IMPLEMENTATION OF BODY-COUPLED COMMUNICATION ON A WEARABLE TAG

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Abstract

Body Coupled Communication (BCC) is a very new technology consisting in transmitting information by sending electrical signals through the human body. It is very interesting to learn what can it provide by now. The basis of this communication system is done and there already are functional models. Now it is worth start trying it and see how can people use it. It must be said, however, that it still needs time of research and development until we can see it as a common technology.

In this work, a detailed and, as easy as possible, to understand explanation is given about the basics of this technology. After this explanation, there is a general review of the history, since it was first mentioned in a thesis by T. G. Zimmerman until now. Finally, it is analyzed what can BCC apport from now on. What must be done to make it useful and known for common people.

Having considered all the previous points, it is time to start the practical part: Implement BCC. An apparently simple application that uses BCC is created, this way one can observe which is the real current state of the technology and what can be expected from it.

Resum

Body Coupled Communication (BCC) és una tecnologia molt nova que consisteix en transmetre informació enviant senyals elèctriques a través del cos. És molt interessant ara per ara veure què pot donar de si. Les bases d'aquest sistema de comunicació estan fetes i ja hi ha models funcionals. Ara val la pena començar a fer proves i veure com ho pot utilitzar la gent. S'ha de dir, això sí, que encara li queda un llarg camí en quant a recerca i desenvolupament fins que ho puguem veure com una tecnologia habitual.

En aquest treball es fa una explicació detallada i el més entenedora possible sobre les principals bases d'aquesta tecnologia. Seguidament es fa un repàs per la història. Des de que va ser mencionada per primera vegada en la tesi de T. G. Zimmerman fins a l'actualitat. Finalment s'analitza què pot aprotar BCC d'ara endavant, què ha de fer per ser útil i coneguda entre la gent en general.

Havent observat tots aquests punts, es comença la part pràctica del projecte: Implementar BCC. Es crea una aplicació aparentment senzilla que utilitza BCC, així es pot observar en quin estat real es troba la tecnologia i què se'n pot esperar.

Resumen

Body Coupled Communication (BCC) es una tecnología muy nueva que consiste en transmitir información enviando pulsos eléctricos a través del cuerpo humano. Es muy interesante por ahora ver que puede dar de sí. Las bases de este sistema de comunicación están hechas y ya hay modelos funcionales. Ahora merece la pena empezar a hacer pruebas y ver como lo puede utilizar la gente. Cabe decir, eso si, que aún queda un largo camino en cuanto a investigación y desarrollo hasta que lo podamos ver como una tecnología habitual.

En este trabajo se hace una explicación detallada y lo más comprensible posible sobre las principales bases de esta tecnología. Seguidamente se hace un repaso por la história. Desde que fue mencionada por primera vez en la tesi de T. G. Zimmerman hasta la actualidad. Finalmente se analiza qué puede aportar BCC de ahora en adelante, que se tiene que hacer para que sea útil y conocida entre la gente en general.

Una vez observados todos estos puntos, se empieza la parte práctica del proyecto: Implementar BCC. Se crea una aplicación aparentemente sencilla que utiliza BCC, así se puede observar en qué estado real se encuentra la tecnología y que se puede esperar de ella.

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1. Introduction

1.1. Motivation

Since Internet was invented, it has grown with astonishing speed. Especially in the last few years it has been introduced at every home and business, and has generated many variants of applications. It has lead to a huge amount of data traffic breaking many predictions. During 2016, the global mobile data traffic was increased by 63% compared to 2015, according to a study released by Cisco Systems. In addition, the company made a forecast for the coming years mobile data traffic. It is interesting to have a look at the resulting graph, shown in figure 1, to get an idea of the magnitude of the situation. Must remember that it is only a forecast. However this increment in data traffic has always been supported by the evolution of technology. Many systems for data transmission have appeared or have been improved in order to cover the traffic demand. We are talking about new codifications, application of optical fiber or more efficient protocols.

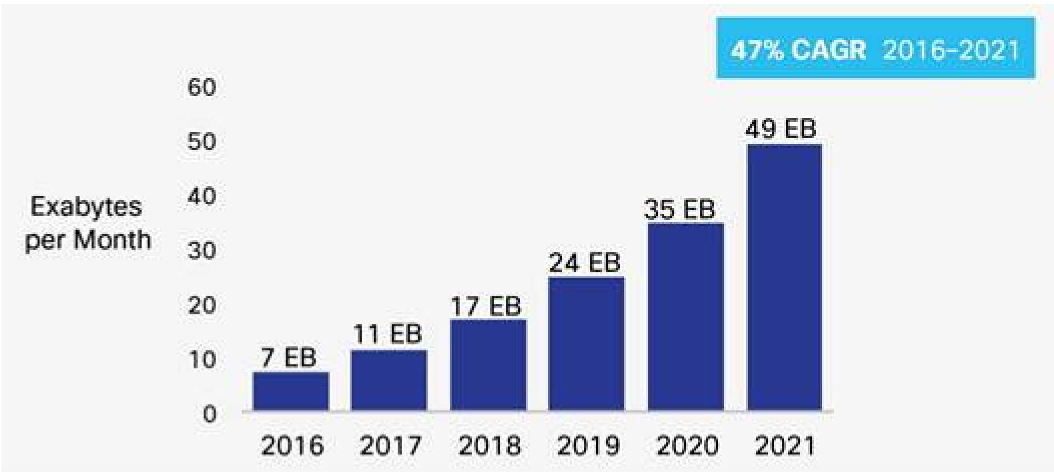

Figure 1.1: Cisco Systems forecast of the upcoming global mobile data traffic. The vertical axis shows the traffic in exabytes per month. The horizontal axis indicates years. It is expected an increment data traffic around 47% every year.
This image is courtesy of Cisco Systems, Inc.

