Master's Thesis

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F3

Faculty of Electrical Engineering
Department of Computer Graphics and Interaction

Device for small-range localisation of searched objects

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MASTER'S THESIS ASSIGNMENT

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II. Master's thesis details

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Device for small-range localization of searched objects

Master's thesis title in Czech:

Místní lokalizátor hledaných objektů

Guidelines:

Analyze existing solutions for the localization of lost or stolen objects of daily use. Explore the technologies used. Perform an analysis of the problem area in the form of user research. Based on the analysis, design a solution and describe how it will work. Implement the design in the form of low-level prototypes. Use iterative formative evaluation in the form of user tests during the design of solutions and the production of prototypes. Then implement the proposed solution. Proceed in the same way as in the production of prototypes, so use iterative testing with users.

Bibliography / sources:

1. Elizabeth Goodman, Mike Kuniavsky and Andrea Moed (2012). Observing the User Experience
2. Colin Ware. Information Visualization, perception for design
3. Bill Buxton . Sketching User Experiences
4. Miroslav Disman (2002). Jak se vyrábí sociologická znalost: Příručka pro uživatele.

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt

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Declaration

I declare that this work is my own work and I have cited all the sources I have used in the bibliography.

Prague, May 20, 2022

Prohlašuji, že jsem předloženou práci vypracoval samostatně, a že jsem uvedl veškerou použitou literaturu.

V Praze, 20. května 2022

Abstract

This thesis analyses existing solutions for the localisation of lost or stolen objects of daily use and proposes its own solution to this problem. During a research among possible users, the possibility of further expanding the solution was revealed by adding a reminder that alerts the user if they forget something at home when leaving. The thesis also includes the procedure for the implementation of the prototype, which uses *Bluetooth Low Energy* technology, its qualitative testing, evaluation and description of the possible approach to further improve the solution.

Keywords: short-ranged localisation, lost objects, Bluetooth, BLE

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Abstrakt

Tato práce analyzuje existující řešení pro lokalizaci ztracených nebo ukradených objektů denní potřeby a navrhuje vlastní řešení tohoto problému. Během rešerše mezi možnými uživateli byla nalezena možnost dalšího rozšíření řešení, a to o upomínku, když si uživatel zapomene něco doma při odchodu. Práce dále obsahuje postup implementace prototypu využívající technologii *Bluetooth Low Energy*, jeho kvalitativní otestování, evaluaci a popis dalšího možného postupu, jak řešení vylepšit a zdokonalit.

Klíčová slova: lokalizace na krátkou vzdálenost, ztracené objekty, Bluetooth, BLE

Překlad názvu: Místní lokalizátor hledaných objektů

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Chapter 1
Introduction

> Human memory is also a maze -
> too many things get lost there.
>
> Jan Werich

Humans are not perfect. Among our imperfections, for example, is that we often forget and lose things. Assigned tasks, wife's or girlfriend's birthday, childhood memories, keys when leaving the apartment, we can forget anything. Therefore, we use tools, mementos, or reminders to limit forgetting as much as possible. For example, we write tasks in a homework book, the birthdays of loved ones in a calendar, and keep memories in photos. This problem plagues most of us, but it seems that the older we get, the more we tend to forget. The main goal of this thesis was to invent a helper to help us find a certain item that we use and often forget where we put it.

This thesis consists of the following chapters.

- Chapter 2 demonstrates the existing solutions, compares them, and shows their advantages and disadvantages.
- Chapter 3 describes the target group for which our solution is aimed and what their requirements are.
- Chapter 4 shows the design process and how our solution can help the target group.
- Chapter 5 introduces the implementation of the prototype used for the tests.
- Chapter 6 summarises the tests and evaluates what appears to be the right path and what issues were discovered.
- Chapter 7 concludes the thesis and discusses future work.

1.1 Motivation

There are already existing commercial solutions that help with the localisation of lost items, some more successful than others. The solution we propose in this thesis is less complex and is aimed at the elderly or people with cognitive, motor, or visual impairment. According to Navabi et al.[4], older people have a negative attitude towards mobile phones, as they find them too confusing and tend to make interaction mistakes, that is, missing the right key, especially on touch screens. The main problem with current solutions is that they require smartphones because they are used as the main search device. This has the effect of disabling the elderly from using such devices, as they usually do not have a smartphone. However, these people should also be the main target group for such devices, as they tend to lose their things the most [5].

Chapter 2

State of the Art

> To know the road ahead, ask those who are coming back.
>
> *Chinese proverb*

As already said in the Introduction, there are several existing solutions to the problem described in this thesis. Some of them are described below. Inspiration from them is a good way to start our development. We can also find out if there is not already a solution that meets our needs. Before we move on, we need to choose our comparative criteria.

First, the solution must not be an accessory of a different product. The user should not be required to have a product of the same brand to use the localisation function. In other words, the solution should be standalone.

Second, the solution should be universal. There must be a way for the user to use the localisation function on many different kinds of objects.

Third, the solution must be easily maintainable. No complex operation should be required from the user every other day.

Fourth, the solution must be stable. In other words, the control elements should not change.

Lastly, the solution must have a localisation function that does not require a smartphone. Not everyone is proficient with smartphones, and we find it important that the user does not need to own one. This means that the solution should be appless.

2.1 Apple AirTag

AirTag (Figure 2.1) is a so-called keyfinder device developed by *Apple Inc.* in the form of a small "tag" that users attach to their items. It uses Bluetooth technology to locate lost items. To improve localisation, *AirTags* are also detected by devices of other users, not just by the owner. This means that the user can get the information where his device is without being close to it. Apple calls this the *Find My* network. On newer *Apple* devices, users can also locate their items via ultra-wideband. [6]

AirTags are only compatible with *Apple* smartphones and tablets, which

Figure 2.1: *Apple AirTag* with a keyring accessory. Image from [6].

means that they do not meet our first criterion. It meets our second criterion because there exist many accessories, both by *Apple* and by third parties, which can be used to attach it to different types of items. *AirTags* battery can last up to one year and is user-replaceable, which means that even our third criterion is met. The main finder device is the user's *iPhone* or *iPad*. This means that the solution does not meet either our fourth or fifth criterion. The control elements might change with an update and, without a smartphone, this solution does not work.

2.2 Samsung Galaxy SmartTag+

Galaxy SmartTag+ is a *Samsung* device similar to the aforementioned *Apple AirTag*. It also uses Bluetooth for localisation, and thanks to the *Galaxy Find* network, which is *Samsung*'s equivalent to *Apple*'s *Find My*, compatible *Samsung* devices can help locate the lost item. *SmartTag+* also supports precise localisation using ultra-wideband. [7]

Galaxy SmartTag+ is only compatible with *Samsung Galaxy* smartphones. This makes it an accessory of a different product and does not meet our first criterion. *SmartTag+* can be attached only by means of a strap or a keychain. After careful consideration, we decided that this is not in compliance with our second criterion, since not all items have a hole through which a strap or a keychain can be pulled. The third criterion is met because the *SmartTag+*'s battery can last up to a year and is user-replaceable. *SmartTag+* does not meet our fourth and fifth criterion for the same reasons as *Apple AirTag*, because the localisation function is only available in a smartphone app.

2.3 Chipolo

Chipolo is a family of finders that take the form of a key ring or a card. Not only does it use Bluetooth as the devices described above, *Chipolo* also has its own implementation of the *Find My* network, or the *Galaxy Find* network, here simply called *Community Search*. [8]

Chipolo is compatible with both *Android* and *Apple* devices, which means that it meets our first criterion. Due to the fact that it takes more than one shape, as described in the previous paragraph, it also meets our criterion of universality. Batteries last from one to two years and can be replaced by the user, or the user gets a discount for a new piece. This makes it pass our third criterion. Neither of the last two criteria is fulfilled because there is no equivalent to the localisation application provided on smartphones.

2.4 Tile

Tile (Figure 2.2) is another family of finders; of the ones mentioned in this thesis, it takes the largest number of shapes. Unsurprisingly, it also uses Bluetooth and has its own community search feature called *Tile Network*. [9]

The same as *Chipolo*, *Tile* is compatible with both *Android* and *Apple*, which makes it pass our first criterion. As mentioned above, *Tile* devices are made in many shapes, such as key rings, cards, stickers, and are also implemented in products by other companies, for example headphones by *Skullcandy*. This high universality makes it easily pass our second criterion. The battery lasts for one year and is user-replaceable, or for three years and is non-replaceable. This also makes it pass our third criterion. There is no equivalent to the finder function in the smartphone app, which makes it fail both the fourth and fifth criterion.

2.5 Fixed Sense

Last solution described is *Sense* by *Fixed*. It uses Bluetooth for localisation, but, apart from other devices, no community search function is implemented. This might change with a future update. It can also function as a motion sensor or as a humidity and temperature sensor. [10]

Similarly to *Chipolo* and *Tile*, *Sense* is compatible with both *Android* and *Apple*. Therefore, it also meets our first criterion. It in itself can only work as a keyring and the offer of accessories is limited. This makes it fail our second criterion. *Sense* uses user-replaceable batteries that last up to a year, which means that it meets our third criterion. The same as all devices mentioned above, *Sense* also fails both the fourth and fifth criteria, because the finder function in the smartphone application is irreplaceable.

