made some observations which concern only the disabled users, the observations are written in the section of the study and not in the section "the touch of only disabled people".

As this subsection includes numerous studies, at the end of this subsection is presented a table with the summary of each study.

Differences of Touch Between Disabled and Non Disabled People

In order to better understand the touch of disabled people, it is important to highlight the differences of touch between the motor impaired and the able-bodied users. It allows providing solutions more adapted to the kind of user. The research can be sorted into two categories: the study of the tap only and the comparison of the different touch interaction techniques.

The following studies are only focused on the tap gesture.

Duff et al. compared the differences of performance (number of errors[2]) by considering the size of the buttons (10, 15, 20, 25 or 30 mm^2), the size of the gap between the buttons (3 or 5 mm^2) and the approach (front orientation or parallel orientation, see Figure 3.2) (Duff et al., 2010).The authors asked the participants to

[2]An error is a tap which triggers the wrong button

enter a four-digit number (which was randomly chosen and then displayed on the screen) by tapping on the touch screen (see Figure 3.2).
In the group of motor impaired users some participants were wheelchair users. Thus, they used their wheelchair during the experiment.
They found that the touch of disabled users was considerably less accurate than the touch of able-bodied users. It indicated that there was some factors other than the wheelchair which could influence the performance of disabled users. The size of the button had a strong effect on the performance: the smallest button (10 mm^2) had the larger number of inaccurate touches and the biggest button (30 mm^2) had the lowest number of inaccurate touches. The gap size between the buttons did not seem to influence the performance of disabled users.
Another observation was that the performance of the front orientation approach was highly better than for the parallel orientation approach for every participant (see Figure 3.2).

Figure 3.2: The front orientation (left) and the parallel orientation (right) (taken from (Duff et al., 2010))

Chen et al. used exactly the same procedure as the previously mentioned study. They submitted two questionnaires before the experimental tasks and they considered different variables from the previous study: they considered the button size (10, 15, 20, 25 or 30 mm^2) and the gap size between button (1 or 3 mm) to compare the

performance (number of errors, number of misses[3] and time to perform the task[4]) (Chen et al., 2013).
As for the previous study, for all users the performance was better when the size of the button was greater. The gap size had very few impact on the performance but the users seemed to have fewer misses with the 1 mm gap than with 3 mm gap. The time to perform the task decreased when the button size increased.
Concerning the disabled users, they faced generally much more misses (3.9 times) and errors (2.9 times) than the able-bodied users. Moreover, it took motor impaired users 2.2 times longer than the able-bodied users to perform the introducing of the four-digit number. Another difference was the button size for which the performance plateaued: for able-bodied people it was at the size of 20mm, for the motor impaired people the improvement in misses and errors continued until the maximum tested size in this study (30 mm) and the plateau of improvement for the timing parameter was reached at the button size of 25mm.
The subjective data obtained from the questionnaires showed that the majority of disabled users favored a size of button greater or equal at 20mm. It seemed that users preferred a button size smaller than the optimal size in term of performance.

Sesto et al. used also the same procedure with the four-digit number which had to be entered. They chose the button size (10, 15, 20, 25 or 30 mm^2) and the gap size (1 or 3 mm) between buttons as parameters to compare the performance (Sesto et al., 2012). The performance was based on different measures: the force characteristics[5], the dwell time[6] and the impulse[7]. They separated the disabled users into two groups following the kind of disabilities of the users: the gross impaired users and the fine impaired users.
They observed that the size of the button influenced strongly the forces (correlation), the impulses (anti-correlation) and the dwell times (anti-correlation). On average, the users applied 4.7 times more force than necessary to depress the buttons. The consequence of that was a greater risk of fatigue. As previous studies, they estimated that 20 mm button size may lead to a better performance and a greater number of impulses. However, they expressed that more research was necessary to

[3]A miss is a tap which doesn't trigger any button

[4]The time to achieve the task is the amount of time taken to introduce the four-digit number

[5]A vector composed of three discrete forces: the horizontal shear force (Fx), the vertical shear force (Fy) and the force applied to the touch screen (Fz, see Figure 3.3)

[6]The dwell time is the total amount of time on which the buttons were activated

[7]The impulse is the amount of energy the user transmits to the touch screen

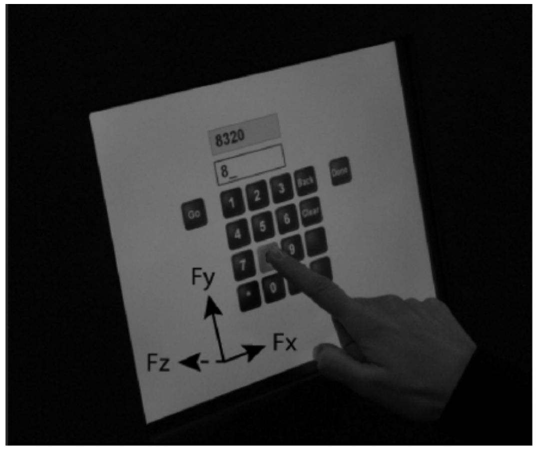

Figure 3.3: the force characteristics (taken from (Sesto et al., 2012))

understand the effects of the forces and the impulses on the fatigue of the user and his performance. Also, the gap had unnoticeable effects on the force characteristics. The dwell time was longer for disabled users than for able-bodied users (2.3 times for gross impairment and 1.6 times for fine impairment). The users with gross impairment transmitted a greater impulse than the fine impairment group and those without disability.

Irwin and Sesto used the same procedure again for another study (Irwin and Sesto, 2009), they also chose the button size (10, 15, 20, 25 or 30 mm^2) and the gap (1 or 3 mm) as a base to compare the performance towards the user categories. The performance was computed with the number of misses and the number of errors.
They made observations very similar to those aforementioned studies: the button size had a significant impact on the performance. More exactly, there was an anti-correlation between the size of the button and the performance. This study confirmed the decrease in performance improvements for button greater than 20mm. It also appeared that the performance tendencies were akin for disabled and non disabled users.

Irwin et al. also tried to understand the differences of touch between disabled and non disabled users by comparing the effects of orientation on the touchscreen tapping (Irwin et al., 2010). They separated the participants into two groups: those with an impairment on the upper extremity and those without impairment on the upper

extremity (in both group there was people who used a wheelchair). They asked the participants to tap alternatively on two buttons as quick as possible during five seconds. The participants performed the task twice (one with front orientation and one with parallel orientation). The only base to compare performance was the orientation of the user. The performance was computed with the number of correct taps, the dwell time and the force used to activate a button.
They observed that the participants tapped fewer times on the screen and used strongly more force when they were on the parallel orientation than when they were on the front orientation. Thus, using an orientation other than the front one leads to a decrease in performance for a simple task. This result confirmed those from (Duff et al., 2010).
Concerning the upper extremity impaired participants, they made generally 50% less taps and had a dwell time 40% longer than the participants without upper extremity impairment.

Irwin et al. have also used the procedure of tapping alternatively on two buttons (Irwin and Sesto, 2012). They chose the peak force[8], the dwell time and impulse as measures to compute and compare the performance. They separated the participants into three groups: the able-bodied, the fine motor impaired and the gross motor impaired people.

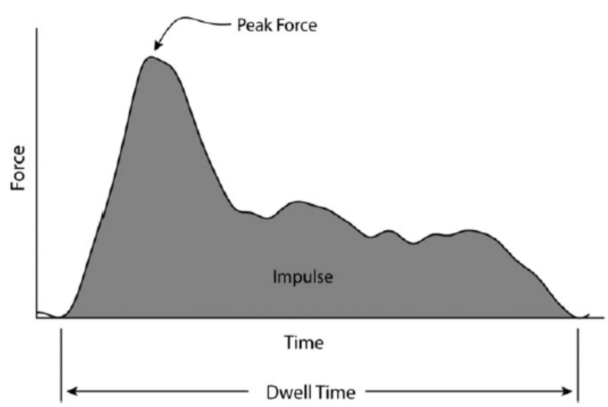

Figure 3.4: The peak force explained (taken from (Irwin and Sesto, 2012))

As (Irwin et al., 2010), (Sesto et al., 2012) and (Chen et al., 2013), they observed

[8]The maximum force used during the dwell time, see Figure 3.4.

that the "disabled participants [...] were significantly slower than non-disabled participants"(Irwin and Sesto, 2012). Also, as (Sesto et al., 2012), they noted that all the participants used strongly more force than required to depress the button. They also found that disabilities had a great impact on the number of correct taps (fewer for disabled users, even fewer for gross motor impaired users), dwell time (longer for disabled users, even longer for gross motor impaired users) and impulses (greater only for gross motor impaired users).

The following studies compared the different kinds of touch.

Chourasia et al. focused their study on the effects of mental effort and on the effects of touch interaction techniques on the performance of disabled and non disabled users (Chourasia et al., 2017). They asked the participants to select four items from a list, the authors changed the mental effort (high and low) and the touch technique that participants had to use (tapping, take-off[9] and mixing (the participant were free to choose the technique between tapping and take-off)) to compare the performance of disabled and non disabled people. They also asked the participants which were their preferred technique by a qualitative ranking after the experience. They observed that in comparison with tapping, take-off took users a longer time to complete the task and led to more misses. However, take-off resulted in fewer errors. Most of the participants preferred the tapping technique. This observation was corroborated for the mixed methods, as participants chose to use the tapping technique 87.2% of the time. One explanation of these observations could be the greater effort required for the take-off technique. Indeed, the user had to kept his finger in contact with the touchscreen until he reached the desired location. Also, the able-bodied participants had better performance (fewer errors, fewer misses, quicker completion time and lower workload) than participants with motor impairment. They also observed that a demand for higher mental effort led an increase in errors.

Nicolau et al. tried to understand the differences between disabled and able-bodied users (Nicolau et al., 2014). In order to do that they compared different interaction

[9] The take-off gesture is a tap where the touch is not interpreted as the location where the finger goes down but is interpreted as the location where the finger goes up

techniques namely tapping, crossing[10] and directional gesturing[11]. They also compared the performance of different target sizes and positions. In order to compute the performance, they chose the following variables: the error rate, the precision[12], the movement error[13] and the movement time[14].
They observed that for tapping, both disabled and non disabled had fewer performance for small targets and that the error rate started to converge for a 12 mm button size. The position had also an impact, disabled participants had a higher precision with targets near the edges. The targets should not be positioned too far from the arm of the user. However, the edges seemed to decrease the performance of the users without disabilities. Their accuracy was three times lower for small targets close to the lower edge. Concerning the crossing, the position had no impact on the performance of any kind of users. Larger sized targets seemed to be easier to reach for disabled users. For the directional gesturing, it was the technique with the greatest differences between disabled and non-disabled users in term of effort. Nonetheless, directional gesture had similar error rates for able-bodied and motor impaired users. The authors also compared the techniques, for the size and the position of the targets, tapping and crossing seemed to be similar in term of performance. Directional gestures had to be used when there is only small targets available. The users seemed to prefer tapping and crossing over directional gesturing with a little preference for tapping (resp.crossing) for disabled users (resp. able-bodied users).