In this project the center of attention is given to Body Coupled Communication (BCC). It is a technology born within this era of Internet, aiming to enhance simple transmissions for very close distances allowing a new wide range of applications, providing low power consumption or interference. It consists in transmitting data between two devices in direct contact with our own body, or very close to it in some cases (the maximum distance between body and device that can be reached with BCC is no more than seventy centimeters, but devices can be designed to reach no further than a few millimeters). The signal will be transmitted through our body or through an equipped component (for example clothes), depending on the system used. BCC, together with many other mobile communication technologies, will open the door to the Internet of Things (IoT). The term Internet of Things first appeared in 1999 in a speech given by Kevin Ashton, a British researcher at MIT. IoT refers to introducing any object of our daily life to the Internet

Network. By attaching chips to the objects, they can receive and send information to global or particular networks, this way, we can gather certain information or improve their performance. What is sure about IoT is that many of these transmissions will be made from the connected object to our personal device, such as our smartphone. And why not making this transmissions just with a touch of our fingertips? Some devices are not meant to connect to the wifi. They do not even need bluetooth. If only one person has to communicate with that device, the perfect system is to communicate by touch having a personal identificator.

Before entering deeply in the project, three main advantages can already be found in BCC among many other transmission system. First of all is low power transmission. Human body is a great conductor, at least much better than air. To present some numbers, air has a resistivity of the order of 10^14 Ω/m, for human body there is more discrepancy but most researchers agree it is in the order of 10 Ω/m. The transmitter does not need many power to reach the receiver. Furthermore, we ensure that the distance between transceiver and receiver is always far less than 2 meters. The second advantage regards interference. When we enter the IoT era, there will be a lot of objects and devices trying to send their own data. If they all use the same channel, air, there will be great interference, which in its time will cause a decrease of bit rate. We have to add that the transmission coding or protocol will be more complicated as more devices are connected, slowing down even more the transmission. Finally, the last advantage is the easy usage it may have. There will not be the need to look for your smartphone in your pockets or find the card that must be attached to the sensor for opening a door. Just by touching the second device with a hand, the transmission will be made. Which is not only very easy for the user, but gives a sense of doing something new very likeable.

For these reasons, BCC has gained many adepts among researchers. Some universities and companies around the world have been studying the technology, such as Massachusetts Institute of Technology (MIT), Korea Advanced Institute of Science and Technology (KAIST) or Erickson. There are patents already registered. BCC will reach the major public within few years, but there is still a lot of development to do.

1.2. Purpose

The project you are about to read, aims to apport a grain of sand by creating an application to implement the available technology in Linköpings Universitet (LiU). They have been working on BCC for 6 years (since 2011). During that time they have made plenty of research including mathematical approaches, simulations and hardware development. The Ph.D. by Muhammad Irfan Kazim must be highlighted as it provided a very complete compilation of simulating and modelling systems to define the physics behind the technology. Through all this research, they have already created working hardware. One example are small tags (about 15 cm²) that are able to transfer information between them when they are coupled with the same body. This tags are attached to boards, which are like the brain of the system. This brain is the target of this project. We dispose of enough material, intellectual and physical, to start working with BCC, so within that project will be made the step of implementing it.

By using functional transceiver and receiver, an Arduino lilypad will be connected to one end and it will react when receiving signal. The reaction of the receiver should not be random. No one wants a useless device, that is why an application for it must be decided before start coding. LiU has a research line centered on how to make devices useful and user-friendly. Taking the necessary information, an application has to be decided for the project, so the lilypad behavior will focus on the accorded application.

Despite being a very new technology, we will not be the first implementing it. Some companies have created products using similar technologies, like RCID by the comany Kaba, which provides door locks that open when the correct person grabs it. There is also a patent registered by Koninklijke Philips N.V., better known as Philips. This patent is Body Coupled Communication Device. Still has no definite purpose, but declares that they want to work on the technology we are about to study.

1.3. Work Plan

The objective is clear, now the path to reach it has to be defined. The work will be divided in three time blocks. The first will be theoretical, for understanding the background of the technology and its possibilities of use. The second one will be the implementation, working on the application. The final one will be the verification. Every work has to be checked and especially in a project like this there is the interest of learning the efficiency in BCC performance. In the following lines this three blocks will be better explained.

1.3.1. Original plan

If any really useful contribution is to be made in any field, first, one must deeply know and understand it. In that case, some pages of the report will be dedicated to gathering information in order to update our knowledge about BCC. The origin, evolution and state of art will be studied, as well as the physics that make it possible. To complete that background part, some motivation must be found for people to start using it. How can BCC reach the people’s interest to start making its own reputation? This will orient the purpose of the application that is about to be made.

Once all the necessary information is reunited, we will be able to proceed with the development. The system will be composed by two PIC microcontrollers and two Arduino boards. The PIC microcontrollers can be considered as the front end of the transmission. They control the flow of data through the body. The Arduino boards will be in charge of controlling the peripherals of the application, allowing a vast range of possibilities. There is great variety of software to choose for coding Arduino. The first names that come are Eclipse or Embrio, but the choice is open. Regarding the PIC controllers, the Microchip company (the supplier of them) provides the required software and documents While programming, there is the intention of trying the code directly on the hardware. For that case the university provides the necessary material.

Once all the code is generated, there will be the need of trying it in different scenarios and make the required modifications. This will be the final phase of the project.

The following figure1.2. shows the proposed Gantt diagram in the beginning of the project.