Figure 2.2: Family of *Tile* tags. From left to right: *Tile Pro*, *Tile Slim*, *Tile Mate* and *Tile Sticker*. Image from [9].

2.6 Comparison of Existing Solutions

The table below is a summary of how existing solutions meet our criteria.

Comparison of existing solutions					
Product Name	Stand-alone	Universal	Maintain-able	Stable	Appless
Apple AirTag	No	Yes	Yes	No	No
Galaxy SmartTag+	No	No	Yes	No	No
Chipolo	Yes	Yes	Yes	No	No
Tile	Yes	Yes	Yes	No	No
Fixed Sense	Yes	No	Yes	No	No

Table 2.1: Comparison of existing solutions

From it we can see that most of the criteria are fulfilled by *Chipolo* and *Tile*. But we consider *Tile* slightly better, because its battery lasts longer and the product takes more shapes. Nevertheless, it still does not meet all our criteria, so it is not sufficient for our use case.

What we can see, however, is that all solutions take the form of a keyring supporting Bluetooth, or rather Bluetooth Low Energy (BLE) to be more precise. BLE is a wireless technology for short-range communication [12]. With these findings, we can proceed to our next chapter.

Chapter 3

Target Group

The small-range localisation device can be used by anyone, but its main target group should be older people and young children, or their offspring and parents, respectively, who would help with the search.

So, we have a person looking for something certain. They know approximately where they last saw it, but cannot find it. A locator might help them do this. If the person knows that they often look for certain things, they could attach a small device (key ring, sticker, or card) to these objects. This device would contain a speaker to help with accurate localisation.

Older people (but not only them) often leave things somewhere and subsequently cannot remember where they did so. If this happens and the item being searched for has the device described above attached to it, a simple button could be used to trigger it to ring, which would always be in its stable place. Alternatively, their children or grandchildren could help them with this by having an app on their mobile phone that serves a purpose similar to the physical button.

This can work similarly for young children. They often lose things and are afraid to confess to their parents because they want to avoid punishment [17]. They may then treat the search as a game where they would take the physical button, or their parents would borrow their mobile phone with the app and the child would go searching for the lost item. At the same time, it would save parents stress, as they would not have to deal with where their offspring had misplaced something again.

3.1 Problem Scenarios

This section contains examples of problem scenarios. Scenarios are used to help other people understand our design goals and empathise with users [18]. A scenario is an account of events from the user's perspective. They are written in such a way that they compel or evoke some emotion.

These scenarios were chosen because they show the situations in which a localisation device can be helpful. For example, scenario *Keys* shows the typical user, *Son* an alternative usage. They are also chosen in such a way that the reader recognises that the solution can take different forms for different situations, that is, the final device used in *TV Remote* might be different from the one in *Wallet*. The scenarios are also written in an informal language, as they want to portray the situations as humanly as possible. Storyboards accompanying the scenarios were created with StoryboardThat [19].

Storyboards are an easy way to visualise scenarios [20]. They communicate a story through images, and because of that, make it easy to understand by other members of a team and stakeholders. Both scenarios and storyboards are included because the combination of images and words tends to be the best way to present something [2]. Each scenario is accompanied by a storyboard, which can be seen in Figures 3.1, 3.2, 3.3, 3.4, 3.5 and 3.6.

3.1.1 Keys

An old lady is preparing to go shopping. She has her bag, her shopping list, her cell phone ready... but no, she cannot find her apartment keys. Where could they be? They must be here somewhere, otherwise she would not have got home before. But where could she put them? She will have to search the entire apartment, which will take a long time. But she wanted to go to the store now, when there are no checkout lines. There is nothing she can do, she cannot leave without the keys. If only she could summon them somehow, as she calls her dog. Just call "Fluffy" and he will come to her. But keys are not living creatures, so she has no choice but to search and hope she can make it to the store in time.

Figure 3.1: Storyboard of *Keys* problem scenario.

3.1.2 Glasses

A retired man would like to relax after a good lunch. Quality literature sounds like a good plan, he started reading a new book by Jo Nesbø yesterday. But for that, he needs his glasses. He had them in his hand a second ago. Where did he put them again? The case is empty and they are not next to his newspaper. His granddaughter has already taught him that if he puts his cell phone down somewhere, he can just ring it and the ringing will help him find it. But glasses are not a phone; they cannot be rung. It's a pity, it would save him time and he could go straight to his favourite past-time activity. There's nothing to be done; he'll find them soon enough, surely. Let's hope he didn't throw them in the trash again like last time...

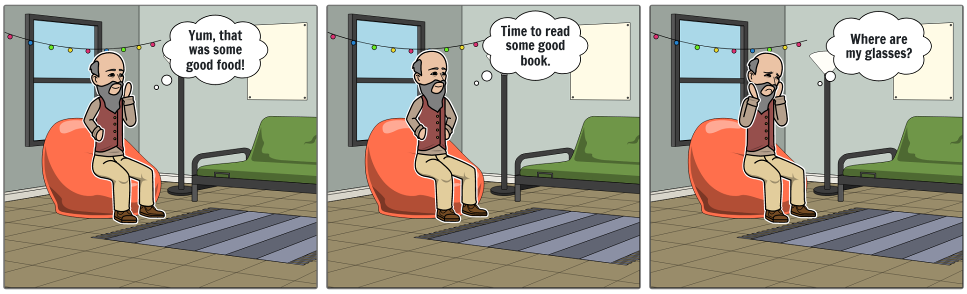

Figure 3.2: Storyboard of *Glasses* problem scenario.

3.1.3 Son

A woman is cooking in the kitchen. Lunch will be ready soon and her son is nowhere to be found. As always, he said he'd be home from the playground before lunch. By the time he gets here, the food will be cold. That's when she hears the doorbell. He's lucky, he made it. Or did something happen? She goes to the front door of the apartment and opens it. Her son is standing there crying. He says he lost his keys on the playground and they're not in his pocket. Well, if she didn't have enough problems. Food on the stove and now looking for her son's keys on the playground. Luckily, her husband is still at home and he'll come back to the playground and help his son find his keys. He originally had other things to do, but this is now more important. Hopefully the search won't take them too long so she doesn't have to heat up the lunch.

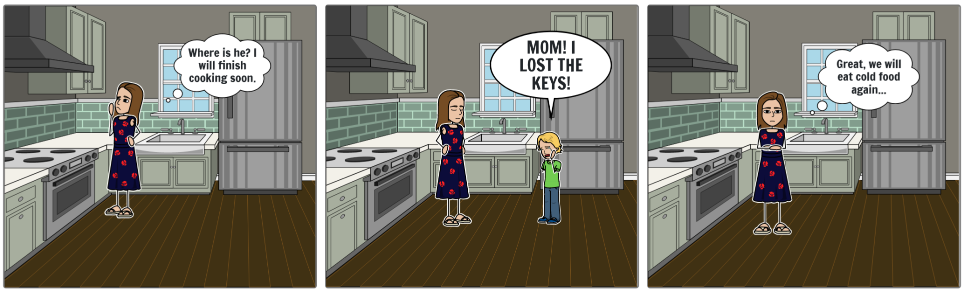

Figure 3.3: Storyboard of *Son* problem scenario.

3.1.4 TV Remote

A middle-aged woman finally returns home in the evening after a long day at work. She's not really hungry, she just wants to sit down and relax for a while. Turning on the television might be a good idea. She'd need the remote for that, but where did it go? Her husband was the last one to watch TV, so he must have put it somewhere. And he won't be home for another hour, at best. So if she can't find it, she's probably out of luck. It's too bad the remotes can't somehow announce their location when you're looking for them. It wouldn't have to be anything complicated, maybe just a beep...

Figure 3.4: Storyboard of *TV Remote* problem scenario.

3.1.5 Wallet

A grandson arrives to visit his grandmother. She has already prepared lunch for him. It was his birthday recently, and since she knows that her grandson is saving up and buying him some nonsense for a few crowns doesn't make sense, she would like to contribute a little money. But the problem is that she can't find her wallet. Earlier that day, she searched for it because she heard on the radio that counterfeit money had been seized in her town. Luckily she didn't find any in the wallet, but then she had to put the wallet somewhere and she can't remember where. She can at least think of it as a game for her grandson and then give him his present as a reward. However, she's nervous about not knowing where the wallet is. If the counterfeiters spent some time figuring out how to make it easier for people to find lost items, they would certainly be more useful to society!