Another study was carried with the same purpose. The authors of this study also compared three interaction techniques: tapping, crossing and directional gesturing (Nicolau et al., 2012). They also compared the performance with different target sizes, positions on the screen and the vertical distance[15]. In order to make these comparisons, they used the error rate parameter.
They found that tapping small targets led to lower performance for able-bodied and

[10]The crossing is made by simply crossing a target, see Figure 3.6

[11]The gesturing is a gesture in one determined direction (this technique is not used with the presence of a target), see Figure 3.6

[12]For targeting and crossing the precision is the minimum length to the center of the target. For the directional gesturing, "precision corresponded to the average distance to the requested direction axis"(Nicolau et al., 2014)

[13]The movement error is "the average absolute deviation from the gesture axis"(Nicolau et al., 2014)

[14]The movement time is the amount of time the user was touching the screen while making the gesture

[15]The vertical distance is the distance between the target and the support of the user. Level 1 is the fewest distance and level 5 is the greatest distance.

disabled users. The error rate started to converge at 12mm. A significant difference between disabled and non disabled users was the magnitude of errors, especially for directional gestures and even more for diagonal gestures. The authors estimated that crossing and directional gestures were suitable alternatives to the tap gesture if there are only small targets. The performance for all the techniques was the same for targets in all the areas on the screen. However, able-bodied users had an accuracy three time lower with the tapping technique when the targets were on the edges (especially the lower edge). The disabled users also had difficulties for tapping a target on the upper edge (due to the greater distance from the arm of the user).

Differences of Touch between Disabilities

Another way to understand the touch of motor impaired people is to compare the differences between the disabilities in regard to the use of touchscreen. This better understanding allows providing solutions more adapted to the user kind of disabilities.

Cook and Hussey provided a functional evaluation which highlighted the grasp capabilities of tetraplegics (Cook and Hussey, 2001). (Guerreiro et al., 2010b) used this evaluation method for the tetraplegic participants (as shown in Figure 3.5). Then,

P	Age	Sex	Lesion Level	Lesion Type	Tip	Palmar	Two-finger	Lateral	Cylindrical	Tee	Spherical	Press
1	28	M	C4-C5	Incomplete	Unable	Unable	Poor	Poor	Unable	Unable	Unable	Good
2	28	M	C5	Complete	Unable	Unable	Good	Good	Fair	Poor	Poor	Fair
3	29	F	C5-C6	Complete	Unable	Unable	Good	Good	Good	Good	Good	Good
4	28	F	C5	Incomplete	Unable	Good	Good	Good	Good	Good	Good	Good
5	61	M	C5	Incomplete	Good	Good	Good	Good	Good	Good	Good	Good
6	30	M	C4-C5	Complete	Unable	Unable	Poor	Poor	Unable	Unable	Unable	Poor
7	34	M	C4	Incomplete	Good	Unable	Good	Poor	Fair	Unable	Good	Good
8	40	M	C6-C7	Complete	Unable	Good	Good	Good	Good	Good	Good	Good
9	61	M	C4-C5	Complete	Good	Good	Good	Good	Good	Good	Good	Good
10	42	M	C5-C6	Complete	Unable	Poor	Good	Good	Good	Good	Good	Good
11	58	M	C5-C6	Incomplete	Unable	Good	Good	Good	Good	Good	Good	Good
12	58	M	C4-C5	Complete	Unable	Unable	Unable	Poor	Unable	Unable	Unable	Fair
13	44	M	C5-C6	Incomplete	Unable	Good	Good	Good	Fair	Fair	Poor	Good
14	64	M	C5	Incomplete	Unable	Poor	Fair	Fair	Fair	Fair	Good	Good
15	27	M	C4-C5	Complete	Unable	Unable	Unable	Poor	Unable	Unable	Unable	Good

Figure 3.5: User profile and evaluation results (taken from (Guerreiro et al., 2010b))

they tried to compare the results of the evaluation with the users' effectiveness on the touchscreen use. In order to do that, they asked the participants to tap on targets presented on a touchscreen device with edges. They used different target sizes

(7,12 and 17 mm) and the screen area of the target to compare the performance. In order to do that, they measured the number of incorrect taps.
They did not find any significant link between the evaluation results and the number of incorrect taps. However, they made some observations about the tap of disabled users. They found that 12 mm was a button size adapted for motor impaired users. They did not found any significant impact of the corners on the performance of the disabled users. With the greatest button size, the edges had a strong impact which was directly linked with the arm that was used by the user. If it was the right (resp. left) arm, the target near the left (resp. right) edge had a strongly lower performance than the right (resp. left) edge. Also, the target on the top of the screen had a lower performance than the target on the bottom of the screen (closer to the user).

Irwin et al. used the four-digit entry as task for the users, they chose the size button (10, 15, 20, 25 or 30 mm^2) and the size of the button gap (1 or 3mm) as the base to compare the performance (Irwin et al., 2008). The performance was computed with the peak force, the impulse and the timing.
They found that the peak force applied by disabled users was between 2.0 and 23.1 times greater than the necessary force to trigger the button. The dwell time was longer for disabled users than for able-bodied users. The dwell time of multiple sclerosis users was 40% shorter than the dwell time of cerebral palsy. Also, the dwell time declined when the size of button increased. Concerning the impulse, the cerebral palsy (CP) users had a greater impulse than multiple sclerosis and non disabled users. The reason for a greater dwell time for CP users is the significantly larger impulse of the other groups of users. Thus, the force only is not a suitable gauge of the button activation effort.

The Touch of Only Disabled People

Another way to understand the touch of motor impaired users is by focusing only on disabled users. The observations of these studies help to better understand the touch of disabled users. This better understanding allows providing solutions more adapted for the disabled users.

Guerreiro et al. tried to determine which way of interacting with a touchscreen was the most adapted for motor impaired people (Guerreiro et al., 2010a). In order to do that they made a questionnaire, a test concerning the capabilities and asked the users to make a target selection using four different techniques of interaction: the tapping, the crossing, the exiting[16] and the directional gesturing. The authors also chose to compare the performance of the techniques in regard to the button size (7, 12 or 17 mm diameter) and the screen areas. The performance was computed with : the task error, the precision[17], the movement error and the movement time.

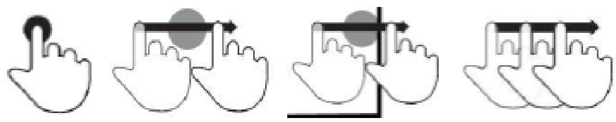

Figure 3.6: Different techniques of interaction: tapping, crossing, exiting and directional gesturing (taken from (Guerreiro et al., 2010a))

They found that for every interaction techniques, the best sizes of target were 12 and 17mm. 12mm better fitted the space constraints induce by to mobile devices. An exception appeared: the exiting technique worked better with bigger targets. Concerning the screen areas, it did not impact the task errors rate. Nevertheless, corners and edges had a positive impact on the precision for tapping and directional gesturing techniques. Thus, physical barriers have some advantages. However, physical barriers can also hinder the correct movement, the precision of crossing and exiting was indeed better for target on the middle of the screen. Also, for the mid-screen area no interaction techniques outperformed the others. However, the diagonals for directional gestures should not be used because it is a very difficult movement for motor impaired users. For the corners, tapping and exiting were the best techniques. Considering edges, tapping was a better suited technique. Regarding the preferences of the users, the data issued from the questionnaires indicated that users preferred tapping and crossing techniques with a little advantage for tapping.Finally, the best combination of technique/target size is the tapping with 12mm. This paper is important to highlight the use of other interaction techniques with the touchscreen when the tapping is not possible.

Trewin et al. used a more practical approach by making an interview and a hands-on session on real Iphone applications and by focusing more on the advice of the users than on the performance (Trewin et al., 2013). They observed different ways of

[16]The exiting is a crossing which is made towards an edge and went beyond the edge, see Figure 3.6

[17]For targeting, crossing and exiting the precision is the length minimum to the center of the target. For the directional gesturing, precision is the mean distance to the targeted direction axis

interacting with touchscreen (tapping, swiping and sliding actions[18], timed taps[19], pinching[20] and three-fingers slide) and they asked the advice from the participants on each technique. They also discussed the accessibility features, the touchscreen mobile device adoption by the users and its customization.

Concerning the touchscreen mobile devices adoption, they observed that the adoption of tablets was greater than smartphones because of the length limitations of the smartphone touchscreen. However, smartphones were considered as very useful and ”physically easy to use” (Trewin et al., 2013). Regarding the customization, it revealed that the users were not aware of the existing accessibility features. They also found a lack of adapted accessibility options for disabled users. Concerning the touchscreen usability, participants were very positive about their capabilities to perform tap, slide and swipe actions. The swiping gesture revealed being easy to make for all the participants. The authors suggested to create the possibility to change the timeout of touch interactions because it was a problem for the participants. They confirmed the greater impulses and dwell times noted in (Sesto et al., 2012) by observing that users slipped when they tapped the touchscreen. They also observed that users touched unintentionally the screen with other parts of their hand causing unwanted actions. For the pinch gesture, it was difficult for the participants to touch the screen with two fingers simultaneously. The three-fingers slide was impossible to perform for all the participants. Concerning the accessibility features, the participants found some of the available features interesting but these features were not designed for disabled users because they did not have the abilities and enough dexterity to perform the required gestures. It also important to add that each participant was unique regarding his capabilities and the gestures which were easy to make for him. The participants who used only simple interaction techniques encountered some problems because these gestures were interpreted as more complex gestures.

Nunes et al. have listed the symptoms of the Parkinson disease. In order to understand the impacts of these symptoms on the people who suffered from Parkinson on their daily use of a smartphone, they conducted interviews with health professionals (Nunes et al., 2016). These impacts are not detailed here because they are out of

[18]The difference between the two movements is that sliding is more precise than swiping. The swipe means a directional gesture

[19]E.g. double clicks and triple clicks

[20]E.g. zoom movement

the scope of this thesis. Then, they made a usability experiment on smartphone applications to measure these impacts. They compared four interaction techniques: the tap, the swipe, the multiple-tap and the drag gestures. They also compared these gestures by changing the size (for tap and swipe) and the space to around elements (for tap, swipe and multiple taps). They used several different parameters to compute the performance, these parameters are detailed in Table 3.1.
They observed that there was an anti-correlation between the button size and the accuracy of touch. Nevertheless, 14mm seemed to be the optimal size for users accuracy (likely due to training). The reaction time was also the fewest for a 14mm size button. They also noted that the space around elements had no impact on the accuracy of touch. Concerning the swipe, people who suffered from Parkinson were able to perform the swipe gesture. Target height and space between target and around elements had no effect on the swipe gesture performance. They also observed that participants performed swipe gesture at very different speeds. Regarding the multiple-taps, participants were able to perform ten successive taps without affecting the speed. This observation is on contradiction in regard with the interview made with health professionals which indicated that bradykinesia impacted the people with Parkinson. For drag gesture, participants were able to perform drag gesture over at least 10 elements without adaptation. However, they made this gesture slowly (about 4 seconds). 4.7mm between elements seemed to be enough for participants to succeed the gesture. Then, the authors compared multiple-taps with drag gestures. The performance was better for multiple-taps (until 10 elements). After that, the authors listed 12 guidelines to design a smartphone application for people who suffered from Parkinson which will be discussed at the Section 3.2.