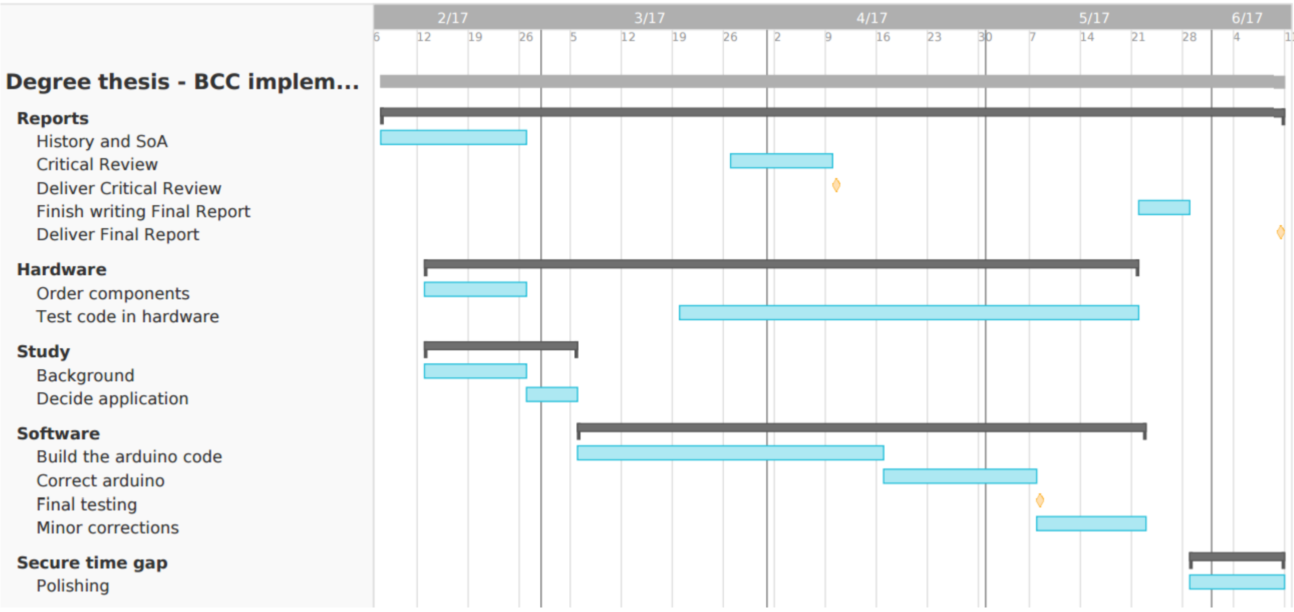

Figure 1.2: Proposed Gantt diagram for the project. Indicating the four main activities: reports, working on hardware, background study and software development. The timeline was calculated in weeks.

This schedule contains the general tasks that have to be done during the project. Some tasks will beget other tasks that will require harder work or even modification of the timetable. For that case there are two spare weeks in the end. Must give a special highlight for the milestones (critical review, final testing and deliver final report), which will help to respect the planning.

1.3.2. Deviations of the plan

The initial idea for the project was gain some knowledge about BCC and make an implementation for it. That way, once the background knowledge was acquired, most of the time was dedicated to create the application on the Arduino boards while substituting the BCC transmission by a Serial data cable, regarding BCC as a black box. This application was precisely developed and ran effectively without important bugs. However, this took longer than planned. This part was finished leaving only a few weeks to attach the BCC system and write the report. Applying the BCC resulted much more complicated than expected, having to manipulate the extensive code of the emitter and receiver that work in a low level of programmation with many registers previously unknown. In addition, some characteristics of the PIC controllers collided with the original programmed application, what required extra time to make the necessary changes This unplanned issues drastically limited the last corrections of the applications and some superfluous features had to be removed.

1.4. Requirements and Specifications

As said in the previous sections, the main requirement is clear. An Arduino code must be generated to implement BCC in a practical system including a wearable tag. That generates some questions and secondary requirements.

1.4.1. Questions

Which application are we going to cover in that project? BCC can be useful in many different fields. One must be chosen, it will determine the data gathered and transmitted and reaction of the receiver.

The transmission method has to be chosen for our system. There are different kinds of BCC that will be explored ahead. In our case we have already decided which one to use. It is the one called Grounded Capacitive BCC, which is not the most advanced model, but is in a stable stage of its development and promises an interesting future. The transmission protocol is already done, however it must be understood and can be revised if necessary.

The final question that arises is if a BCC system can work efficiently with the technology we dispose. Until now BCC has been very theoretical with few implementations. We have to see if it can work properly, how ready it is to be used in consumer products.

1.4.2. Limitations

All this requirements are framed by some restrictions. The first one is that we limit ourselves to the Grounded Capacitive case, explained above. We also have hardware limitations. There are devices already created in LiU and the project must be adapted to them. And the Arduino models that are going to be used: Arduino Uno (Mega328p) and Lilypad Arduino (ATMega32u4). All these components have a determined number of pins and processing speed that will frame the application.

Regarding another aspect of hardware, the mobile side of the system must be as small and simple as possible. It is supposed to be wearable, something that can be hidden in a piece of clothes if necessary.

Finally, there are also human and time limitations. Eighteen weeks is the time available for the project, without taking into account that I could not go to the lab everyday. Adding to it, there is the fact that I had no deep knowledge of the hardware, leading to an organization of time that was not perfect.

2. Background and Theory

In this chapter we will make a brief revision of the history of BCC, considering the main milestones that have led to the BCC we know nowadays. In the end, there will be a review of its most recent developments that have been published for the general public. This is the best approach that can be made to the State of Art of BCC. But before that revision, to allow a better comprehension of the report, an explanation will be given of the technology that makes BCC possible, with special emphasis in the different models we can find.