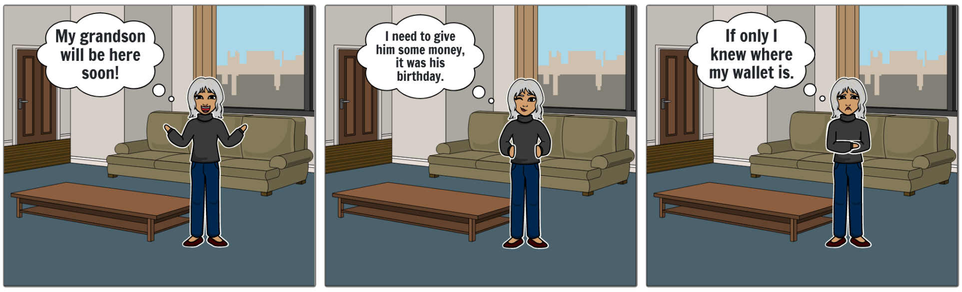

Figure 3.5: Storyboard of *Wallet* problem scenario.

3.1.6 Locked-out

A retired man is getting ready to go to the bus. He is going to visit his daughter and her family. He hopes to see his grandchildren after a long time, because he didn't see them for a while due to the COVID-19 pandemic[1]. He packs all the things he needs and checks the time. The bus leaves in ten minutes. The walk to the bus station takes about five minutes and he would like to be there a bit earlier, just to be sure. It's time to go. He gets dressed,

[1]If you are reading this in the future, COVID-19 was a disease that caused a pandemic in early 2020s.

takes his things, leaves his apartment and closes the door behind him. And then it hits him, he forgot his keys. Again. This has already happened many times; his keys are hanging right next to his door, but it doesn't matter, he always leaves them there. Well, what can he do now? His daughter has a spare key, which means he can continue his journey and borrow it from her, but he hates the idea of looking like a forgetful old man. However, it is the easiest way, and he certainly doesn't want to pay for a locksmith. He will have to admit his mistake and hope that he can figure out a way to stop forgetting his keys all the time.

Figure 3.6: Storyboard of *Locked-out* problem scenario.

3.2 High-level Usage

The device (key ring, sticker, card) is paired with a mobile application or a web application. From the application, it is possible to personalise the device (change the name). It is also possible to switch on search mode from the app. The search mode can also be activated with a physical button. In search mode, the searched device starts to ring with the built-in speaker (possibly also by flashing visually) when it comes within range of the mobile phone or the physical button. This should be possible by using Bluetooth Low Energy (BLE).

3.2.1 Keys

The user will have a key fob attached to their keys. The key fob should not be too large and heavy so that it does not interfere with carrying the keys (for example, in a pocket). When searching for keys, the user will turn on search mode using a physical button or a mobile phone. With the button or mobile phone in this mode, they will then start walking around the area where they think the keys might be found. The moment the device on the keys detects that it is being searched for, it will sound an audible alarm. Therefore, the user will be able to locate the keys. The device will be powered by a battery. When the battery capacity drops below a certain value, a red LED will flash on the key fob to let the user know that the battery needs to be changed. This should happen well in advance so that the user knows in time when to change the battery, prepare for it, and do not be surprised. There is also the possibility that the battery might not be able to be replaced at all to improve resistance to water.

3.2.2 TV Remote

The user will have a locator device, similar to the key fob described above, that is attached to the controller. Since a TV remote is a device that the user does not often carry outside of their home, a larger solution could be used here, such as a complete enclosure into which the controller would be inserted. Localisation would work in the same way as for a key fob. The battery situation would be the same as well.

3.2.3 Wallet

The device in this case would take the form of a thicker card that would be inserted in a wallet. The functionality would be the same as for the devices described above.

3.3 Exploratory Interviews

One of the most important parts of user-centred design is including users in the development. This section contains interviews with two participants. They were asked questions about losing and looking for items and then showed the main controller (Figure 3.7) and presented the idea of a localiser of searched objects.

3.3.1 Interview 1

The participant is 78 years old. She often finds herself looking for her keys in her apartment. The last time, she searched for half a day and finally found them in a drawer among the cutlery. Once, about 15 years ago, she had a key ring on her keys that alerted her about its whereabouts when she whistled at it. She often used this function, but unfortunately the key ring broke when she moved and she never bought a new one. She really liked the idea presented to locate lost items and said that she would definitely use it. After being shown a mock-up of the main controller prototype, she immediately knew how to use it. She remarked that she liked the idea of bell buttons. In addition to helping her find it, she said that it would also be useful to have something to alert her that she had forgotten to take her keys when leaving her apartment. She had already had to call the locksmith several times because she had closed the door behind her.

3.3.2 Interview 2

The participant is 73 years old. He often searches for things in the apartment. Not his keys, because he has a special place next to the door where he always places them. However, his glasses and his mobile phone are a problem. The

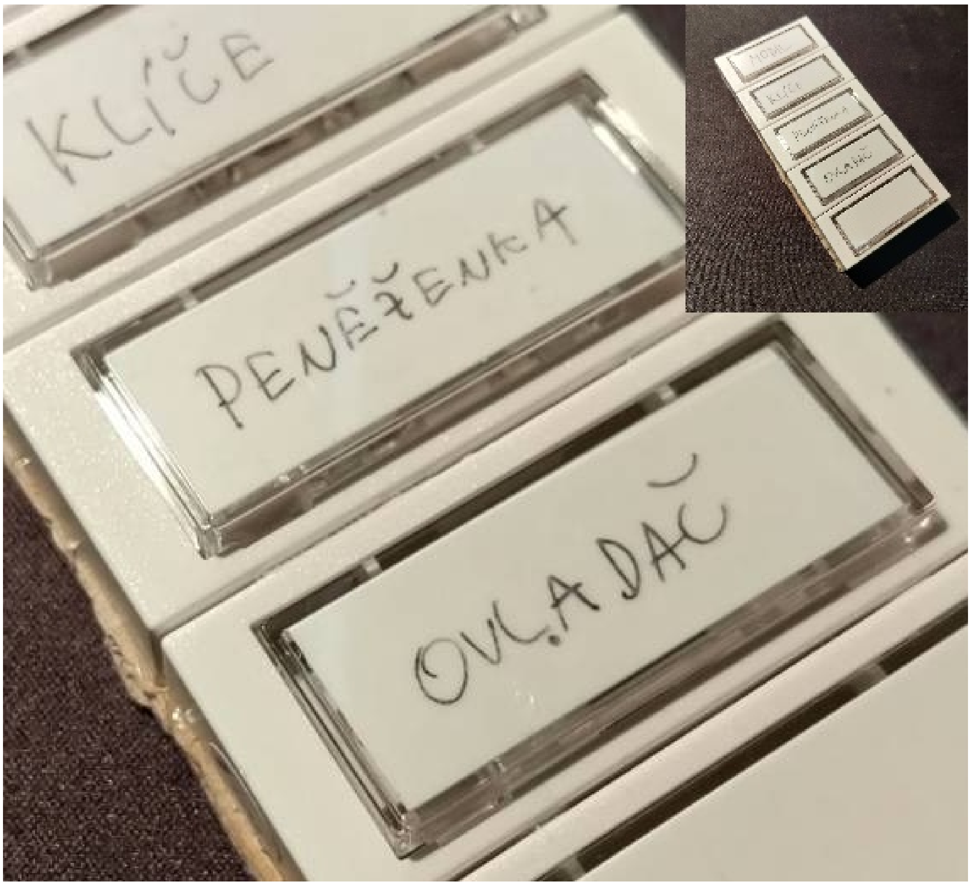

Figure 3.7: Mock-up of the main controller with physical buttons for localisation. This mock-up was used for first interviews and also in later usability testing.

mobile phone can be easily found if someone else is home with him, because it can be rang from the other person's phone. It is worse if he is home alone. The same applies to his glasses, which he probably looks for most often around the house. He says that it would be ideal if he could somehow call them up in that case. He liked the idea and the prototype presented to him. At the same time, he has a problem with forgetting his wallet when leaving the house. He had a problem a couple of years ago when he was stopped by the police while driving and he did not have his documents with him because he carries them in his wallet that he left at home.

3.4 Conclusion of Interviews

Besides liking the idea, both participants also shared the problem of forgetting things (keys or wallet) when leaving home. This could be solved by having these items ring when the front doors are opened, similar to the way they would ring when the user is looking for them. The problem scenario 3.1.6 was created as a result of these interviews.

Chapter 4

Design

Now that we know the target group and what their needs and desires are, we can continue with the design process. This chapter describes what the components of the final solutions will look like and what their features are. It also contains user scenarios which describe the possible use of the final solution and a hierarchical task analysis (*HTA*) in Figure 4.4.

4.1 Main Controller

A central device with several described buttons to search for lost items with attached "tags". It must not be too complex, so it is easy to understand, even for a population that is not familiar with new technologies. The buttons should be large enough to accommodate a description of their function, i.e. what the user is looking for at the moment and wants to "ring". Buttons should have some physical response, such as a click, so that the user knows that he has pressed the button correctly. There are two ways to start the search mode and leave it running. The user presses the button and holds it down, thus maintaining the search mode. Once the button is released, the search mode is turned off. The second option is to have the button act as a toggle, which means that when the user presses and releases the button, the search mode will turn on. If the user presses and releases the button again, the search mode is turned off. The main controller should also have a built-in speaker, as the user may not be able to find it but will be carrying one of the tags to "ring" it.