Mott et al. tried to understand the way of touch of motor impaired users (Mott et al., 2016). The authors asked the users to touch the center of a crosshair in order to analyze the intended target and the areas of the screen which were really touched. They measured the number of touches which were simultaneous, the duration of the trial[21] and the ”distance from the center of the ellipses that represent the first and last registered touches to the center of each crosshairs” (see Figure 3.7).
They observed that motor impaired users touched unwillingly the screen with their palm or with other fingers before the intentional touch and at the end of it. The

[21]The duration of the trial is the amount of time between the registering of the first touch event and when ”all registered touches were removed”(Mott et al., 2016)

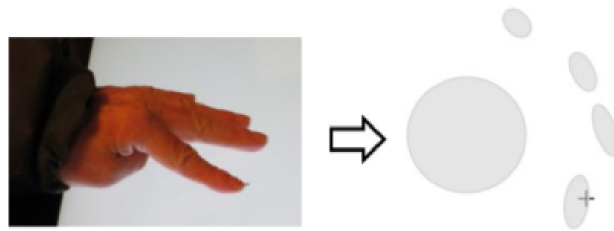

Figure 3.7: Example of various contact regions with the touchscreen when several fingers touch the screen (taken from (Mott et al., 2016))

authors noted also that when the users approached the target, they use the screen as a support to slide on it. Another observation was that because of a lack of dexterity, when the users tried to touch the target with one finger, they made concurrent touches. Some users used only their fist or their hand to interact with the touchscreen. In order to improve the touch of disabled users, Mott et al. developed a template matching solution named ”Smart Touch” which will be detailed at the Subsection 3.2.6.
It is important to add that the experiment was made on a tabletouch which is a much more larger touchscreen than those of mobile devices.

Table 3.1 presents a summary of all the studies detailed in this section. This table includes the reference of the study, the objective, the methodology (the way used, the hardware used for the experiment, the variables chosen and the measures used), the observations and the solutions.

Study	Objective	Methodology	Observations and proposed solutions
(Duff et al., 2010)	Understand the differences between motor impaired users and able-bodied users (analyze of tapping)	Way used: Experiment: Enter a four-digit number with the touchscreen Hardware used: ATM (15 inch resistive touchscreen and a force plate) Variables: Size of button (10, 15, 20, 25 or 30 mm^2) Gap between buttons (3 or 5 mm^2) Orientation (parallel or in front) Measure: Error rate	Observations: Performance for front is better than for parallel orientation The smaller is the button, the fewer is the performance The greater is the button, the better is the performance The gap has no influence Proposed solutions: At least 20 mm^2 for button size Settings system for a solution more adapted for each user
(Chen et al., 2013)	Understand the differences between motor impaired users and able-bodied users (analyze of tapping)	Way used: 2 interviews An experiment: Enter a four-digit number with the touchscreen Hardware used: ATM (15 inch resistive touchscreen and a force plate) Variables: size of buttons (10, 15, 20, 25 or 30 mm^2) Gap between buttons (1 or 3 mm) Measures: errors Misses Time to complete	Observations: The greater is the button, the better is the performance Disabled users have more misses, more errors and are 2.2 times longer Able-bodied users: the top of performance is reached at button size of 25mm Disabled users: the performance increases until 30 mm (25 mm for the time measure) Gap of 1 mm leads to slightly better performance than a gap of 3 mm When button size increases, time to complete decreases Users have a preference for 20 mm in term of button size (they prefer a fewer size than the size for which the performance is the best Proposed solution: At least 30 mm for button size
(Sesto et al., 2012)	Understand the differences between motor impaired users and able-bodied users (analyze of tapping)	Way used: Questionnaires 2 self-report studies Experiment: Enter a four-digit number with the touchscreen Hardware used: Kiosk (15 inch resistive touchscreen and a force plate) Variables: Size of buttons (10, 15, 20, 25 or 30mm^2), gap between buttons (1 or 3 mm) Measures: Force characteristics Dwell time Impulse	Observations: Correlation between size and impulse Correlation between size and dwell time Anti-correlation between size and force 4.7 times more force used than necessary (for all users) Longer dwell time and greater impulse for gross motor impaired users Gap has very few effect on touch performance Proposed solution: None
(Irwin and Sesto, 2009)	Understand the differences between motor impaired users and able-bodied users (analyze of tapping)	Way used: Experiment: Enter a four-digit number with the touchscreen Hardware used: ATM? N/A Variables: Size of buttons (10, 15, 20, 25 or 30 mm^2) Gap between buttons (1 or 3 mm) Measures: Errors Misses	Observations: Button size impacts performance Anti-correlation between button size and performance After 20 mm decrease of performance improvements Performance tendency akin for disabled and able-bodied users Proposed solution: None
(Irwin et al., 2010)	Understand the differences between motor impaired users and able-bodied users (analyze of tapping)	Way used: Experiment: Tap alternatively on 2 buttons during 5 seconds Hardware used: Kiosk Variable: Orientation Measures: Number of correct taps Dwell times Force	Observations: Upper extremities impaired users made 50% fewer taps and take 40% longer dwell time than those without upper extremities impairment The parallel orientation leads to fewer taps and strongly more force used than front orientation Proposed solution: None
(Irwin and Sesto, 2012)	Understand the differences between motor impaired users and able-bodied users (analyze of tapping)	Way used: Questionnaire Experiment: Tap alternatively on 2 buttons during 5 seconds Hardware used: Kiosk (15 inch resistive touchscreen and a force plate) Variable: None Measures: Number of correct taps Peak force Dwell time Impulse	Observations: Disabled users are slower than non disabled users, all participants use more force than required The disability has a great impact: on number of correct taps (even fewer for gross impaired users), on dwell time (even longer for gross impaired users), on impulses (do not impact fine impaired users) Proposed solution: Adapt the dwell time for disabled users
(Chourasia et al., 2017)	Understand the differences between motor impaired users and able-bodied users (analyze of different techniques of touch, focus on mental effort)	Way used: Advice of users Experiment: use of a mobile application Hardware used: Tablet device (Samsung galaxy tab 10.1inch) Variables: Mental effort (low and high) Technique of touch (tapping, take-off and mixing) Measures: Errors Misses Time to complete task	Observations: Take off takes a longer time, has more misses and fewer errors than tap Most participants prefer tapping For the mixed technique, tapping was chosen 87.2% of time An increase of mental effort leads to an increase of errors Able-bodied users have better performance (fewer errors and misses, quicker completion time and lower workload) than disabled users Proposed solution: Use identical interfaces with accommodations such as longer time to complete task

(Nicolau et al., 2014)	Understand the differences between motor impaired users and able-bodied users (analyze of different techniques of touch)	Way used: Advice of users Experiment: use different interaction techniques to select a target Hardware used: PDA (QTEK9000) Variables: Tapping (size: 7, 12 and 17mm, position: middle and edges) Crossing (size: 7, 12 and 17mm, position: middle) Directional gesturing (position: middle and edges) Measures: Errors Precision Movement error Movement time	Observations: Tapping: • Fewer performance for small targets • Error rate starts to converge at 12mm • Disabled users have more precision if the target is near the edges (and not too far from their arm) • Able-bodied users have 3 times lower performance near the edges Crossing: • Screen area has no impact • An increase of size leads to an easier use for disabled users Directional gesturing: • Technique with the greatest difference of effort needed between disabled and non-disabled users but they have similar error rate Comparison of techniques: • For the size and the position, tapping and crossing have similar performance • Directional gesturing is suitable if small target are only available Proposed solution: None
(Nicolau et al., 2012)	Understand the differences between motor impaired users and able-bodied users (analyze of different techniques of touch)	Way used: Experiment: use different interaction techniques to select a target Hardware used: PDA (QTEK9000) Variables: vertical distance (level 1 to 5) Tapping (size: 7, 12 and 17mm, position: middle, corners and edges) Crossing (size: 7, 12 and 17mm, position: middle) Directional gesturing (position: middle, corners and edges) Measure: errors	Observations: Small targets lead to fewer performance for tapping There is a big difference of performance (number of errors) between disabled and non-disabled users Crossing and directional gesturing are suitable alternatives of tapping if there is only small targets available The performance of all techniques is the same for target in all the areas on the screen The accuracy of able-bodied users is 3 times lower with tap technique when targets are on the edges (especially lower edge) The disabled users have much difficulties for tapping target which are on the upper edge (because of the greater distance from the arm of the user) Proposed solution: None
(Guerreiro et al., 2010b)	Understand the differences between disabilities	Way used: Capabilities assessment test Experiment: tapping on a target Hardware used: PDA (QTEK9000) Variables: Screen area (position) Size (7, 12 and 17 mm) Measure: Correct taps	Observations: No link between capabilities results and number of incorrect taps The corners have no impact on the performance The edges have a great impact for greatest size The performance of targets near the edges is dependent of the arm used (the right arm leads to lower performance for targets near the left edge, and conversely) Targets on the top of the screen lead to fewer performance Targets on the bottom of the screen lead to greater performance Proposed solutions: 12 mm is a suitable size Buttons have to be closer to the arm of the user
(Irwin et al., 2008)	Understand the differences between disabilities	Way used: Experiment: Enter a four-digit number with he touchscreen Hardware used: Kiosk (touchscreen and a force plate) Variables: Size of button (10, 15, 20, 25 or 30mm²) Gap between buttons (3 or 5 mm²) Measures: Peak force Impulse Timing	Observations: The peak force of disabled users is between 2 and 23.1 times greater than the necessary force For disabled users dwell time is longer than for able-bodied users Dwell time of multiple sclerosis users is 40% shorter than dell time of users with cerebral palsy The dwell time decreases when size increases The impulse of cerebral palsy users is greater than users with multiple sclerosis and able-bodied users The force only is not a good gauge of button activation effort Proposed solution: None
(Guerreiro et al., 2010a)	Understand the different touch techniques of disabled users only	Way used: Questionnaire Capabilities assessment test Experiment: use different interaction techniques to select a target Hardware used: PDA (QTEK9000) Variables: Tapping (size: 7, 12 and 17mm, position: middle, corners and edges) Crossing (size: 7, 12 and 17mm, position: middle) Exiting (size: 7, 12 and 17mm, position: edges and corners) Directional gesturing (position: middle and edges) Measures: Errors Precision Movement error Movement time	Observations: The sizes with the best performance are 12 and 17 mm for tapping and 17 mm for exciting The screen area has no impact on task error but targets on corners and edges increase the precision of tapping and directional gesture, and decrease precision for crossing and exciting There is no best technique for targets on the middle of the screen Diagonal of directional gesturing should not be considered because it leads to very few performance For the corner, tapping and exciting are the more suitable technique Users prefer tapping and then crossing The best combination of interaction technique and size is tapping and 12mm Proposed solution: None