2.1. The technology

Body-Coupled Communication consists in transmitting data from one device to another using the body as channel. For a successful transmission both devices must be in almost direct contact to the same body, creating a Body Area Network (BAN). The devices must have a metallic printing, tag or surface that will serve as the contact component. This tag is the part of the devices that will emit the signal to the human body so the other tag will detect it. However, the communication between these two tags has some details that make it become far more complicated than one could think. Because of this details BCC has spread in three main different models. Circuit BCC, Capacitive BCC and Wave-Guided BCC. Graphical description can be found in figure2.1.

2.1.1. Circuit BCC

The first one, apparently more simple is Circuit BCC. In that case transceiver and receiver are connected in a closed circuit including the human body and using a wire as a return path. This implies that both the transceiver and receiver must be connected, not only through the body, but also via a cable, which misses part of the point of body coupled communication, as it limits the freedom provided by the other models. For that reason, it has been studied to replace the cable by smart clothes. Having graphene printed clothes can serve as the needed wire. This way the wire is eliminated so the connection is much easier, simply made by a touch. It would be made by having the transceiver and receiver in direct contact to both, clothes and body.

Having a closed and defined circuit allows a very good quality in data transmission. In addition, it is the most mature technology of the three presented. However, despite having a longer useful lifetime than the others, there are not many publications studying Circuit BCC.

2.1.2. Capacitive BCC

Capacitive BCC (also known as grounded BCC), to make a simplification, can be considered as a closed circuit in which the return path is the earth ground. That way the transceiver has one electrode connected to ground (floating ground in case of mobile device or directly connected in the case of a base) and another electrode connected to the human body. The signal passes through the body and reaches the receiver, which has a similar disposition as the transceiver. One electrode connected to the body and the other left in the air or connected to the ground. The body could be considered as a transmission line coupled to the ground. This is the most used method by now. It is reliable enough and has had long time to develop, since it was first conceived in 1995 by Thomas G. Zimmerman. We can already find some patents using this technology. There is, for example, Philips, the Dutch company, which has presented a Patent called "Body Coupled Communication Device". However, the first patent registered is from 1997, by MIT, called "Method and apparatus for transbody transmission of power and information".

Despite having that much followers, Capacitive BCC is not the optimum model, as the capacitances between electrodes and ground present too many variables. This parameters can present great variations from one scenario to another, depending on the size of the person, the shoes, the posture or the material of the floor for example. For that reason, the research has kept going and another model has appeared. Wave-Guided BCC. However, despite Wave-Guided presents better characteristics, it still needs a long way of improvement, that is why we are going to consider Capacitive BCC for the final implementation of this project.

2.1.3. Wave-Guided BCC

Wave-Guided BCC (also known as Galvanic) deletes the annoying ground issue that presented Capacitive BCC. It does not need to rely on the environment any more because the ground electrode is also connected to the body. Transmitter and ground electrode, together act as the emitting port of a transmission line. They create a voltage variation between them is created within the body, and it expands in all directions, eventually reaching the receiver. The variations of this voltage contain the data. Receiver also has two electrodes, all of them attached to the human body. The receiver's electrodes feel the variation in the voltage and recognize the data from it.

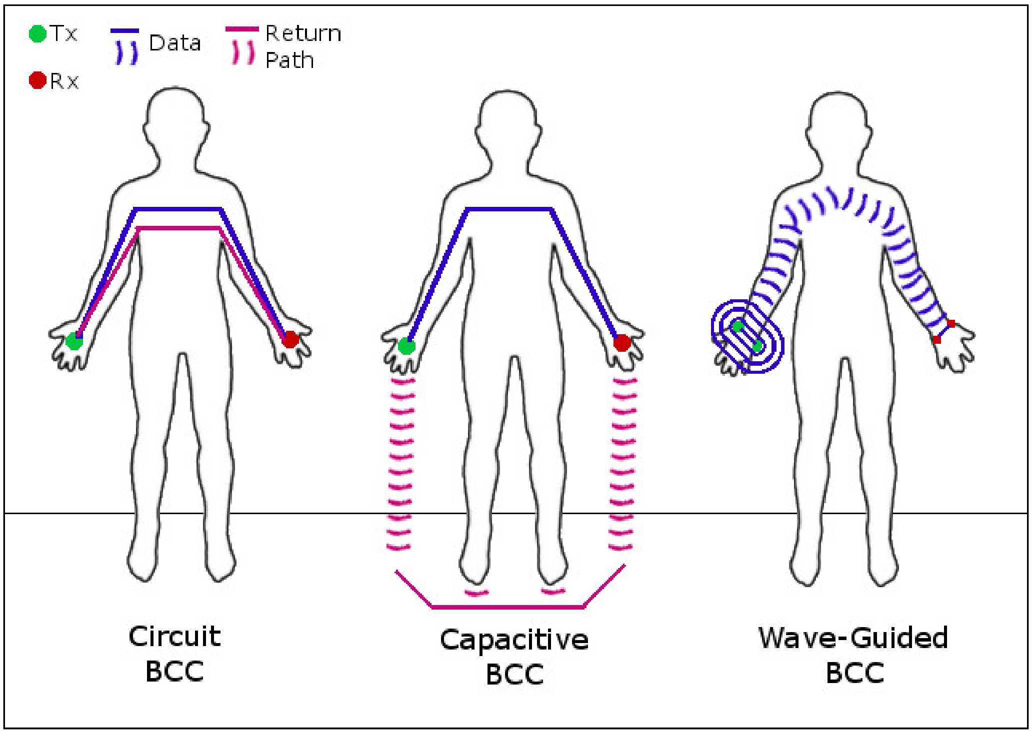

Figure 2.1: Graphical representation of Circuit, Capacitive and Wave-Guided BCC, reading from left to right. Note that blue lines refer to the transmitted signal and the purple indicates the return path, in case it exists. The green spot shows the transmitter electrode while the red is the receiver.