The device should not be too large, but at the same time be easy to work with. The ideal size estimated would be about 20 cm high, 7 cm wide and 1.5 cm thick. I would set the weight at 200 g. The shape is also important; It must be immediately clear how the device is held, what the front and back are, and where the top and bottom are. The back could be rounded in some way to make the device easier to hold. The main controller is treated as a device that has a designated place somewhere at home, so the user will know where to expect to find it. This place can also be used to charge the device, but it would make more sense to incorporate a non-rechargable user-replaceable battery, since the whole device should not consume too much energy. Given the size of the device, the battery can be large and last for a long time.

4.2 Tag

The tag is a simpler device than the main controller. It serves as a "smart tag", i.e. it attaches to another object that the user often loses/looks for, so that the user can find it using the main controller. It must have a built-in speaker that serves for localisation and also some LED light in case the user has hearing problems. If the tag detects that it is being searched for, an audio and visual alarm is triggered. It will also include a single button that will "ring" the main controller. The function will be exactly the same as the tag search with the controller, but in reverse.

The tag must not be too big, about 5 by 2,5 cm, with thickness about 0,5 - 1 cm, but definitely not more. It depends on its location. If it is inside a wallet, it can be like a "thicker" wallet; as a keyring, it could be a bit thicker, but we are more limited in other ways. I estimate the weight to be about 50g. The battery must last a long time, preferably at least a year. If it is about to run out, the device should alert the user. It would be preferable to have the battery user-replaceable, but non-replaceable batteries can last longer. Many existing solutions already use non-replaceable batteries, which adds the benefit of longer battery life and better water and dust resistance.

4.3 Doorkeeper

A device whose design emerged from interviews. Participants have a problem forgetting certain things when leaving home. The doorkeeper represents something like a simplified form of the main controller. It will be attached to the front door of the house or apartment and will detect if the door has opened. Once it does, it will switch to a mode similar to the search mode; that is, it will start "ringing" predetermined tags. At the same time, it needs to know if all tags are within its range. If not, it means that a tag is further away from the door, the user does not have it to himself, and it is not possible to ring it. In such circumstances, the doorkeeper itself must start ringing to alert the user that something is missing.

The dimensions of the doorkeeper are not too limited; it must have a built-in speaker and probably magnets that will sense whether the door is closed or open. The battery may be replaceable.

4.4 User Scenarios

User scenarios are stories created in such a way as to show how users can interact with our solution and, in doing so, achieve their goals [21]. They usually take situations from problem scenarios and include the final solutions in them. This puts a contrast between frustration or obstacles in problem scenarios and happiness or success in user scenarios.

The following scenarios are equivalent to those in 3.1, but only three were created, as more would be ambiguous. They are accompanied by storyboards in Figures 4.1, 4.2 and 4.3.

4.4.1 Keys

An old lady is about to go shopping. She has her bag, her shopping list, her cell phone ready... but no, she cannot find her apartment keys. Where could they be? They must be here somewhere, or she would not have gotten home before. But where could she put them? Luckily, her son bought her a gadget that she can use to help her find them. He attached a key ring to the keys and gave her a controller of some kind that causes the key ring to start making sounds. She picks up the controller from her drawer and presses the button labelled "Keys". A simple melody begins to play from a nearby coat hanger, where she hanged her jacket yesterday when she came home. Has she left the keys inside the jacket, in a pocket? She approaches the jacket and begins to search the pockets when, lo and behold, she finds the keys in one of them. Fortunately, she will get to the store on time. The next time her son visits, she needs to thank him.

Figure 4.1: Storyboard of *Keys* usage scenario.

4.4.2 Son

A woman is cooking in the kitchen. Lunch will be ready soon and her son is nowhere to be found. As always, he said he'd be home from the playground before lunch. By the time he gets here, the food will be cold. That's when she hears the doorbell. He's lucky, he made it. Or did something happen? She goes to the front door of the apartment and opens it. Her son is standing there crying. He says he lost his keys on the playground and they're not in his pocket. Well, if she didn't have enough problems. Luckily, her husband recently bought a device that he thinks might solve problems of this kind. Time to test it, the woman thinks to herself and hands her son the controller. There are several buttons on it, one of which is labelled "Keys". She tells her son to press the button when he gets back to the playground and listen carefully. He then runs out of the apartments, not crying anymore, knowing that he can still find the keys. Hopefully, he will be home soon, so his mother doesn't have to warm up his lunch.

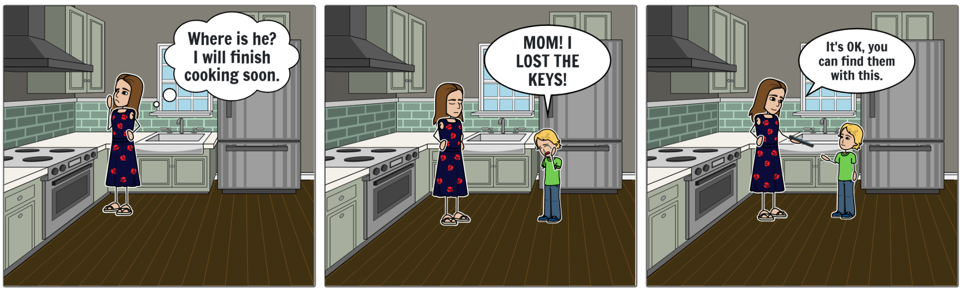

Figure 4.2: Storyboard of *Son* usage scenario.

4.4.3 Locked-out

A retired man is getting ready to go to the bus. He is going to visit his daughter and her family. He looks forward to seeing his grandchildren after a long time, because he didn't see them for a while due to the COVID-19 pandemic. He packs all the things he needs and checks the time. The bus leaves in ten minutes. The walk to the bus station takes about five minutes and he would like to be there a bit earlier, just to be sure. It is time to go. He gets dressed, takes his things, opens the door to his apartment... what's that noise? A melody plays from a rack of keys next to his door. Oh, right, he almost left his keys at home. He kept forgetting them, so he asked his daughter if there isn't some way to help him, because she is really into modern technology. She bought him this device, which reminds him of his keys when he leaves his house. He picks the keys, closes the door behind him, and locks them. His daughter saved the day again.

Figure 4.3: Storyboard of *Locked-out* usage scenario.

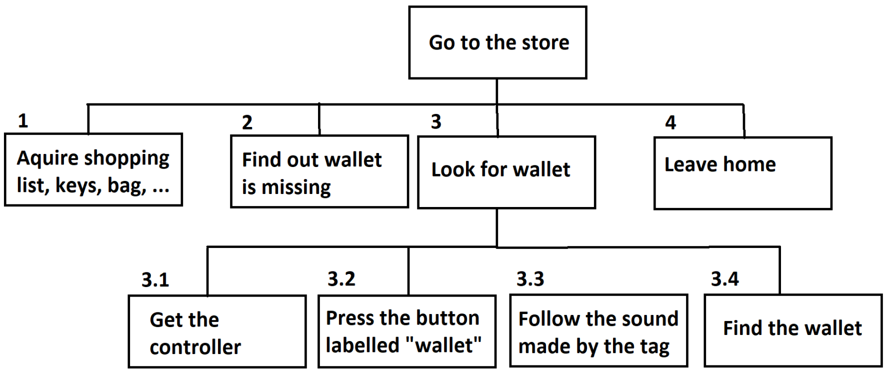

Figure 4.4: HTA - Going to the store.
Plan 3: 3.1 - 3.2 - 3.3 - 3.4
Plan 0:
Do plan 1
if plan 2 is not true, skip to plan 4
otherwise do plans 3-4.

Chapter 5

Implementation

> She wasn't certain what the future held, but coffee would be involved if she had any say in the matter.
>
> Terry Pratchett
> *Moving Pictures*

This chapter describes the implementation stage of the prototype used for user testing. The goal is to implement a high-fidelity prototype consisting of three parts, the tag, the tag control application, and the user controller.

Due to simplicity, the user controller functionality will be emulated by the tag control application. The user controller itself will not have any actual functionality and will only take the form of a mock-up. This means that the important part of the implementation is the tag and the control application. That being said, Figure 5.1 visualises the communication between the tag and the controller application.

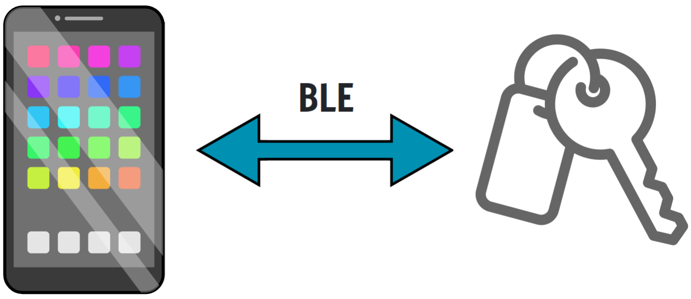

Figure 5.1: Simple visualisation of the communication between the tag and the control application.