(Trewin et al., 2013)	Understand the different touch techniques of disabled users only	Way used: Interviews and hands-on sessions: use of mobile application Hardware used: Smartphone (Iphone) Variables: Accessibility features Touch interaction techniques: tap, slide, timed taps, pinching, three-fingers slide Measures: Observations and advices For tapping: touch location start and end,touch length while tapping	Observations: Tablets are better adopted than smartphones smartphones are considered as "physically easy to use" and very useful Users are not aware of the available accessibility features but they find it interesting Lack of adapted accessibility options (require high dexterity) Participants are very positive about their capabilities to perform tap, slide and swipe actions swiping is easy for all the participants A problem encountered is the timeout of gestures Users slip when they tap (due to the greater impulse and dwell time) Unintentional touch with other parts of the hand Difficulties to touch the screen simultaneously with two fingers for pinch gestures The three-fingers slide is impossible for all the participants Each participant has unique capabilities and unique combination of gestures found easy Gestures of users who used only simple interaction techniques are interpreted as complex gestures Proposed solutions: Fix the easiest technique for the user between take-off and tapping (the swipe has to still be enabled) Change the timeout for touchscreen interactions Create undo feature If the user uses only one finger,suppress any additional touch (which are unintentional) Disable complex gestures when the user uses only simple gestures
(Nunes et al., 2016)	Understand the different touch techniques of disabled users only	Way used: List of Parkinson disease symptoms Interviews with health professionals Usability experiment: use of mobile application Hardware used: Smartphone of 4 inch Variables: Button size (7, 10.5, 14, 17.5 and 21 mm) Distance from target from around elements (3.5, 7 and 10.5 mm) Interaction techniques: tap, repetitive taps, swipes and drag gestures Measures: For tapping: (reaction time, number of try before reaching the target, coordinates of each touch) For swiping: (reaction time, taps per target, coordinates of each touches, distance of gesture, gesture duration) For multiple tap: (completion task time, time to reach a certain level in the application, number of touches) For drag gestures: (completion time task)	Observations: Anti-correlation between size and accuracy of touch Tapping: • 14 mm button size leads to the best accuracy and best reaction time (influenced by the training) • The space around elements has no impact Swiping: • Users are able to perform the swipe gesture • The space between targets and around elements has no impact • Users have very different level of speeds Multiple-taps: • Users are able to perform the multiple-taps until 10 taps (contradicts the interview with health professionals) Drag gestures: • Users are able to perform drag gesture when there is at least 10 elements • Slow gestures (4 seconds) • 4.7 mm between elements is enough Multi-taps is better adapted (until 10 elements) than drag gesture Proposed solutions: Guidelines Button size of 14 mm
(Mott et al., 2016)	Understand the way of touch of disabled users only	Way used: Usability experiment: touch the center of crosshairs Hardware used: Microsoft Pixelsense interactive table Variable: None Measures: Number of concurrent touches Duration of trial "Distance from the center of the ellipses that represent the first and last registered touches to the center of each crosshairs"	Observations: Motor impaired users touch unwillingly the screen with their palm or with other fingers before the intentional touch and at the end of it When disabled users approach the target, they use the screen as a support to slide on it Disabled users make concurrent touches when they try to touch the target with one finger Some of disabled users use only their fist or their hand to interact with the touchscreen Proposed solution: Smart Touch (a template matching solution)

Table 3.1: Table summarizing all the studies presented in this subsection

3.1.2 The Use of the Touchscreen in Context and its Effects

Most of the studies detailed in Subsection 3.1.1 were made inside a laboratory with a minimum of influence. However, as mentioned before (see Section 2.1), the environment can influence the importance of the difficulties experienced during the use of the touchscreen (Naftali and Findlater, 2014). This is why some research was made specially by analyzing the touchscreen use in context and its effects. These effects of the environment on performance are often called situational impairments.

Another aforementioned paper (see Section 2.1) is an analysis of Youtube videos generated by the users themselves showing disabled people using a touchscreen mobile device (Anthony et al., 2013). In addition to the observations already mentioned, they noticed that some users adopt physical adaptations for their devices. One of these adaptations was a screen protector (see Figure 3.8) because one of the users of the tablet interacted with the screen by licking it. Another adaptation was the use of (homemade) physical barriers (see Figure 3.9).
They also noted that in 83% of the videos analyzed the touchscreen device was layed flat on a surface (42%) or it was used in vertical position (41%).

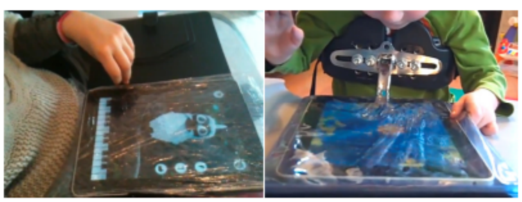

Figure 3.8: Examples of screen protector (taken from (Anthony et al., 2013))

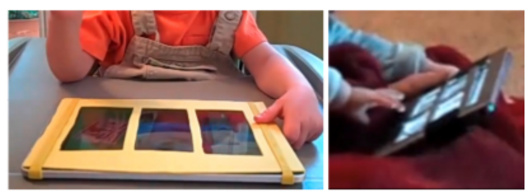

Figure 3.9: Examples of physical barrier (taken from (Anthony et al., 2013))

Montague et al. have also made a study in the wild. Furthermore, they made an investigation more oriented on the temporality (Montague et al., 2014). They conducted a four-week study during which they measured the touchscreen abilities of nine motor impaired people. In order to do that they asked the participants to fill out sudoku grids. It allows studying the differences between the intentional target and the target deducted by the gesture recognizer of the device in an entertaining way for the participant. To determine if the action was made intentionally or not, they applied the following methods:

- If a tap is made on an empty cell, the keyboard appears to let the user enter the desired number and the tap is considered as correct and intentional.

- If a tap is attempted on a cell which is already filled, the application does not provide any interaction feedback (see step A in Figure 3.10).
  Indeed, the game does not allow a wrong number in a cell, thus when a cell is filled it means that the number is correct so the cell is not interactive anymore. Nevertheless, the application records the wrong tap. Then, the user will retry his tap on the desired cell (see step B in Figure 3.10). After that, the user will fill the correct number (see step C in Figure 3.10). Then, if he taps on the "hide" button or on another empty cell (see step D in Figure 3.10), the first try on the filled cell will be considered as a wrong target and refined to the cell tapped at the second try and the other taps will be considered as correct and intentional.

- If the user tries to tap on an empty cell but the touch performed is not recognized by the device, the application does not provide any interaction feedback (see step E in Figure 3.11). However, it records the tap as an unrecognized tap. Thus, the user will retry his tap on the desired cell. This time, the tap will be accepted (see step F in Figure 3.11). The following scenario will be the same as detailed in the previous toggle. At the end of the scenario, the first try will be refined into a intentional tap gesture.

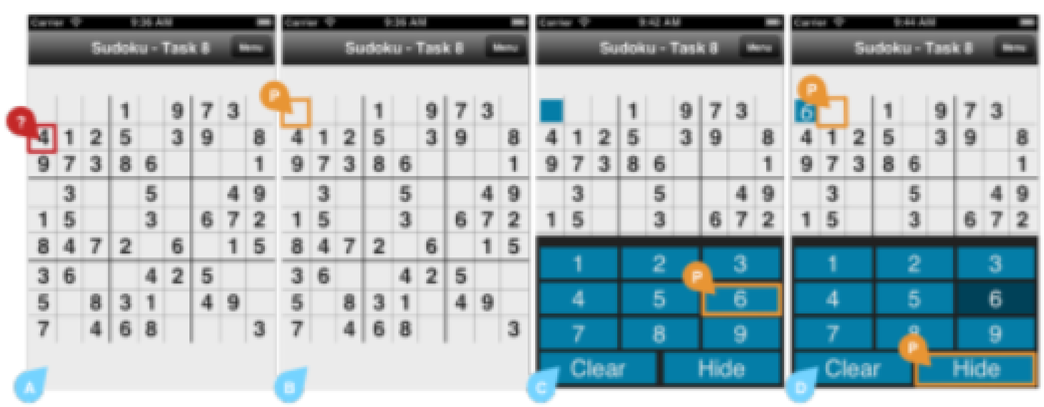

Figure 3.10: Wrong target refining (taken from (Montague et al., 2014))

The results of this study are obtained by comparing the number of recognized and unrecognized gestures and by comparing if these gestures were correct or incorrect.

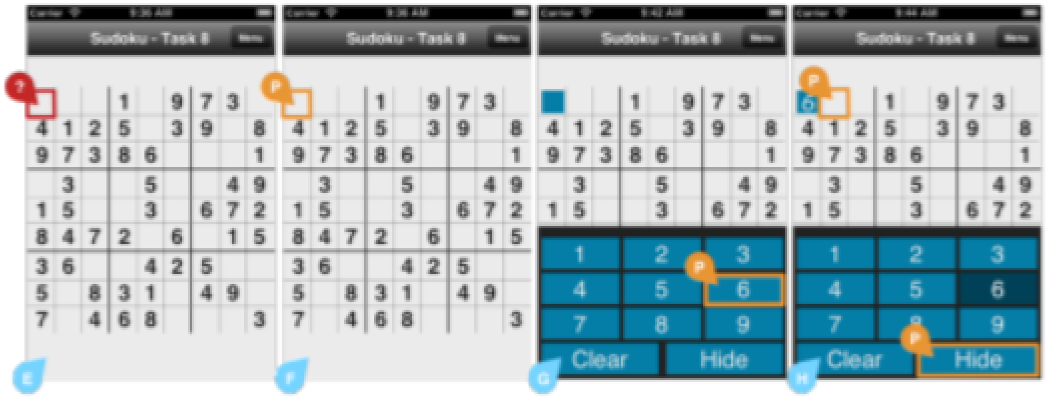

Figure 3.11: Unrecognized gesture refining (taken from (Montague et al., 2014))

They found that the performance varies a lot between the participants. Furthermore, a high variation of performance was even found between the own sessions of the users. They also noticed that the default tap recognizer of the device was not adapted to interpret taps from users with varying disabilities. Thus, 39.9% of the unrecognized gestures were taps made with intent on the correct target but not accepted by the recognizer because the interaction outreached the timing and movement parameters. Another observation was that 14.1% of the taps which were recognized were related to a wrong target, with consequences such as the launch of unintended actions.

Another in the wild study was made by Kane et al. by conducting an interview and a diary study. They focused on non touch mobile devices but some of their observations are relevant for touchscreen devices. They noticed that the users have difficulties to ”physically interact with a device when in a moving vehicle”(Kane et al., 2009). They also observed that for some participants it was challenging to use a mobile device while walking. This reduces their situational awareness and their motor control.

It is important to add that situational impairment concerns both disabled and non disabled users. The analysis of situational impairments on non disabled people is not detailed in this subsection because it is beyond the scope of this thesis. However, some of the solutions found for non disabled users will be detailed in Section 3.2

because they can also be used for motor impaired people.

3.2 Reducing Error Rate Solutions

Another important consideration is the question of how to reduce the error rate of heavily motor impaired users when they use a touchscreen. Solutions which improve the touchscreen use by heavily motor impaired users are detailed in this section. However, developing a solution for all kind of disabilities is ”a very difficult, if not impossible task” (Newell, 2008). Scientists used different kinds of solutions. This is why this section is divided into six subsections:

- Methodologies to follow
- Ergonomic solutions
- Hardware solutions
- Haptic solutions
- Multimodal solutions
- Software solutions

Figure 3.12 presents the exact structure of this section.

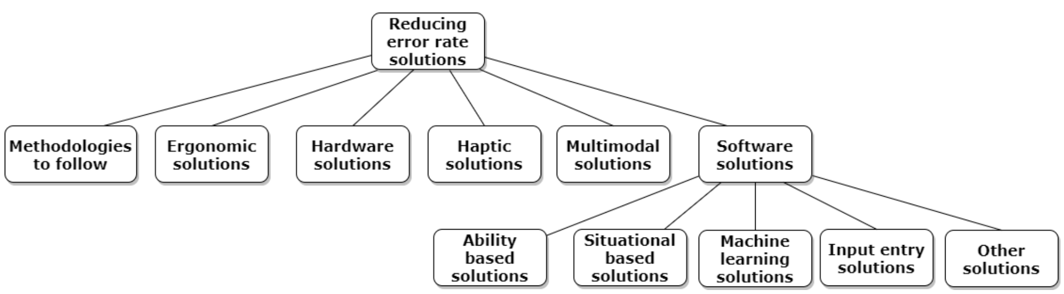

Figure 3.12: Detailed structure of Section 3.2

3.2.1 Methodologies to Follow

Some studies provided a way to design solutions which are adapted for disabled users. They are detailed below.

Newell et al. recommended a methodology where disabled and/or old people are directly involved at the center of the design, as member of the development team (Newell, 2008). They even suggested to use live theater and actors to get an easier discussion with the users. They also highlighted the importance of the aesthetics in the solutions for disabled and/or old people.