2.1.4. Deeper insight in the technology

Now we know the main features of each transmission method, but for better comprehension it is good to learn what happens in a deeper level. Let's see what happens since the signal is generated in the transmitter electrode until it reaches the receiver. Both Circuit and Grounded BCC use very similar principles, so they are going to be explained together in the first part. In the end of the section 2.1.4. there will be the explanation of Wave-Guided. The reader must take into account that I have personally seen only the BCC systems owned by Linköpings University. Systems in other institutions may present some variations, but all based in the same principles.

The touch surface in the transmitter side is formed by two separate layers of conductive material fitting like puzzle pieces in fork shape without touching each other. One layer is connected to the ground (ground electrode) and the other is connected to the sensor that detects the touch. The sensor is all the time changing its state. When human contact is made, the body makes a bridge, acting as a capacitor between ground and sensor, so its pulses are softened. In that moment the transmitter knows it is time to start the communication. The ground layer is no more connected to the ground but left floating and the transmitter (before acting as touch sensor) layer will send data pulses modulated at 8MHz following the Manchester coding. The Manchester coding is specially useful for coupled communications because its clock is self contained within the data stream. Every bit transmitted will take a clock period and two states, having a state for the first semi-period and changing it for the second half. If the bit sent is a one, during the time the clock is high, the data transmission will be low, and when the clock goes down, the data will rise. The same but inverted states apply for sending a zero. The benefits of that coding, is not only that it is self-clocking, but also is equally high and low, avoiding to overcharge the human body.

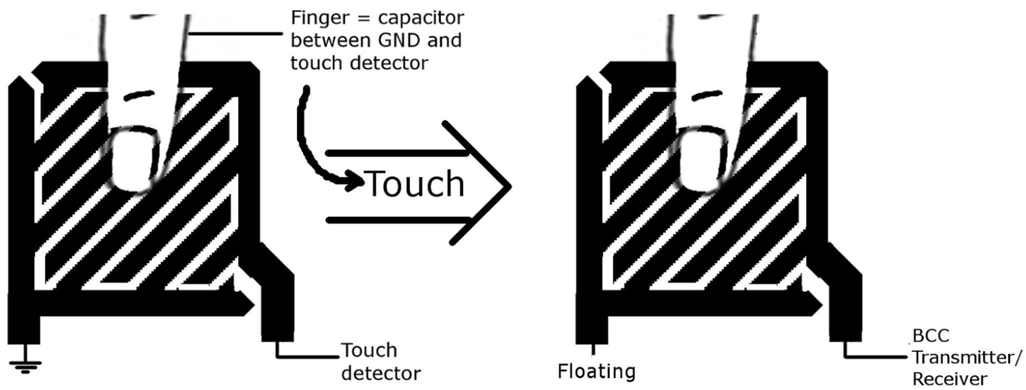

Figure 2.2.:BCC touchpad in the transmitter side reacting when being touched. Observe that the conductive layers change their role with the contact. In the first stage there is one layer connected to ground and the other to touch detector. The human body acts as a capacitor,

coupling the ground and touch. Once coupled, the ground layer is left floating and the touch sensor becomes the transmitter.

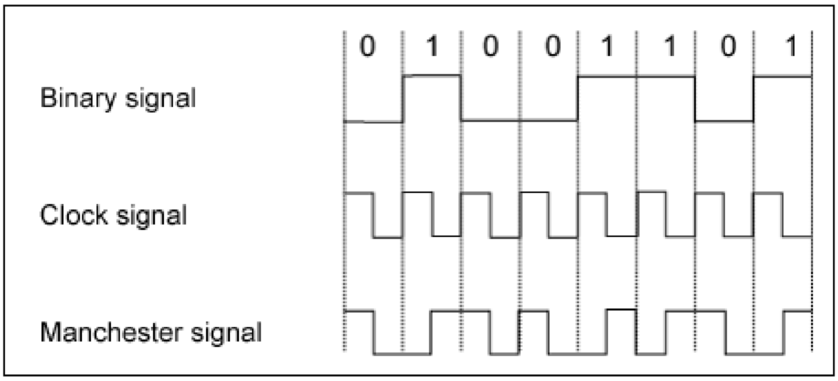

Figure2.3.: Example of Manchester coding. Notice that the coding sends a bit for every clock period. The value of the bits are determined by an increase or decrease of the signal, changing the state of the signal in the middle of a clock period. This coding contains the clock in itself. Image from AS-Interface website. Link in the references.

After the sensor, the emitted signal is thrown into the body. Many different models have been used to describe the behaviour of the human body with BCC. In the first studies, the human body was even regarded as a perfect conductor. Later on with M. S. Wegmüller's dissertation a far better electrical description was made. First of all the signal must travel through the air gap that is somehow present between body and sensor. This represents a capacitor with approximately $8.85 \cdot 10^{-12} F/m$. After the air, the signal must cross the skin, which has a high impedance, acting as an isolator for the rest of the body. The more dry and calloused the skin is, the highest the impedance will be. On the other side, the impedance lowers by increasing the frequency of the signal. Taking everything into account, the skin represents an impedance of the order of 10kΩ to 100kΩ, both in imaginary and real components. When the signal enters the inner tissues of the human body, the transmission is made much easier due to the water and saltiness. There we can find a resistance between 1 to 100Ω/m depending on the circumstances. Some of the signal that has entered the body will be diverted and coupled to the ground or dispersed in the air, while the rest will go on to reach the other electrode, following the path through skin and air again. At this point the signal will have suffered great attenuation.