The tag is implemented using a *ESP32* board. It plays the roles of both the tag and the doorkeeper described in the design section in Chapter 4. This means that it needs to signal its location so that the user can find it.

The tag control application is meant for the person who manages the testing, i. e. the facilitator. It needs to inform the facilitator whether the tag is connected and turn on and off the signalisation of the said tag. The tag and the control application communicate with each other using Bluetooth Low Energy (*BLE*).

The user controller is just a mock-up meant to be a substitute of the actual controller for the user. It needs to have several buttons, even though the buttons themselves will not have any functionality, meaning that pressing the buttons will not result in a system reaction. Creating a smartphone application rather than a hardware controller is easier and faster, while still sufficient for our testing purposes.

With these prerequisites in mind, we need to talk about the technology that we used for the implementation of the prototype.

5.1 Bluetooth Low Energy

In earlier chapters, we talked a lot about Bluetooth Low Energy, so a small introduction to a technology, which is used for the creation of our prototype, should not hurt anybody.

Bluetooth Low Energy (BLE) is a radio specifically designed for low-power solutions. It supports many communication topologies, which are point-to-point, broadcast, and mesh, making it more universal than Bluetooth Classic, which only supports point-to-point topology. BLE is widely used as device positioning technology because it includes features that allow one device to determine the presence, distance, and direction of another device [11].

Each device that supports BLE uses the Generic Attribute Profile (*GATT*), which is a communication protocol. *GATT* introduces two roles [13]:

- *Client*, which is a device that sends requests to a server and receives responses.
- *Server*, which is a device that receives requests from a client and sends back responses.

Each device also has its attributes, called *services*. Each service can also contain attributes, or *characteristics*, and each characteristic can include *descriptors*. This hierarchy is visualised in Figure 5.2.

5.2 ESP32

Although the Internet of Things (IoT) [22], an important field of information technology (and also a misnomer[1]), is not the aim of this thesis, we need to briefly introduce *ESP32*, a system on a chip (*SoC*) microcontroller with integrated Wi-Fi and, more importantly, Bluetooth [14].

ESP32 is robust and universal and is designed to achieve this with low power consumption. Its universality perfectly fits our use case, and it is why it was chosen to be the backbone of our prototype.

[1]a wrong name or inappropriate designation [23]

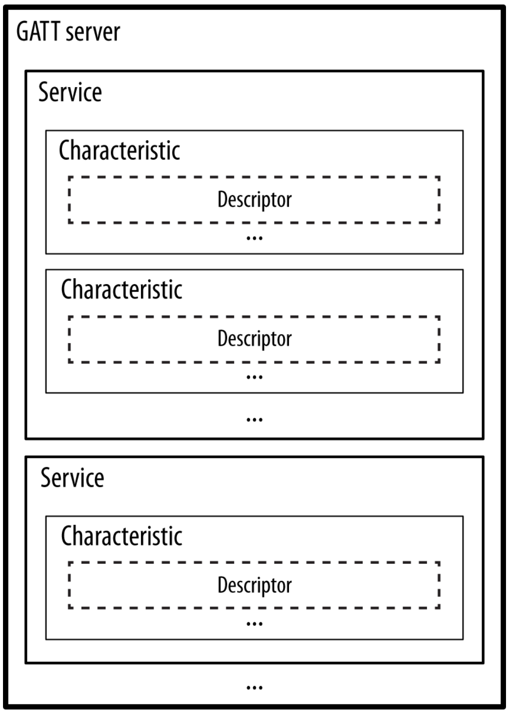

Figure 5.2: Illustration of the data hierarchy introduced by *GATT*. Image from [13].

Now that we know what technology we are using, we can talk about the prototype units.

5.3 Tag

As mentioned above, the prototype of the tag is meant to simulate both the tag and the doorkeeper. Because it is an *IoT* device, in addition to the software implementation, we also need to talk about the hardware one. The tag consists of the following components:

- One *WeMos ESP-WROOM-32*, an ESP32 board (Figure 5.3).
- Two passive piezo buzzers *MH-FMD* (Figure 5.4).
- One 400-pin breadboard.
- Six male-to-male *DuPont* jumper wires.
- One USB-A to micro-B cable.
- One 16000mAh *Xiaomi Mi Power Bank*.

Figure 5.3: *WeMos ESP-WROOM-32*, the ESP32 board used as the backbone of our prototype. Image from [15].

Figure 5.4: *MH-FMD* speaker. Image from [16].

5.3.1 Hardware Implementation of the Tag

The connection of the components is fairly simple. First, we need to connect one of the ground pins (labelled *GND*) of the ESP32 board to the ground pin (also labelled *GND*) of the piezo speakers. Then, we need to connect one of the five volt power pins (labelled *5V*) of the board to the voltage common collector pin (labelled *VCC*), i. e. the power input pin, of the speakers. Now, the speakers are powered by the ESP32 board.

Next, we need to connect the data pins so that our board can send signals to the speakers. We can choose any data pin of the board, and I chose pin 12 (not surprisingly labelled *12*). It is important to remember the pin number for later, because we will use it in the software implementation. The data pin on the board must be connected to the input / output pin (labelled *I/O*) of the speakers. Now all that is left is to connect the board to the power bank using a USB cable. The complete connection schema of the tag is shown in Figure 5.5.

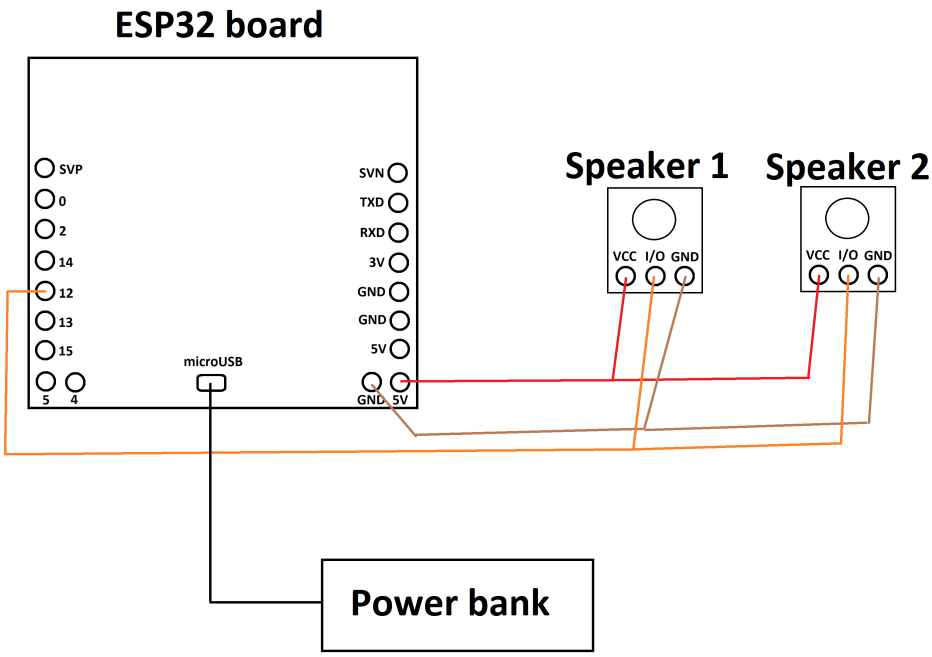

Figure 5.5: Simple schema of the tag.

5.3.2 Software Implementation of the Tag

Now that we have completed the connection of all the components, we can continue with the software implementation. The code was written in Arduino IDE [24], an IDE developed to write and upload code to Arduino boards, which is compatible with ESP32.

An Arduino program is called a *sketch*. Every sketch needs to have two special functions:

- *setup()*, which is called once at the beginning of the sketch and is used for the initialisation of pins, libraries, etc.
- *loop()*, which is called repeatedly during the execution of the sketch. In it lies the logic of the sketch.