As mentioned before, Newell also advised to understand and to be aware of the characteristics of the potential old and/or disabled customers and to include them in the design process for this purpose (Newell, 2003).

De Barros et al. used this methodology to design 4 smartphone applications for users who suffered the Parkinson disease (de Barros et al., 2013). They used it in an iterative design process. First, they designed the interfaces on paper, then they evaluated these interfaces. After that, they developed working applications which were also evaluated and, with the results of the evaluation they adapted the applications. Then, they made an evaluation of the adapted applications. For the designing steps, Parkinson sufferers were integrated in the development team. Concerning the evaluation steps, old people (for the paper interfaces) and people with Parkinson disease (for the working application) were the test users. This efficient methodology allowed the authors to clearly understand the existing problems with the applications and to create more adapted applications for people with Parkinson.

3.2.2 Ergonomic Solutions

Researchers also provided recommendations concerning the ergonomics of the touchscreen for disabled users. Some of their observations are also detailed here because they can be regarded as recommendations.

Concerning the button size, Duff et al. advised a button of at least 20 mm (Duff et al., 2010), Chen et al. preferred at least 30 mm (Chen et al., 2013). It is important to add that Duff et al. and Chen et al. made their studies on ATM touchscreen (bigger screen than smartphone).
For the authors who made their study on smartphone or PDA observed that the best suitable size was 12 mm (Guerreiro et al., 2010a,b; Nicolau et al., 2014) or 14mm (Nunes et al., 2016).

Some authors advised to put the button closer to the arm of the user (Guerreiro et al., 2010b; Nicolau et al., 2012) and closer to the edges of the screen for the tapping technique (Nicolau et al., 2014; Guerreiro et al., 2010a,b).

Another proposed solution was to allow a longer dwell time in order to avoid the timeout due to the slower gesture of disabled user and also due to the standard gesture recognizer which was not adapted to this reality (Chourasia et al., 2017; Irwin and Sesto, 2012; Trewin et al., 2013; Sesto et al., 2012; Irwin et al., 2008).

Concerning the orientation, a recommendation was to prefer in front to parallel orientation (Duff et al., 2010; Irwin et al., 2010).

Another recommendation was to design the interface in order to use the tapping (Chourasia et al., 2017).

Duff et al. proposed a system of settings which allows configuring the system for the own requirements and capabilities of the disabled user (Duff et al., 2010).

Trewin et al. recommended to find the easiest technique for the user between tapping and take-off (Trewin et al., 2013). They also advised to create an undo feature. Another of their recommendations was to suppress any additional touch when the user uses only one finger. They also proposed to disable complex gestures when the user uses only simple gestures.

Wacharamanotham et al. developed and evaluated another interaction technique: the swabbing (Wacharamanotham et al., 2011). The swabbing is the same technique as take-off but targets are only on the edges of the screen. This study is not detailed further because it was based on elderly people with tremor. Thus, it is not in the scope of this thesis.

Trewin and al. also developed a new interaction technique (initially made for the mouse use but easily adaptable for the touchscreen): the steady tapping (Trewin et al., 2006). It freezes the cursor when the user clicks in order to avoid activating another button if the user slips before releasing the mouse button. If the user goes beyond a certain distance (about 100 pixels) without releasing the mouse button, the cursor goes to where it would be and the click is not taken into account. As mentioned before, this study was based on the use of the mouse by disabled users, this is why it is not detailed more deeply in this thesis.

Nunes et al. concluded that multiple-taps are better adapted for motor impaired users than drag gestures (Nunes et al., 2016). They also provided twelve guidelines which are very similar to the aforementioned recommendations:

- ”DG1 - Use tap targets with 14mm of side;
- DG2 - Use the swipe gesture, preferably without activation speed;
- DG3 - Employ controls that use multiple-taps;
- DG4 - Use drag gesture with parsimony;
- DG5 - Prefer multiple-tap over drag;
- DG6 - Adapt interfaces to the momentary characteristics of the user;
- DG7 - Use high contrast colored elements;
- DG8 - Select the information to display carefully;
- DG9 - Provide clear information of current location at all times;
- DG10 - Avoid time dependent controls;
- DG11 - Prefer multi-modality over a single interaction medium;
- DG12 - Consider smartphone design guidelines for older adults.”

(Nunes et al., 2016)
Siebra et al. proposed another list of guidelines. The part of it for motor impaired users is more based on the solutions which require less gestures for motor impaired users, such as:

- ”Avoid time limits to use functions;
- Automatic activation of the first field of filling forms;
- Offer a resizable selection area to a higher size, so that users can select buttons in an easier way;

- Place the more frequently used functions in the first level of navigation, avoiding that users need to perform several steps to reach them"

(Siebra et al., 2017).
In addition to these guidelines, Apple[22], Google[23] and W3C[24] provided guidelines for mobile development. However, these recommendations are more general than just the improvement of the touchscreen.

3.2.3 Hardware Solutions

As mentioned before, the use of physical barriers (Anthony et al., 2013), corners and edges (see Subsection 3.2.2) can be useful to help and guide the touch of disabled users. This is why some studies tried to find physical solutions to improve the use of the touchscreen for motor impaired people.

Wobbrock et al. developed a solution for PDA which can easily be adapted for touchscreen devices and the use of the hand or the finger directly to the touchscreen. They created a text entry where all the alphabet and some special characters could be entered by making combinations (see Figure 3.13) on a square hole in a transparent plastic (see Figure 3.14).
This is an "easier, faster and more stable"(Wobbrock, 2003) solution than text-entry without edges. The solution created by Wobbrock et al. led to an accuracy improvement for text entry in comparison with another technique they evaluated.

Froehlich et al. developed a solution which used the edges of a PDA (see Figure 3.15) (Froehlich et al., 2007). It improved the accuracy of the motor impaired users. This solution requires a stylus but it can easily be adapted to be used with the hand or the finger.

Kane et al. proposed a solution with touchplates (transparent plastic in which some holes are made, see Figure 3.16) for visually impaired people on touchscreen tabletop (Kane et al., 2013). An adaptation to smaller touchscreen of smartphone

[22] `https://developer.apple.com/library/content/documentation/UserExperience/Conceptual/iPhoneAccessibility/Introduction/Introduction.html#//apple_ref/doc/uid/TP40008785` consulted on August,8

[23] `https://developer.android.com/guide/topics/ui/accessibility/checklist.html` consulted on August 2017,8.

[24] `https://www.w3.org/TR/mobile-accessibility-mapping/` consulted on August,8.

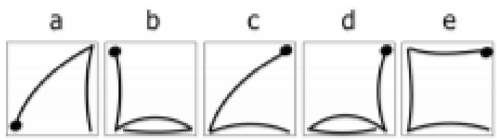

Figure 3.13: Example of combinations for the 5 first letters of the alphabet (taken from (Wobbrock et al., 2003))

Figure 3.14: The transparent plastic with the square hole (taken from (Wobbrock et al., 2003))

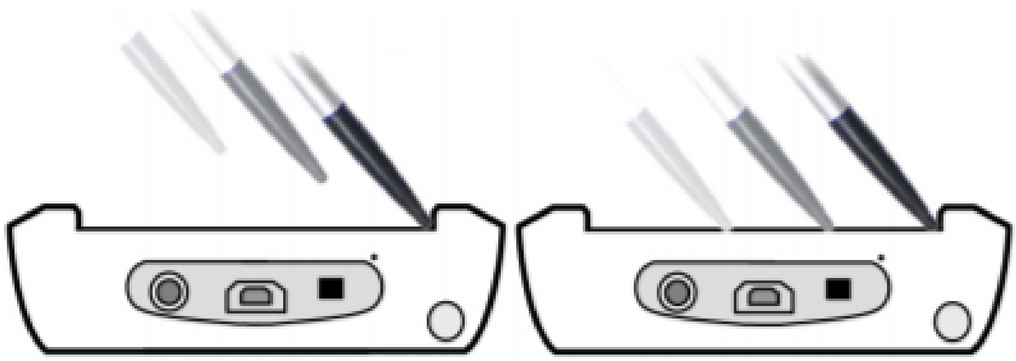

Figure 3.15: Example of different gestures which uses the edges of the PDA (taken from (Froehlich et al., 2007))

can also be done. Thanks to this hardware solution, haptic feedback was provided which is highly useful for blind users. However, it is complicated to take the touch-plates everywhere, the use of a touchscreen is required. More haptic solutions will be detailed in the Subsection 3.2.4.

Cofre et al. also used an hardware solution (acrylic plate, see Figures 3.17 and 3.18) to avoid that motor impaired users make unintentional multi-clicks or slip when they use the smartphone touchscreen with their finger (Cofre et al., 2012).

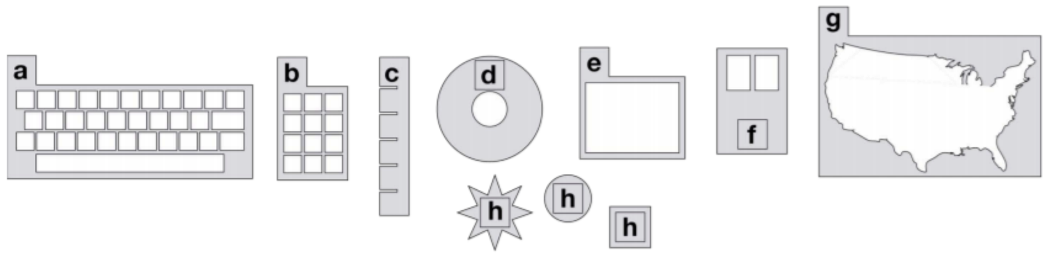

Figure 3.16: Examples of touchplates (taken from (Kane et al., 2013))

Figure 3.17: Acrylic plate avoiding multiple unintentional touches (taken from (Cofre et al., 2012))

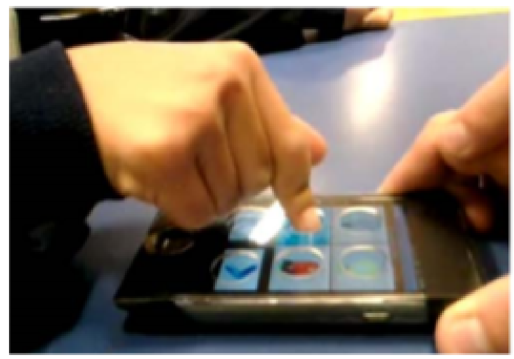

Figure 3.18: Acrylic plate avoiding slipping when too much pressure is applied (taken from (Cofre et al., 2012))

3.2.4 Haptic Solutions

The haptic feedback is also a solution provided to improve the touch by giving the user censorial information.

As mentioned in the Subsection 3.2.3, Kane et al. provided a solution with a passive haptic feedback (Kane et al., 2013).

Lin and O'Modhrain developed a solution based on a bullseye (see Figure 3.19) which is a double circle with a haptic texture composed of waves (Lin and O'Modhrain, 2016). Thus, the user can pass his finger on the first circle and feels it thanks to the haptic texture. It allows using the touchscreen without looking at it. It is a good solution for visually impaired people but also for motor impaired people because it involves smaller movement distance (it can easily be used on a smartphone) and also because this solution has shown good performance for able-bodied users even if the bullseye was very small. Thus, it can be used by motor impaired people if the bullseye is bigger.