The receiver touchpad, differently from the transmitter can be a flat surface, connected only to a sensor. It is because the receiver is not activated by human contact, but for the signal received. In general, the receiver controller is in sleep mode, when it detects that there is an electric variation in the touchpad following the manchester codification and at the right frequency, it will react. If this received data has the correct information such as its Address ID (or broadcast) and some coherent command, the device will wake up and take the action as it has been programmed to. Normally the receiving devices are programmed to answer the call with some confirmation message or providing the asked data. The answer is also coded by the manchester model and, in that case, it is modulated at 128kHz.

To explain how a Wave-Guided system sends the data into the body, a new paragraph is needed as it differs notably from the others. In the transmitter side there are two electrodes, that can be considered transmitter and reference, or positive and negative electrodes. In that case they have to be totally separated, and the further the better. When contact with the human body is made, both of them must stay in touch with it, and differently from Capacitive or Circuit, their role will not change. On the receiver side there is the same system behaving in a passive way. Once the contact is made, the emitter from the transmitter side generates some voltage differences from its reference, acting as the source. This signal travels through the body seeing it as a transmission line with its own electric characteristics, and coupled to the ground. At the end of the transmission line, the receiver's electrodes feel a slight voltage difference, being it the result of the expansion of the first voltage difference that has spread through all the body. It generates a two port S parameter in which each side acts like a port..

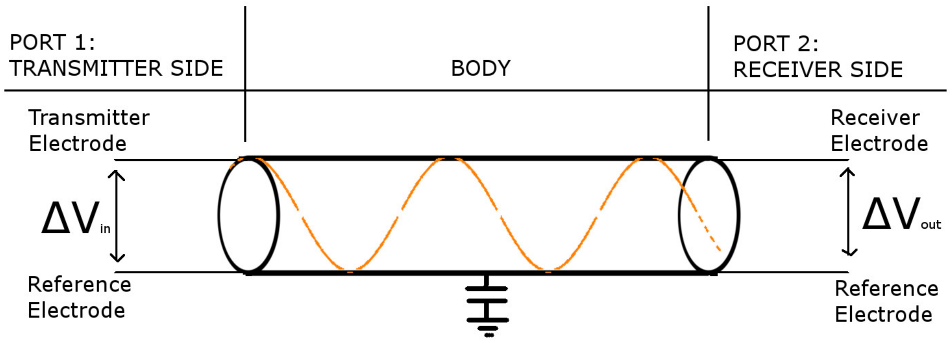

Figure 2.4.: Representation of Wave-Guided BCC observing the body as a transmission line.On the transceiver side, two electrodes behave as the source and reference for the input port. A similar disposition is shown in the receiver side, reading the alteration caused in the line.

BCC Model	**Development level**	**Complexity**	**Accuracy**
Circuit	Mature. Uses simpler technology that is already developed	Simple. One sensor per end and uses a wire as return path.	High. The circuit is closed and definite. It is little affected by environment
Capacitive or Grounded	Middle stage. Has many patents and research lines, but is still far from the final product	Medium. Uses one sensor per end, and the return path is the ground, coupled to the (floating, in case of mobile board) electrodes that act as ground.	Low. Presents many variations depending on the environment.

Wave-Guided or Galvanic	Beginning. A very young technology with no remarkable patents	High. Needs two electrodes per end and uses the principle of propagation of a differential voltage through the body.	Good. Does not depend on the environment as much as the capacitive, but still the performance might change from one body to another.

Table 2.1: Comparative table of the existing BCC models

2.1.5. Which model will remain?

By the present day the two remaining important models are Capacitive BCC and Wave-Guided BCC. Each one of them might be more adequate depending on the situation. For stable scenarios Capacitive BCC is a trusty and well developed option, however for more changing situations Wave-Guided BCC is the chosen one, though it still needs more development. Time will probably decide that one of both is the standard so everybody can communicate without incompatibilities, and all chances point to Wave-Guided.

2.2. History

If we want to talk about BCC, there is a name that must always appear, Thomas Guthier Zimmerman. He is the author of the first publication mentioning BCC, under the name of Electrostatic Coupling, and providing a solid basis for it. This document is his master thesis written in 1995. In his work, he used for the first time the term Personal Area Network (PAN), which englobes all the networks with a range of a few meters (maximum 30 approximately). By the time Zimmerman wrote the thesis there were some technologies that could be already considered PAN, such as Infrared Transmission and RF Transmission. However, this technologies present some inconvenients that Zimmerman decided to solve by developing Electrostatic Coupling technology, which brings us to BCC. Electrostatic Coupling consisted in attaching electrodes to the body and use the body as the channel, and the earth ground as the return path. This is how Capacitive BCC was conceived in the beginning. In that study the body was considered as a perfect conductor.

What Zimmerman wanted was to connect all the small devices we carry with us to allow an easier access to each one of them and get information in a simple way from the objects around us. We can say that without knowing it, he was visioning the era of Internet of Things (IoT). The era in which every device and common object will be interconnected and sharing all the possible information.

On 1996 IBM patented the first system capable of transmitting small amounts of data through the human body at very low speed. Our well known pioneer, Zimmerman participated in it.

During the following years some companies found potential in it. We can find patents of Microsoft or Philips during that period. There are no important progresses during that time. It is remarkable though, that many laboratories linked BCC with healthcare monitoring systems.

On 2004, Nippon Telegraph and Telephone (NTT) researchers, with special mention for Mitsuru Shinagawa, published a paper about replacing the receiver electrodes by a transducer based on the electrooptic effect, consisting in an electric field sensor composed by an electrooptic crystal and a laser diode. In experiments with normal electrical sensors the average performance allowed a transmission range of 30 cm and a speed limit up to 40 kb/s. Using electrooptical sensors allowed them to reach speeds of 10Mb/s in a range of 150 cm. It was due to the Electrooptical sensors provided an extremely high input and ultrawide detection bandwidth. This parameters were really high back in 2004. To have a reference, at that year the internet speed was approximately 980 kb/s for average users. It must also be highlighted that this optical sensor did not need to rely on the ground electrode despite being a derivation of Capacitive BCC.