Because we are using *BLE*, our sketch must include the *ESP32_BLE_Arduino* library, which is already included in the Arduino IDE. In the *setup()* function, we need to create and initialise our *BLE* server, including characteristics and descriptors. The code of the function *setup()* is as follows:

```
void setup() {
  Serial.begin(115200);

  // Create the BLE Device
  BLEDevice::init("dipl_tag");

  // Create the BLE Server
```

```
8   BLEServer *pServer = BLEDevice::createServer();
9   pServer->setCallbacks(new MyServerCallbacks());
10
11  // Create the BLE Service
12  BLEService *pService = pServer->createService(SERVICE_UUID);
13
14  // Create BLE Characteristics
15  BLECharacteristic *pCharacTX = pService->createCharacteristic(
16                      CHARACTERISTIC_UUID_TX,
17                      BLECharacteristic::PROPERTY_NOTIFY
18                    );
19
20  pCharacTX->addDescriptor(new BLE2902());
21
22  BLECharacteristic *pCharacRX = pService->createCharacteristic(
23                           CHARACTERISTIC_UUID_RX,
24                           BLECharacteristic::PROPERTY_WRITE
25                           );
26
27  pCharacRX->setCallbacks(new MyCharacCallbacks());
28
29  // Start the service
30  pService->start();
31
32  // Start advertising
33  pServer->getAdvertising()->start();
34  Serial.println("Setup finished!");
35 }
```

In line *5*, *dipl_tag* is the name of our server. The values *pCharacTX* and *pCharacRX* are characteristics of the service, *pCharacTX* is for sending data, *pCharacRX* for receiving. In lines *12* and *27* we add custom callbacks to the server and characteristic *pCharacRX*, respectively. The server callback code is as follows:

```
class MyServerCallbacks: public BLEServerCallbacks {
    void onConnect(BLEServer* pServer) {
      deviceConnected = true;
    };

    void onDisconnect(BLEServer* pServer) {
      deviceConnected = false;
      pServer->getAdvertising()->start();
    }
};
```

We can see that all it does is set the variable *deviceConnected*, which represents if a client is connected, to *true* or *false*. If the variable is set to *false*, it also starts to advertise the server back to its surroundings; otherwise, no other client would be able to connect to the server after a client disconnects.

The callback of the characteristic *pCharacRX* is as follows:

```
class MyCharacCallbacks: public BLECharacteristicCallbacks {
    void onWrite(BLECharacteristic *pCharacteristic) {
      std::string rxValue = pCharacteristic->getValue();

      if (rxValue.length() > 0) {
```

```
        if (rxValue.find("A") != -1) {
          Serial.println("SEARCHED");
          searched = true;
        }
        else if (rxValue.find("B") != -1) {
          Serial.println("STAND-BY");
          searched = false;
        }

        Serial.println("*********");
      }
    }
};
```

Here, we can see that the variable *searched* is set to *true* or *false*, depending on whether the letter received from the client was *A* or *B*, respectively.

Now that we have initialised everything, we can move on to the *loop()* function. In it, we only check if a client is connected (*deviceConnected*) and the tag is searched for (*searched*). The code is as follows:

```
void loop() {
  if (deviceConnected) {
    if(searched)
      play();
  }
  delay(500);
}
```

If both Boolean variables are set to true, the *play()* function is called. The *play()* function is where the melody of the audio output is programmed. *ESP32* supports eight musical octaves, but we only need two. The piece in which the tag plays is the beginning of the *Family Frost* theme (Figure 5.6), best known from the late 1990s and early 2000s.

```
void play(){
  ledcAttachPin(12, 1);
  ledcWriteNote(1, NOTE_Eb, 4);
  delay(750);
  ledcWriteNote(1, NOTE_G, 4);
  delay(250);
  ledcWriteNote(1, NOTE_F, 4);
  delay(500);
  ledcWriteNote(1, NOTE_Gs, 4);
  delay(500);
  ledcWriteNote(1, NOTE_G, 4);
  delay(500);
  ledcWriteNote(1, NOTE_Bb, 4);
  delay(500);
  ledcWriteNote(1, NOTE_Eb, 5);
  delay(2000);

  ledcDetachPin(12);
}
```

The function *ledcAttachPin()* attaches the pin *12*, i. e., the pin to which we have connected the speakers, to the channel *1*. We then use the channel in the function *ledcWriteNote()*, which tells the speaker which note to play. At

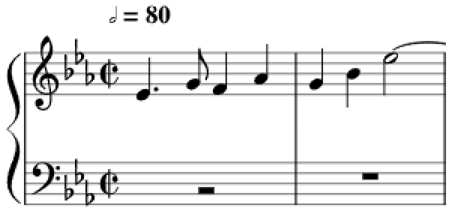

Figure 5.6: Musical notation of the *Family Frost* theme, the melody played by the tag. [26]

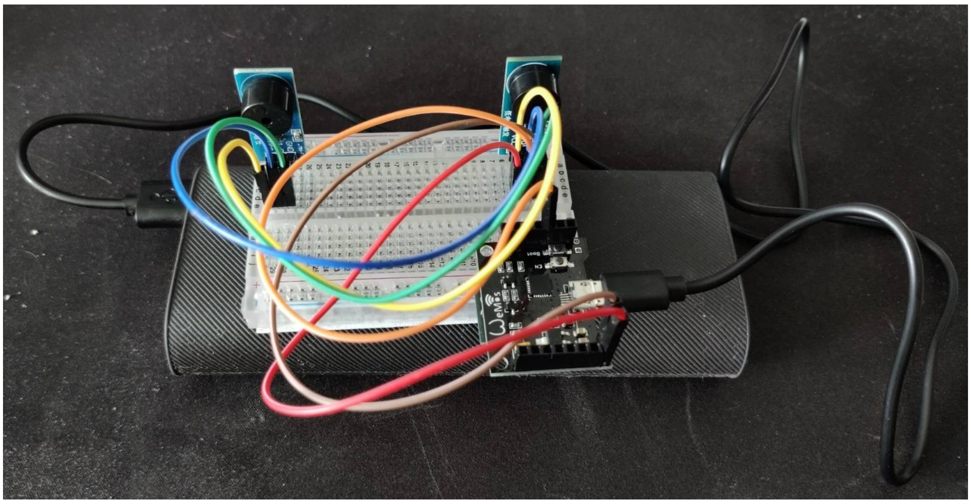

Figure 5.7: The tag prototype.

the end of the function *play()*, the pin *12* is detached by calling the function *ledcDetachPin()* with the pin number as a parameter.

We have finished the tag prototype; its image can be seen in Figure 5.7. We can now continue with the tag control application.

5.4 Tag Control Application

The tag control application is an application for the facilitator with the sole purpose of controlling the tag. It was developed in *Thunkable* [27], an easy-to-use development tool for mobile applications for both iOS and Android. Its strength is that it does not require any strong knowledge in software development and the development is universal, meaning that there is no difference in developing an iOS application or an Android application.

We will start with the design of the main page. We need two buttons, one smaller to connect to the tag, and one larger to start the search mode. An error message label is also added. A screenshot of the application can be seen in Figure 5.8.

We shall continue with the implementation of the logic. Programming in Thunkable is done by code blocks, similar to other visual programming

Figure 5.8: Screenshot from the tag control application.

languages. We need to implement two main functionalities, connecting to the tag and starting the search mode. The logic can be seen in Figures 5.9 and 5.10.

For connection 5.9, the application first looks for all BLE devices around the phone and checks if the tag is one of them. If so, it attempts to connect to it, and if a connection is established, it notifies the user and disables the *Connect* button.

For localisation 5.10, the application sends a character A or B to the tag, depending on whether the text colour of the localisation button is set to black or red. If it is black, it means that the search mode is deactivated, so the application sends the letter A to the tag and sets the text colour to red. Vice versa, if the text is red, the character B is sent, and the text colour is set to black. If an error occurs during transmission, a message is shown on the label mentioned above, the text colour is set to black, and the *Connect* button is enabled.

As mentioned above, the applications developed in *Thunkable* are universal and can run on both *iOS* and *Android*. During testing, the applications ran on *OnePlus Nord*, an Android phone. For the application to work, the *Bluetooth* and *Location* functionalities must be enabled on the phone.

We have now covered everything related to the tag control application. The next part contains a brief description of the user controller prototype.

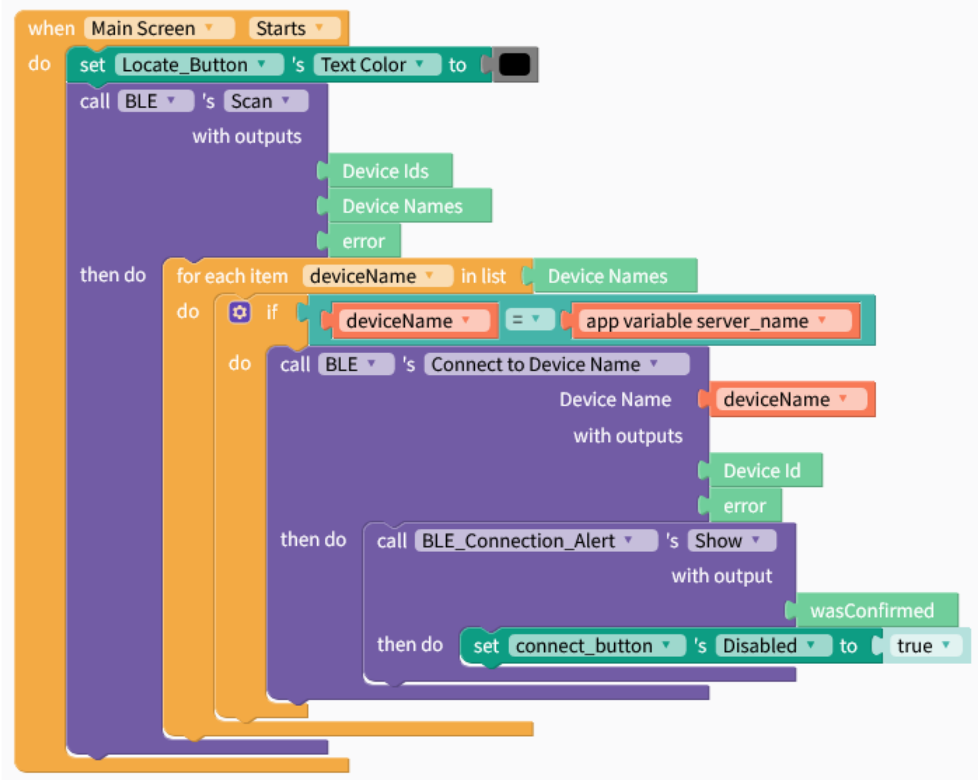

Figure 5.9: Code block of connection to the tag.