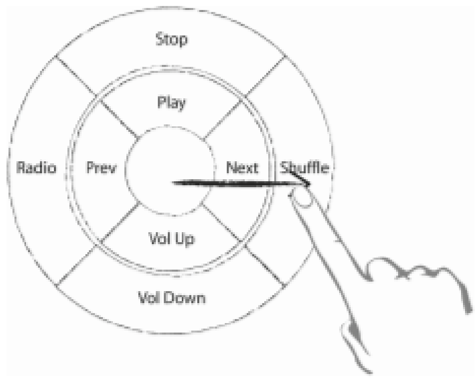

Figure 3.19: Example of bullseye menu (taken from (Lin and O'Modhrain, 2016))

3.2.5 Multimodal Solutions

Another way to reduce the error rate of the motor impaired users is to use multimodality.

Multimodality gives solutions which use another modality to bypass the problems due to the touchscreen for the motor impaired users. This section is not detailed further because the main goal of this thesis is to find solutions which reduce the error rate linked to the use of the touchscreen by disabled people. Thus, the multimodality is not central with regard to this thesis.
Moreover, as shown for visual impaired users, some solutions using multimodality can be significantly slower and have an error rate greater than a solution using only the touchscreen (Bonner et al., 2010). Thus, the use of multimodality is not always a good solution.

3.2.6 Software Solutions

Another way to answer the reducing of error rate is to propose some software solutions which adapt the touchscreen to motor impaired users.

There are several categories of solutions:

- Ability based solutions
- Situational based solutions
- Machine learning solutions
- Input entry solutions
- Others solutions

This subsection is divided into these categories. It is important to add that these categories are not exclusive. It is possible to find an ability based solution which is also a machine learning solution as it is possible to find an input entry solution (which is on the software solutions category) also based on an hardware solution. In these cases, the solution is placed where it is the more relevant.

Ability Based Solutions

Some of the software solutions provided were the ability based solutions.
Before going further, in order to be the clearest possible, it is important to clarify some definitions about the adaptation. There is a big difference between adaptability and adaptivity: adaptability is "the capacity of the system to allow users to customize their system from a predefined set of parameters" whereas adaptivity is "the capacity of the system to perform adaptation automatically without deliberate action from the user's part" (Thevenin and Coutaz, 1999).

Gajos et al. developed an adaptive solution based on what the user can do rather than what he cannot do and without wanting changing the users. It is called ability-based design (Wobbrock et al., 2011). Gajos et al. developed a solution (SUPPLE++) which adapts the interfaces in function of the user capabilities (by analyzing his performance) (Gajos et al., 2007). Thanks to this solution, motor impaired users were faster and made less errors. However, it was developed and tested on PC without including the touch interaction technique. But, the idea can be completely applied on smartphone touchscreen.

Montague et al. provided an ability-based solution (SUM) for touchscreen smartphone and tablet which records and provides information on the user models to all the applications (Montague et al., 2012; Montague, 2012; Montague et al., 2011).

The user models include information (button size, duration of the touch and font size) captured in all the applications. With this information, the applications can adapt the elements on the screen to fit the abilities of the users. This solution led to a decrease of the number of errors.

Mott et al. created an ability based solution named ”Smart Touch” which uses the template matching and machine learning to avoid that the touchscreen detects unintentional taps (Mott et al., 2016). The Smart Touch proceeds in three steps and is user-specific. First, it ”analyzes a user’s touch process to extract the most relevant touch data”. Then it ”matches that data to previously observed training examples (the templates)”. Finally, it ”resolves the user’s intended (x,y) touch point” (Mott et al., 2016). In average, this solution had a third less longer distance between the intentional target and the interpreted target than the standard touch sensor.

Situationally Based Solutions

Another way to improve the use of touchscreen by motor impaired users is to adapt the interface and the interaction in function of the context of use.

Kane developed a framework which is adaptive to the situation of use (Kane, 2009). It uses different variables such as the current location of the user, his ability level and his activity. With this information the framework adapts the interface to better fit the user needs (see Figure 3.20). The author gave some examples of adaptations linked to situational impairment which are given at Figure 3.21. These adaptations work as good as for able-bodied users than motor impaired users.

Goel et al. developed ”WalkType”, an adaptive text entry solution based on the accelerometer data and machine learning techniques to compensate the inaccurate touches due to the situational impairment caused by walking (Goel et al., 2012). The results of ”WalkType” were a decrease of uncorrected error and an increase of typing speed. This solution is designed for able-bodied users but can also be useful for motor impaired user by being adapted for them (e.g. to be used in a wheelchair or to be used for motor impaired user when they walk).

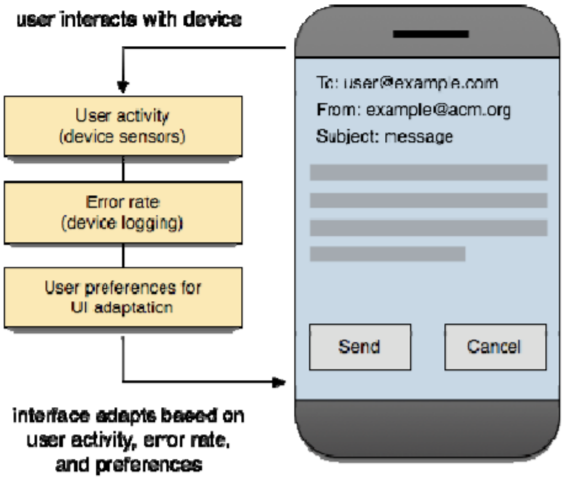

Figure 3.20: Example of the steps used to adapt the interface (taken from (Kane, 2009))

Situation	Impairing effects	Interface adaptations
User is in motion	Reading ability is reduced	Text size increased; text-to-speech activated
User is in a busy bus station	Attention is reduced; crowded space impairs movement	Bus schedule application automatically launched
User is riding on a bumpy bus	On-screen targets are difficult to hit while moving	On-screen target size increased; keyboard error correction activated
Phone is in pocket	User cannot see the screen	Voice output activated; touch screen gestures enabled

Figure 3.21: Examples of situational impairments and adaptations (taken from (Kane, 2009))

Machine Learning Solutions

As mentioned before, some authors used probabilistic solutions such as machine learning (Goel et al., 2012; Mott et al., 2016) to improve the use of the touchscreen.

Montague et al. used the training set of touch issued from the filling out of sudoku grids by motor impaired users (see Subsection 3.1.2) to train the session-specific gesture recognizer they created. More precisely they used the individual's data as training set. This gesture recognizer is based on a machine learning algorithm and trained to understand the touch of the users. It provided 95.1% recognition accuracy, strongly better than the standard gesture recognizer. They also observed that the results were greater by training the algorithm with data from other users.

Weir et al. developed also a machine learning algorithm to improve the touch accuracy of able-bodied users (Weir et al., 2012; Weir, 2012). They asked the users to tap on a crosshair on touchscreen. Then they trained their algorithm with the user-specific raw data of the touch position (resp. the user-specific data of the touch position already interpreted by the standard recognizer) for the first experiment (resp. second experiment). Thanks to this training the algorithm could guess the intended target position just by knowing the real touch position. This solution can be used directly for motor impaired users. Indeed, the results showed an improvement of accuracy for button of 2, 3 and 4 mm. By assumption, for disabled users the size of button would just be greater.

Input Entry Solutions

As mentioned before (Goel et al., 2012; Wobbrock, 2003), some studies tried to improve the way of entering texts or numbers with a smartphone/tablet touchscreen.

Condado et al. developed a text input solution named ”EasyWrite” (Condado et al., 2011). They presented a central key on which characters are displayed (following the QWERTY keyboard characters order). In order to navigate through the groups of characters and the subgroups of characters, the user has to touch the directional key or the option he wishes (see Figure 3.22). This solution has some limitations but it can be suitable for moderate impaired users (the authors had not tested it on heavily motor impaired).

Mertens et al. proposed a solution which uses the swabbing technique of interaction (Mertens et al., 2010). They proposed to use a circular division of the screen rather than a checkered division (see Figure 3.23). They designed this solution for people with tremor but it can also be used by heavily motor impaired users.

Bonner et al. developed a very similar solution designed for visually impaired users: ”No-Look Notes” (Bonner et al., 2010). The big difference is that the screen is divided into eight areas and not twenty-six. Thus, after having selected the area of three (resp. four) letters, the screen is divided into three (resp. four) spaces, one for each letter (see Figure 3.24). This solutions required also a different technique of

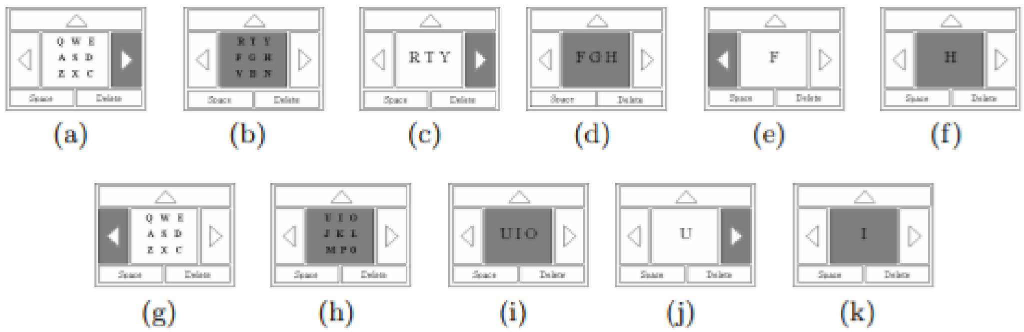

Figure 3.22: ”The first low-fidelity prototype of the EasyWrite keyboard. The various figures from (a) to (k) illustrate the sequence of steps required to type the word “Hi”. Steps (a) through (f) are the ones required to select the character ’H’. Likewise, steps (g) to (k) illustrate the sequence of steps required to select the character ’i’. If mistakes are made, the user can navigate up the hierarchy by tapping the up arrow.” (taken from (Condado et al., 2011))

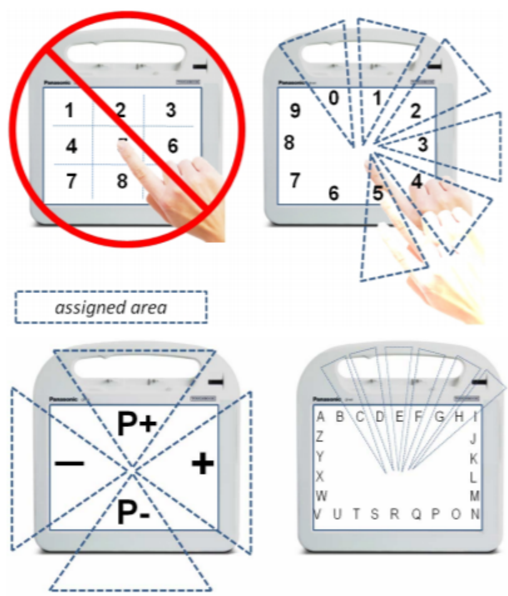

Figure 3.23: Illustration of the screen division and assignation of aeras for the swabbing technique (taken from (Mertens et al., 2010))

interaction (which needs more dexterity than swabbing): the user keeps his finger in the screen until he reaches the right area (step one, there is a text-to-speech which pronounces the letters of the area on which is the finger in order to help the user to find the right area). Then the user has to touch the screen with a second finger to perform the click (see Figure 3.24 step two). The technique is the same to select the letter (steps three and four). Concerning the space or the backspace, it requires a particular gesture (a slide in a certain direction depending on the command).