During some years NTT has kept its research line on it, and on 2005 they named this new technology Red Tacton. However, in spite of the 10Mb/s they presented in the IEEE paper, Red Tacton only offers a transmission rate of 2Mb/s, with the possibility of having the transmitter device separated up to 20 cm from the body (with it we learn that the 10Mb/s are only a laboratory or theoretical achievement). This is a very interesting aspect as it allows the user not to be in direct contact with the device, having it, for example, in a purse or a pocket.

The latest publication of NTT regarding RedTacton dates from 2010 and does not mention the electrooptical sensors any more. In addition, the technology is explained as regular Grounded BCC. We can assume that electrooptical sensors have been left behind and Red Tacton is in the danger line, if not disappeared.

The next remarkable study about BCC was released by Marc Simon Wegmüller on 2007, providing a far more detailed study of the conducting properties of the human body. This study was specially focused on medicine. Wegmüller took into account the dielectric properties and the developed electrical model of the body, marking a difference with the perfect conducting body considered by Zimmerman. In his exhortation he wanted to see the transmitting parameters varying some conditionals. Frequencies from 10kHz to 1MHz were tried in different parts of the body, demonstrating that the best zone of transmission was the thorax, and the most decisive elements were water distribution in cells and the state of the skin. Other important parameters to take into account is that decreasing the transmitter electrode’s size, the attenuation is increased, while receiver electrode’s size does not matter.

Wegmüeller’s work also includes a detailed comparison between Capacitive BCC and Galvanic BCC (also known as Wave-Guided BCC). He remarks that by now Capacitive BCC offers better performance (with speeds up to 10Mb/s) but also it has had more time to develop. Wave-Guided BCC omits the dependence on the ground, but needs more complicated transceivers that still have to improve for surpassing Capacitive BCC.

The last research group included in this project is the Korea Advanced Institute of Science and Technology (KAIST). They have a long history in the field of BCC, as their publications date from 2006 to nowadays. During that time, they have provided a more detailed BCC transmission model of the human body using Maxwell's equations. The model may vary according to the operating frequency and channel distance. Depending on these parameters, the BCC mechanism is composed by three parts. The quasi-static near-field coupling, the reactive induction-field radiation and the surface wave far-field propagation

The quasi-static field is considered when wavelength is much longer than the body, so the electric field around the human body is almost constant in time. It occurs for frequencies smaller than tens of MHz. For higher frequencies the surface wave far-field propagation method is used.

Apart from this models they have studied how to improve the electrodes to compensate the path loss. In a publication from 2016 they presented a non contact compensation IC. This is the only compensator that does not require contact up to date, consuming 635 uW for a 14 dB channel compensation using a 65nm CMOS.

2.3. Commercial Influence

On 2010 started an european project called eGo. This project had the objective of suppressing passwords or other security factors such as car keys. They wanted to implement BCC as a widespread security and identification technology applied in many different daily situations. For example use restringed printers, opening door locks, easy profile configuration for temporal usage devices, as the handsfree car phone or even other people's phone (making them work as if they were yours while they are in contact with you), and many more applications. However, this project had a limited time, from 2010 to 2013, and no evidence of their results has been seen by now. Once the program was finished it has had no more continuity.

However, the most remarkable BCC product is the one ideated by the lock company Kaba. Kaba is specialized in advanced locks for general doors, and they not only have researchers studying BCC, but they were the first ones to present a fully functional commercial product. It is called TouchGo and consists in security identification for opening doors. The user has the id card in his pocket and the id is transmitted through his body as soon as the door handle is grabbed. The main target of this service are the hotels, which are intended to leave behind the use of keys or magnetic band cards to make a step towards practicality. Apart from hotels, it has many other target users, such as car doors or even particular houses. The technology was baptized as Resistive Capacitive Identification (RCID) and was presented for the first time in 2007 as part of the prototype car Rinspeed eXasis. It was launched to the market on 2009, or at least it is how it was planned. There are no news about RCID after the launch announcement.

Some other interesting patents are appearing, like the “method for operating an acoustic system and wearable acoustic device”, by Philips. The patent consists on a system in which an audio signal is transmitted from a master device to a pair of headphones that behave as slaves using BCC., and it is only one among many patents they have regarding BCC. It is remarkable that the dutch company is strongly investing in this technology.

These are the most remarkable companies and projects worth to be mentioned, and they mostly consist in patents or projects. As one can notice, there is still a long way to go until BCC is in every home

2.4. What can BCC offer?

As we can see BCC is still very unknown to the people. It is a technology that has only lived in labs and some specialized companies and still has to be born in the real world. One fundamental part in the project is to see how to make the next step to make BCC reach the common people, for that reason two researchers from Linköpings Universitet in the area of Human-Machine communication provided some key points. They are:

- Mattias Arvola: Senior lecturer in cognitive science. Knowledge in psychology, artificial intelligence and philosophy. Working in human-computer interaction design.
- Mathias Nordvall: Ph.D. student. Working in the field of computer games innovation. Bachelor Thesis in Linköping and game developing specialization in Copenhagen.

2.4.1. Competitors

In the meeting, the first mention was for the already existing different communication systems working in low range that might compete with BCC. Infrared has had a great importance. Bluetooth has been around many years and still survives. And probably the main competitor now is NFC (Near Field Communication).