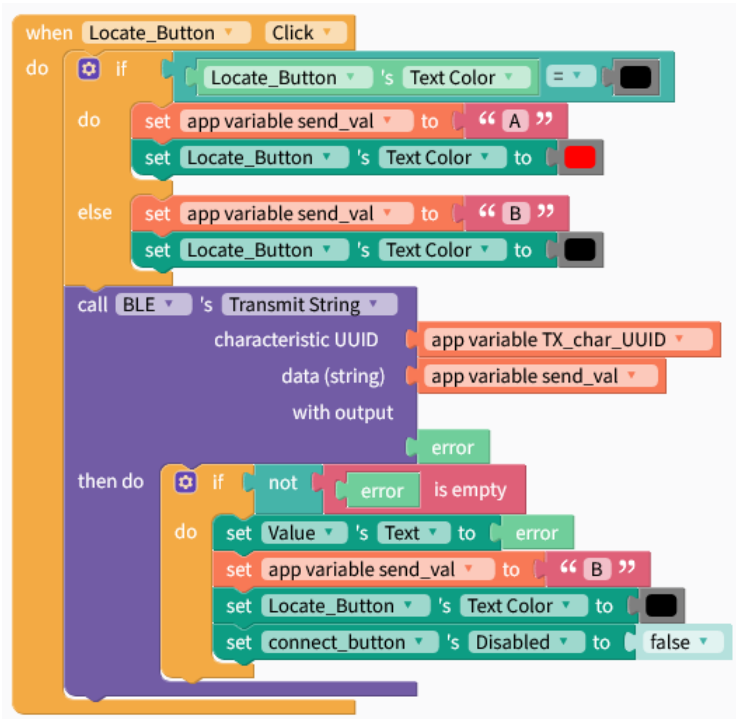

Figure 5.10: Code block of starting the search mode.

5.5 User Controller

The user controller prototype was already mentioned in Chapter 3 and can be seen in Figure 3.7. It is meant as a mock-up for the participants and does not contain any actual programmable logic. It consists of five *ABB* bell buttons [28] glued to a piece of cardboard. Four of the buttons are labelled (in Czech) - *MOBIL* (mobile phone), *KLÍČE* (keys), *PENĚŽENKA* (wallet), *OVLADAČ* (TV controller), and one of the buttons is left blank. The idea behind labelling the buttons is to show the participants that the controller is a universal and customisable localisation device.

That is the end of the *Implementation* phase. We will now proceed to the next chapter *Tests*.

Chapter 6
Tests

> Trust but verify.
>
> *Czech proverb*

This chapter describes the prototype testing procedure. Formative testing is one of the most important parts of user-centred design. The goal is to evaluate design decisions as soon as possible, preferably in the design stage. In formative research, you can figure out what participants think about a topic, determine when a feature is not working well and why, and suggest changes based on those findings [29].

The main goals of our tests are to evaluate whether our solution helps participants solve their problems and to determine if it is easy for them to use it. We will achieve this by observing the participants during the tests while they interact with the prototype and also by interviewing them afterwards.

6.1 Participants

As already mentioned in Chapter 3, the main target group of our solution is older people who do not own a smartphone, but we also wanted to test the localisation device with people not belonging to this category, for example, elderly people who use smartphones or people who are not yet retired but for some reason refuse or are unable to use a smartphone.

The group of participants who participated in the usability testing had the following characteristics:

- There were six participants.
- Their average age was 69.
- Half of the participants did not own or use a smartphone.
- All participants confessed that they had searched for a certain item repeatedly or forgotten it when leaving their home.

If we take a formula by *Jakob Nielsen* and *Thomas K. Landauer* [30]:

$$Found(i) = N(1 - (1 - \lambda)^i)$$

where

- ***Found(i)*** is the number of problems found in the tested interface.
- ***N*** is the total number of problems in the interface.
- $\boldsymbol{\lambda}$ is the probability of finding an average usability problem when observing a single average subject (the calculated mean number is *0.31* [30]).
- ***i*** is the number of participants.

and modify it:

$$\frac{Found(i)}{N} = 1 - (1 - \lambda)^i$$

we can calculate that our six participants will find *89%* of all problems:

$$0.89 = 1 - (1 - 0.31)^6.$$

This is a sufficient number because only the first version of the prototype was tested.

6.2 Wizard of Oz

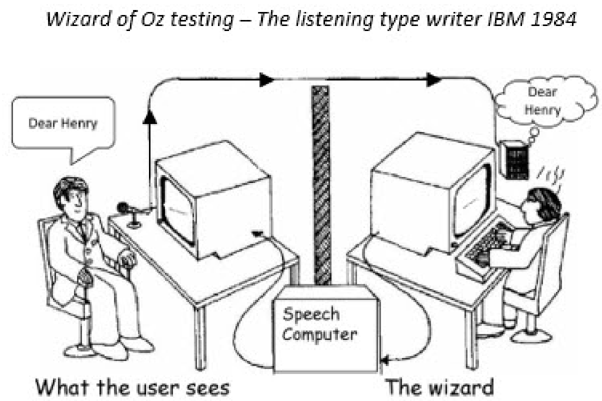

Figure 6.1: The listening typewriter, an example of *Wizard of Oz* method [31].

Wizard of Oz testing is a method in which we can test a system that does not yet exist [3]. It is named after a character of the same name from the book *The Wonderful Wizard of Oz* by *L. Frank Baum*, in which an ordinary man is hidden behind a curtain and pretends through the use of technology to be a powerful wizard [31].

Thanks to this method, we can test a concept before implementing it, saving us a lot of time. A great example is the *IBM listening typewriter*, which can be seen in Figure 6.1. The participant is sitting in one room talking to a microphone, while the facilitator is in another room typing what the participant is saying, so it appears on the user's screen as if it were done by the computer. This gives the participant the illusion that he is dictating his words to the computer [31].

We have already mentioned in Chapter 5 that the user controller prototype does not have any actual functionality and its functionality is being emulated via *Tag Control Application*. Here is exactly where we can use the *Wizard of Oz* method. When the participant presses a button on the user controller, thinking that pressing activates the search mode, the facilitator will activate the search mode from his smartphone, giving the participant an illusion of control.

6.3 Pilot Testing

Before the actual testing started, atleast one round of pilot testing needed to take place to discover obvious mistakes in the prototype, and for the facilitator to try the testing process.

The pilot testing was conducted with one participant and revealed a problem with the volume of the audio signalisation, which was not loud enough. Originally, the prototype had only one piezo speaker. The prototype was modified to accommodate a second speaker. Chapter 5 already takes this change into account.

6.4 Testing Process

At the beginning, each participant was introduced to the purpose of usability testing. They were assured that it is not them who are being tested, but the prototype, and if something goes wrong, it is the prototype's fault, not theirs. The facilitator also asked for permission to take notes and record an audio recording of the test.

Subsequently, the participant was given three tasks successively. Each started with its own introduction, explaining to the participant what the situation was like and what their goals were. The tag controller was shown to them and explained how it works. After that, they tried to finish the assigned task. Each task ended with an interview in which the facilitator asked the participant primarily questions about whether they considered the task easy or difficult and what they did or did not like.

6.4.1 Task 1 - Find Your Wallet

In this task, the goal was to find the participant's wallet. The wallet was hidden with the tag somewhere in the participant's home (Figure 6.2). The task started with an orientation:

You want to go to a store. You already have your keys, your grocery bag, and your shopping list, but you cannot find your wallet. Peak hours will soon start in the store and you want to avoid them. You know your keys

Figure 6.2: Image from Task 1 - The *tag* hidden with a wallet.

are somewhere in your house because you used them earlier, but you cannot remember where you put them. Your offspring recently bought you a device with which you can find items that you are frequently losing. You have this device in your wallet. Use the controller that comes with this solution and find your wallet.

After the orientation, the participant began his adventure trying to complete the task. When they pressed a button on the controller to start the search mode, the facilitator activated the search mode from *tag control application*. After the task was completed, a short interview was conducted and the next task followed.