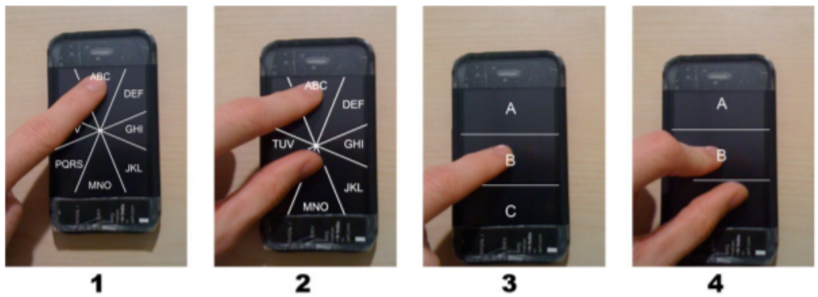

Figure 3.24: Example of use of No-Look Notes (taken from (Bonner et al., 2010))

The Other solutions

Some studies are not easy to put in a category. They are gathered in this subsection.

Zhong et al. proposed ”Touch Guard”, a service which reduces the need for precision in tapping and improves the performance of disabled users (Zhong et al., 2015). It provides an enhanced area touch which draws a green circle underneath the finger when the user touches the touchscreen. The interaction techniques used with this solutions are the take-off or the steady tapping[25]. As the green circle is large, there is often an ambiguity on which button was the intended target of the user (see Figure 3.25 (A) and (B)). This is why they developed two methods of disambiguation. The first one is ”magnification”, it enlarges the screen where the touch was performed (C). The other one is ”targets list mode”, it displays a list of the potential targets (D).

They also developed an ”unintentional movements filter” which reduces the inaccuracy due to hand tremor. Another feature is the swiping to ”scroll forward or

[25]As a reminder, the steady tapping is an interaction technique (initially made for mouse use) developed by Trewin et al. (Trewin et al., 2006). It freezes the cursor when the user clicks in order to avoid activating another button if the user slips before releasing the mouse button. If the user goes beyond a distance (about 100 pixels) without releasing the mouse button, the cursor goes to where it would be and the click is not taken into account.

Figure 3.25: Touch Guard: (a) touch without ambiguity, (b) touch with ambiguity (on multiple targets), (c) magnification disambiguation, (d) targets list mode disambiguation (taken from (Zhong et al., 2015))

backward by one page". The results showed that users had better performance with targets list mode while magnification did not improve speed and accuracy.

It is important to add that Google[26] and Apple[27] provide some software solutions thanks to their accessibility options. These options are not detailed here because they are not included in the scientific literature and overall, they are often based on multimodality and not only on touchscreen as explained at Subsection 3.2.5.

3.3 Mobile Telephony Solutions

Concerning the mobile telephony solutions adapted to heavily motor impaired users, it would seem that they are few (if not none). Indeed, some solutions proposed the contact management, the possibility to make outgoing calls,... But, it seems that none offered the possibility to answer incoming calls[28]. This can be explained by the

[26] `https://support.google.com/accessibility/android#topic=6007234` consulted on August 15, 2017

[27] `https://www.apple.com/uk/accessibility/iphone/physical-and-motor-skills/` consulted on August 15, 2017

[28] The only complete telephony solution found was a solution for visually impaired user called IFreePhone developed by Haque et al. (Haque et al., 2014; Ahmed et al., 2017). They argued that their solution allows the people with sight disability to send/receive calls and to send/receive messages. However, they did not mentioned how they have developed the call receiving feature and

permission problem mentioned before (see Section 2.3). Moreover, even incomplete, there is few solutions adapted heavily disabled users. These solutions are detailed below and the scope is expanded to elderly people because of this lack of solutions.

Regarding the solutions for motor impaired users, a Parkinson disease charity named Parkinson UK proposed an application which allows to call a pre-recorded contact by clicking on a circle button[29]. With this solution, the people with Parkinson disease does not need to dial the number or to search in their contacts to call their relatives (see Figure 3.26).

Figure 3.26: The application interface designed for people with Parkinson disease (taken from `https://play.google.com/store/apps/details?id=co.uk.org.parkinsons`)

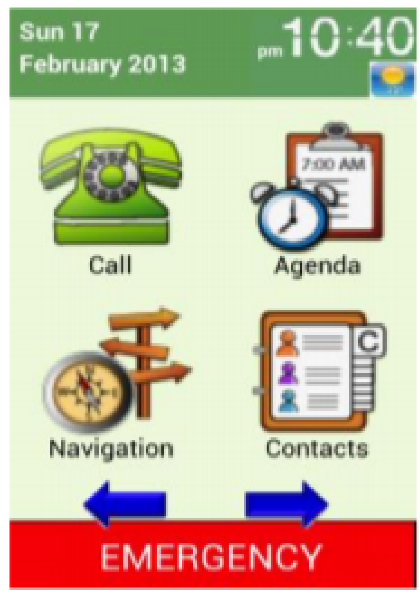

Figure 3.27: The main menu interface of PhonAge (taken from (Arab et al., 2013))

Concerning the solution for the elderly, Abdulrazak et al. proposed PhoneAge,

they did not showed the interface linked with this feature.

[29]`https://play.google.com/store/apps/details?id=co.uk.org.parkinsons` consulted on August 16, 2017

a smartphone solution which is designed to improve the quality of life of the elderly (Abdulrazak et al., 2013; Arab et al., 2013). As shown at Figure 3.27, they divided the interface into three sections. The top section is the ”Spatiotemporal Assistance Section” because ”temporal information is central to elderly people”. The center section is the ”Main Activity Section” which is composed of icons (to access to phone features) and directional arrows (to easily navigate in the icons and to ”to facilitate the use of those who are not accustomed to Smartphone or scrolling features on touch screen phones”). The bottom section is the ”Emergency Section” which is made to contact the user relatives if urgently needed.

Balata and al. designed the user interfaces of an applications launcher called Koala-Phone (Balata et al., 2015). The Figure 3.28 shows the high fidelity interfaces designed for this solution.

There are some existing off the shelf solutions for the elderly. The Doro smartphone[30] which runs on an adapted version of Android for elderly people, the silverline application[31] which provides, among others, the telephony functionality. There are other solutions such as the big launcher[32] which also provides the telephony functionality. Seniors phone[33] and Necta Launcher[34] are also telephony solutions for elderly people.

All these applications and smartphone solutions are useful for the elderly users and even for the motor impaired users for some of them. However, behalve the Doro solution (which is a smartphone and not an application), none of these solutions can hang up an incoming call.

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[30] `https://www.dorobelgium.be/doro-8031.html` consulted on August 17, 2017

[31] `https://www.indiegogo.com/projects/silverline-smartphones-for-seniors--6#/` consulted on August 17, 2017

[32] `http://biglauncher.com/fr/` consulted on August 17, 2017

[33] `https://seniorsphone.mobi/`consulted on August 17, 2017

[34] `https://play.google.com/store/apps/details?id=com.necta.launcher` consulted on August 17, 2017

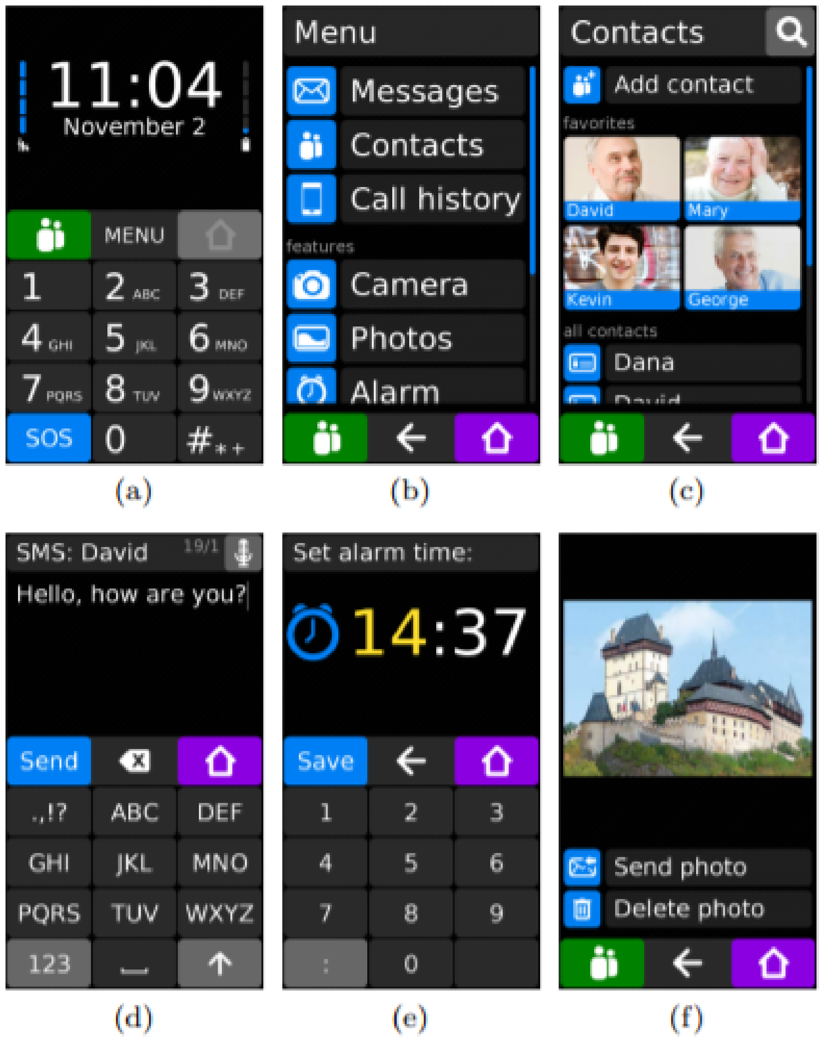

Figure 3.28: The KoalaPhone interfaces: "main screen (a), menu (b), contacts (c), SMS (d), alarm (e), photo detail (f)" (taken from (Balata et al., 2015))

Chapter 4

Analysis and Future Work

This section presents the future works that can be done to improve the application. It is divided into two subsections:

- The future works issued from discussion with Home Based
- The future works inspired by the state of the art

4.1 Future Works Issued From Discussion With Home Based

As the application is currently used by several users, they gave their feedback and some ideas for improvement to Home Based.

One of these users advised that it would be interesting to know who has ”knocked” on the door when there is a missed call from the video door entry.
In order to do that, the application has to send a JavaScript command when a call is emitted from the video door entry. The result of this command is that the video door entry takes a picture thanks to its camera and sends this picture to the Android application (the only condition is that the person has to be in front of the camera when the picture is taken). If the user hangs up the call from the video door entry (and thus sees the person who pushes on the video door entry button), the picture would be erased. If the user does not answer the call, this pictures would be saved in the data of the missed call and displayed in the details of this missed call.
A low fidelity prototype of the interface of this solution is shown at Figure 4.1.

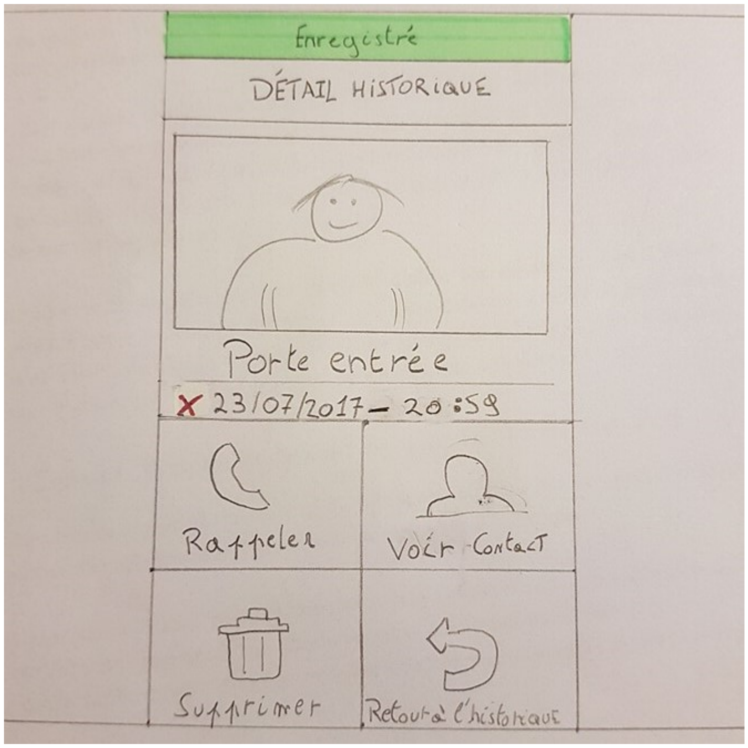

Figure 4.1: Low fidelity prototype of the missed call details interface

An improvement discussed with Home Based and Pierre Rousseau is the synchronization of the contacts and the history.
Concerning the contacts, the fields of the contact were discussed with Pierre Rousseau and are the same for the application on Windows and for the application on Android. It only misses a protocol to transfer and sync the data. An exchange of the concerned contacts can be done when a contact modification or a contact creation is made. Concerning the protocol, HTTP and JSON could be used. Another possibility is the recording of the contact in the vCards format in order to have the possibility to synchronize the contacts with other kinds of devices.
Concerning the history, as the VoIP account connected on the Android Application and on Windows is the same, it just requires an update of some calls. Indeed, when the user hangs up a VoIP call with one device, the other device records the call as a missed call. For the phone history, a solution similar to the contacts synchronization solution can be considered.

Another future works discussed with Home Based is the integration in the application of some home automation features such as the house lights control. In order to do that a low fidelity interface designed is shown at Figure 4.2 and 4.3. When the light is on, the button background is colored in orange and when the light is off, the button background is colored in the same color as the other buttons background.
The interface is designed to control one lamp because a potential user needed to manage only one light. However, if the user needs to manage more lights an access to a lights control menu can be added on the main menu interface. This lights control menu would be composed of buttons similar to the light control button shown at Figures 4.2 and 4.3. This menu can provide the control of the different lamps of the user house.

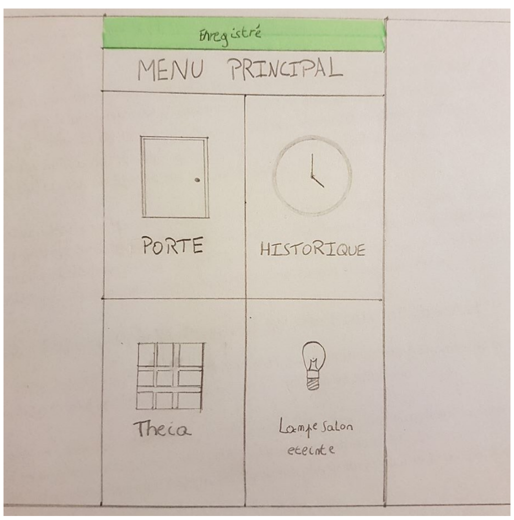

Figure 4.2: Low fidelity prototype of the main menu interface with light management (light off)

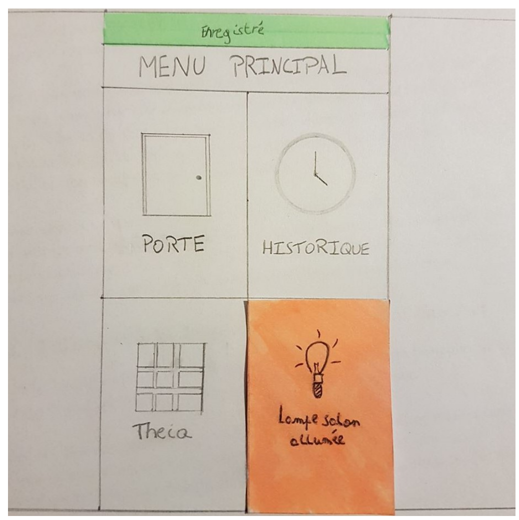

Figure 4.3: Low fidelity prototype of the main menu interface with light management (light on)

Another idea is to use the protocol designed during the internship (see Chapter 2) to provide some automatic features such as the flashing of a house light when there is an incoming call in order to avoid the missing of calls (e.g. due to hearing problems or distance with the smartphone which avoid to see the screen). This idea is not further detailed because it concerns the multimodality and it is not the core of this thesis.

4.2 Future Works Inspired by the State of the Art

After having reviewed the state of the art, some solutions provided by the scientific literature can be applied in order to improve the application. This section presents the adaptation of these solutions for the application developed during the internship.

As it was observed that there would be no complete mobile phone application designed for the heavily motor impaired, this thesis presents a solution to fill this gap. The major problem with doing a complete telephony functionality is the permission which is not given by Google to hang up the incoming calls for third party application. This is why this thesis proposes to make a custom Android OS to match the requirements of a complete telephony solution.
The Android OS is an open source project which can be downloaded, compiled and overall modified. The source code and the way to download and compile it is presented at these Android Open Source Project (AOSP) pages[1]. When the code is compiled it is possible to flash it on an Android device (preferably a Nexus) in order to replace the OS.
The application presented at the Chapter 2 has some adapted interfaces for incoming call and ongoing call (see Figures 4.4 and 4.5) which can be reused and applied on the system default interfaces when there is an incoming call or an ongoing call.

This solution has some further advantages such as the possibility to modify the system message application in order to adapt it to motor impaired users. It is possible to implement one of the input text entry presented in the state of the art or to propose a modified version of one of them. For example, the No-Look Notes (Bonner et al., 2010) solution which would include the take-off interaction technique. Or, another improvement would be to propose different kinds of text entry solutions which would be used with different techniques of interaction and could be configurable by a system of settings as advised by Duff et al. (Duff et al., 2010).
The reading of the message by Soline is also possible with the protocol created during the internship.

However this custom OS solution has some limitations, by default, the OS com-

[1] `https://source.android.com/`,`https://source.android.com/source/requirements` consulted on August 16, 2017

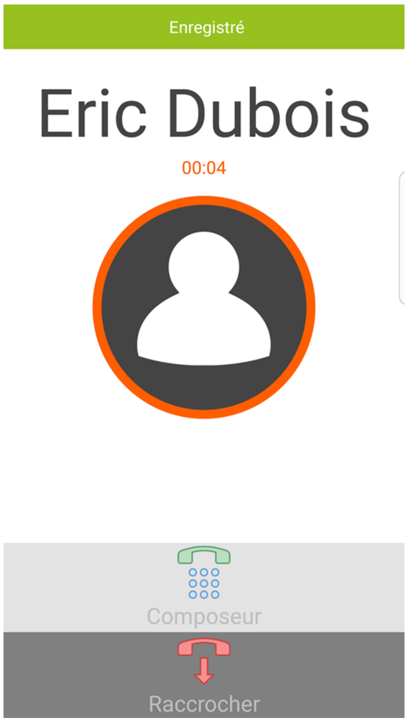

Figure 4.4: Interface for ongoing and outgoing phone call

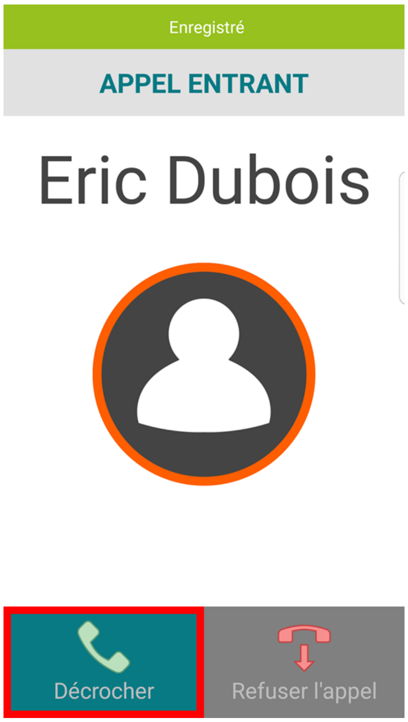

Figure 4.5: Interface for incoming phone call

piled from the AOSP does not have access to the Android Play Store. It is possible to get the access to the Android Play Store on the OS by contacting Google[2] in order to buy the required licence.

Concerning the validation of the application, there is a lack of long-term use validation. Indeed, the interviews were made directly after having shown the application to the user. In order to fill this gap, diary studies can be made. A diary study is a study made by the user itself. He maintains a journal by reporting the problem he encountered with the application, the experiences and the emotional feelings he had by using the application. Moreover this diary study can be completed by periodic questionnaires.
In addition, a further interview can be made with the users who use the application for some time.

[2]https://source.android.com/source/faqs#if-i-am-not-a-manufacturer-how-can-i-get-google-play consulted on August 16, 2017

Concerning the error rate improvement of the application, a solution is to enable the user to use the tapping, take-off or steady click interaction technique. If the user chooses tapping, the ”Smart Touch” (Mott et al., 2016) seems to be a suitable solution.

An improvement would also be possible by creating some physical barriers to help the motor impairment users to have a better accuracy as advised by (Nicolau et al., 2014; Guerreiro et al., 2010a,b) and realized by (Froehlich et al., 2007).

Regarding the ergonomics, a check could be made to be sure that the application follows the guidelines provided and takes into account the observations made by the studies presented in the state of the art.

It is important to add that some solutions can be used together. For example, by checking that the guidelines are followed, by using the ”No-Look Notes” text entry solution and by creating physical barriers. All these solutions can be used together in the application in order to facilitate the use of the touchscreen by heavily impaired users.

Chapter 5

Conclusion

First, a mobile and VoIP telephony application facilitating the use of the touchscreen by heavily motor impaired was presented. To create and improve the application, a method composed of iterations was used. This solution provided was validated by two interviews made with a motor impaired user and by several interviews made with experts.

After this practical approach, a more theoretical approach was taken with the review of the scientific literature. The review was made to understand the use of the touchscreen by heavily motor impaired users and to highlight the challenges they encountered. These observations were important to improve the use of the application by heavily motor impaired users. The review was also made in order to find reducing error rate solutions proposed by experts and to find some existing telephony solutions for disabled users. These solutions can also improve the use of the application by disabled users.

Then, with regard to the solutions detailed in the state of the art, some application improvements were proposed such as the development of a complete mobile telephony functionality for heavily motor impaired user. It would seem that the solution proposed in this thesis is currently the first providing a mobile and VoIP telephony solution on touchscreen mobile device, adapted for heavily motor impaired users.
Some improvement ideas were directly issued from the feedback of some users of the application such as the integration of a picture in the interface when there is

a missed call from the door. Some improvements were also discussed with Home Based during the internship: the synchronization of the contacts and the history between the Android application and the Windows application developed by Pierre Rousseau. Another example is the lights control directly integrated in the application.
Improvement ideas were also taken from the state of the art such as the development of a message functionality which would allow the motor impaired users to write message by using some solutions detailed in the literature review. Another idea is to use several solutions directly issued from the state of the art, together in the application. Also, a long term validation such as diary studies could be made by users in order to have more feedback and to further validate the proposed solution.

Finally, this thesis answers the two sub-questions stated in the Chapter 1 by presenting a review of the scientific literature for each of this two subjects.
This study also answers the research question, but only partially because the solution provided concerning the complete mobile telephony (and more exactly, the incoming phone call feature) was not validated by potential users or experts. However, the complete answer to the question is probably close to the proposed answer.

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