6.4.2 Task 2 - Do Not Forget Your Keys (Tag on Keys)

At the beginning of this task, the participant was given the following orientation:

You are leaving your home in a hurry because you need to catch a bus. You already have everything packed. Or not?

This task and the following one are very similar; their only difference is what signals the participant that they had forgotten their keys. In this case, it is the keys themselves. They are near the entrance door that the participant opens (Figure 6.3). When they do so, the facilitator activates the search mode, and the tag starts to audibly signal its location. The melody plays several times to give the participant some time to find the keys. As for the previous task, a short interview follows after the task.

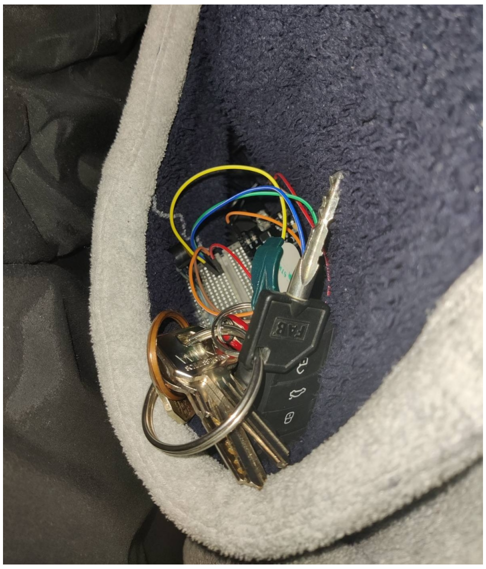

Figure 6.3: Image from Task 2 - The *tag* hidden with keys.

Figure 6.4: Image from Task 3 - The *tag* as a doorkeeper.

6.4.3 Task 3 - Do Not Forget Your Keys (Doorkeeper)

The third task is very similar to the second one. The orientation is the same, but the tag is placed right next to the entrance door on its own (Figure 6.4). When the participant opens the door, the tag starts to signal that the participant forgot his keys. The participant then has to find them using the controller. It should be said that while the participant is away to get the controller, the facilitator must remove the tag from the door and place it near the keys, so that the participant can find them. The task is also followed by a short interview.

6.5 Findings

During the tests, several important problems emerged. This section describes them and suggests solutions to the problems. In addition, the testing had several positive discoveries, which this section also mentions.

6.5.1 Problems

The following is the list of identified issues.

- ***Tag inside a drawer*** - This was probably the most critical issue. If the tag was placed inside a drawer or cabinet, the audio signalisation was dampened. This made it harder for the participant to find it. Giving the tag a visual signalisation would not help because if the tag is completely enclosed inside something and the user cannot see it, they would also not see any light emitted from the tag. One solution comes to mind, that is, signal the direction of where the tag is on the controller in some way. *Apple AirTag* and *Galaxy SmartTag+* already have a similar feature using the ultra-wide band, but it would be harder to signal such a thing on a device without a display. Another possibility is to signal proximity to the searched item by voice commands from the controller.
- ***Stopping signalisation triggered by the doorkeeper*** - Another discovered issue was when to stop the signalisation triggered by the doorkeeper. Originally, the tag played the melody a few times and then turned off, but this raises the issue of turning off too early. One possible solution is to add an accelerometer and turn the signalisation off when the tag moves, but if the tag were inside a coat in a closet, the user might move the coat, which would turn off the signalisation too early. A better solution might be to turn off the signalisation by pressing a button on the tag, which already has one (for finding the controller). Therefore, this button can have two functions.
- ***Speaker loudness*** - Two participants mentioned concern that the audio signalisation might not be loud enough for them. The melody of the tag is between *311 Hz* and *623 Hz*, and according to Wiley et al. [32], the greatest hearing change in threshold for older adults occurs at lower frequencies around *500 Hz*. A simple solution might be to play the melody an octave higher, which means between *623* and *1245 Hz*. Also, installing better speakers that can produce more decibels would not hurt, but they also cannot be too big.
- ***Melody changing for doorkeeper*** - One of the participants came with the idea of a changeable melody for the doorkeeper. They said that if the melody stayed the same every time, they would get used to it and start ignoring it. On the other hand, a different participant preferred the melody to remain the same, saying that if it were to change every time, it would confuse them.

6.5.2 Positive Discoveries

Listed below are several positive discoveries made during the course of the testing.

- All participants found the solution easy to use. They quickly understood the idea and immediately knew how to use the controller.
- All participants liked the simplicity of the controller having only labelled buttons.
- Participants who did not own a smartphone said that they think this solution is suitable for them and even those who use smartphones preferred to use the controller with physical buttons instead of a smartphone application.
- Only one participant was unable to complete a task. The problem was that the tag was inside a drawer and could not be heard.
- All participants preferred not holding the button while searching, favouring a toggle like button.
- One of the participants kept asking when the final product would be available.

6.6 Conclusion of the Tests

Overall, the tests were a success. It showed that the participants liked the idea and would use it if it was available. They praised its simplicity and ease of use. They all learnt to use it very quickly and quickly understood what to expect. The next step is to work on the issues listed above in Subsection 6.5.1 and do another round of tests.

First, we need to solve the problem that the tag is enclosed inside a different object, for example, a drawer. If this situation occurs, the audio signalisation is muffled, and the chance of finding the item worsens. We discussed two possible solutions to this problem in the previous chapter. One is to give the controller visual directions of where the tag is. This might be too tricky because the controller does not have a display and we do not want to make the controller look too complicated. Another possibility is to add the controller a functionality to audibly signal if the user is getting closer to the tag. The game *Hot and Cold* might be a good inspiration (in Czech *Přihořívá, hoří*). If the user is far from the tag, the controller would say "*cold*", when he gets closer, it would say "*warmer*", and when he is right next to it (right next to the drawer in which the tag is), it would say "*boiling*". Due to the fact that it is a game for children, it should be easier for users to understand what is going on.

Second, the problem of when to disable the signalisation triggered by the doorkeeper can be solved by pressing a button located on the tag. Disabling it by movement of the tag is a double-etched sword. It might seem like a good idea because it does not require any special action from the user, but it might lead to the signalisation switching off too soon, as discussed earlier.

Third, the problem of speaker loudness can be solved by using louder speakers, but we should also take into account the frequency of the melody. With age, human hearing worsens and occurs primarily at the ends of our hearing spectrum. If we manage to play a melody in the middle of this spectrum, that might also help.

Fourth, adding more melodies is definitely a feature that should be in the final product. This is more to the user's taste, because if you need to listen to a melody and for some reason you do not like that melody, using the product can be quite unsatisfying. Also, in the doorkeeper situation, it is true that users might get too used to the melody playing when they open their entrance door and then start to ignore it, but it is also true that if the melody changes every time, it can confuse them. This can then be a customisable feature which should be tested.

Chapter 7
Conclusion

The aim of this thesis was to propose an easy-to-use solution that would help users find items that they tend to lose or forget where they put them. We are not computers or programmed to be perfect, and forgetting is part of being human. The target group for this solution is older adults and young children.

A survey of existing solutions was conducted that showed that there are already existing and successful solutions, but all of them need a smartphone, which they use as a finder device. This distracts people who do not own and use a smartphone in their daily lives, mainly older adults who do not trust modern technology.

The development process implemented user-centred design techniques that focus on the user at every stage. First, user research was carried out, which showed that potential users would be interested in the solution and also added an extension of the original solution, called *doorkeeper*, which helps users to not forget important things when leaving home.

Subsequently, a prototype of the future solution was created using *ESP32* development board supporting *Bluetooth Low Energy*, *Thunkable* development tool for mobile applications and some bell buttons with a piece of cardboard. In the end, the prototype consisted of three parts: a tag consisting of two buzzer speakers, a controller mock-up, and a smartphone application for the facilitator.

In the end, the prototype had to be tested and evaluated. The user testing showed that older adults are in favour of the solution and would gladly use it. All of them found it easy to use and understand. The tests also showed some issues that need to be addressed before the next testing phase is carried out, but this was discussed in the previous chapter.

We need to discuss how the final product should look. We can create a completely new product and become a competitor of *AirTag*, but it would also make sense if the user controller were to become a part of one of the already existing solutions. Surely, companies want to expand their user base, and making their product more friendly to the older population is a good way to do it. People over 60 make up 15% of the world's population, but the percentage is much higher in developed countries [33].

When it comes to *doorkeeper*, Alex Wulff [34] has developed a different solution that uses NFC. When the user opens the door, a signalisation starts and can only be turned off by scanning an NFC tag, which is attached to the user's keys. This is a great solution, but it would mean adding NFC to the tag, which would also make it bigger. Another possibility is to turn off the signalisation by pressing a button on the tag, as mentioned before.

In conclusion, it was shown that the solution proposed in this thesis heads in a good direction and with enough time, money, and support, it can be a device which would be beneficial to people.

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