NFC consists in a radio frequency transmission working in a very small range (about 20 cm). It works with a chip that has a similar behaviour as BCC, when it is close enough to the transmitting device it reacts without necessary previous pairing. It is beginning to be applied to the human body, in which the user has a chip implanted within its body, usually in the hand, in the space between the thumb and the index finger. For successful communication the chip must be very close to the main device, leading sometimes to uncomfortable gestures to achieve it. Here we already find two advantages in BCC. You do not need any implant and it allows transmission by making contact with any part of your body, independently of where your personal tag is situated. The strong points of NFC are that it is based in RF, providing a very mature technology that allows efficient and reliable communication. Another strong point is that it is already supported by some companies. They have implemented it on their employees to keep track of them as well as giving them access to the facilities by something more practical than a card.

Bluetooth also works with RF and is designed for short distances, but it provides a different service. The field covered by Bluetooth is far bigger than a BAN, and for using it you need to take and activate your device, while BCC can be activated just when it feels another device is trying to contact it.

2.4.2. How BCC can make a difference

The examples mentioned before have more acceptance in the society and, in general, offer higher bit rates. That is why an important point to take into account when interacting with BCC is that we must not see it as just another transmission system, but we must see what makes it special. The touch. Being able to detect the contact. This led them to talk about, not only being able to transmit data through contact, but also detect the quality of the touch. Detect if the contact is made by one finger or another. By a hand or a foot. The hardness of the touch. The contact surface... This ideas are very promising and in the future they should be explored. But, as the previous points of the project have shown and the implementation will reaffirm, we are very far away from it. The current stage of Grounded BCC (the one implemented in this project) is that it still presents low efficiency when transmitting simple data, even in a stable environment.

Another remarkable idea are the three levels of BCC, representing three barriers that BCC has to surpass to unleash all its capacities. The first level, in which we are now, there is communication with only one user. One device interacts with just one user. In the second level, there would be interaction between two users. Let’s say that with a handshake they could be exchanging information, such as email or phone number. Finally, in the third level, BCC would be connected to the internet so all the information registered by the tags would be stored and easily accessed from a computer. That way, if I get the email of someone by a handshake (second level), it would be stored in my cloud account instantly. In addition, for good or bad, it would make the acquisition of big data even easier and more accurate. This three levels can set very important milestones in the path that BCC has to follow to reach its full potential. However, like for the quality of touch, I do not have enough knowledge, neither material, to enter the second or third level. So the implementation in this project must stay in the first level.

2.4.3. What can be done with current BCC

While revising the history and State of Art of BCC, it is easy to find medical references. Many laboratories have found convenient to provide an improvement in medical equipment communications. For sensors that are situated within the body, BCC can represent a fairly useful solution to transmit the data from the sensor to the exterior world. It presents no harm for the body and no more invasion than the one done by the sensor, that could have a small BCC system incorporated.

Another explored field in which BCC can have a good role is in identification. The first purpose someone might think of it might be unlocking doors, but as eGo suggested, it can provide access to any device, object, or anything you might have in mind, that might require personal recognition or a log in. It can change the behaviour of an object depending of the person who touch it.

Considering both subjects, in this project no great improvement can be done for these fields. I do not have enough knowledge in medicine, and this field is already thoroughly explored. And for the Id, there is nothing else to be done than transmitting an array of symbols. The tricky thing is what to do when you are already identified. When exposing these ideas, the human-computer interaction researchers reminded that the importance was in the touch, not only in the data transmission. A good field to try new technologies is in games. Not only in videogames, but also in playground or table games. The fact that you can transmit data by touching an object can bring new mechanics into gaming. One example Mattias used was a card game in which, whenever you touch a card, information is displayed, or any other reaction you can think of, and you can hold more than one card to make combinations. People when playing are open to try new things, looking for different experiences. It is a good area to introduce new and exciting technologies. They also added, that it would be great to have a user friendly BCC kit. Just a simple kit with some sensors and default functionalities, and an adapted code to be easily reprogrammed. This would help, not only people from human-computer interaction design, but many researchers and even non professional people to develop very interesting prototypes.

2.5. Conclusions

For what we have seen in this chapter 2, History and Technology, now BCC is making progressions at a slow rate. The path of the PAN begun in 1995 with the idea conceived by Zimmerman's team. On 2004 NTT reached the 10 Mbps in a lab, which by now is still the maximum transmission speed. The final great progress came in 2007 by Wegmüller when he compared the two main types of BCC: Capacitive BCC and Wave-Guided BCC, that are now competing to become the definitive model. Since then no big improvements have been made. Some companies have tried to implement BCC in their products and many companies are interested in implementing it in the future, but by now there has not been evident grand success in the market for BCC. We are in the stage of polishing the technology, to make it more user-friendly and reliable. There are many lacks or desired functionalities that are being detected to make BCC more attractive for the general public and more optimal in data transmission. After all, it is a working technology in its primary state, and is going to need long years for becoming common in everyday life.

3. Methodology / project development

The basic necessary research has already been done and explained in the background chapter (2). Now it was turn to take action and get going on the application. The core of the prototype was formed by the following components:

- BodyCom technology kit, by Microchip Technology Inc. : It consists in two boards ready to act as BCC transceiver and receiver, with demonstration software provided. The base board runs with a PIC16LF1829 microcontroller and has a BCC touchpad attached. It also incorporates some peripherals as an LCD display and some buttons for interaction with the user. The mobile board, smaller so it can be worn, disposes of a PIC16LF1827 microcontroller and a thin and flexible touchpad.
- Arduino Uno (ATMEGA328P-PU) and Arduino Lilypad USB (MEGA32U4). They are in charge of administrating the sent or received information for taking the required actions.

The following figure 3.1. shows the disposition in the final version. It will be shown again in the end of chapter 3 when the reader will be able to further understanding of each part of the system.

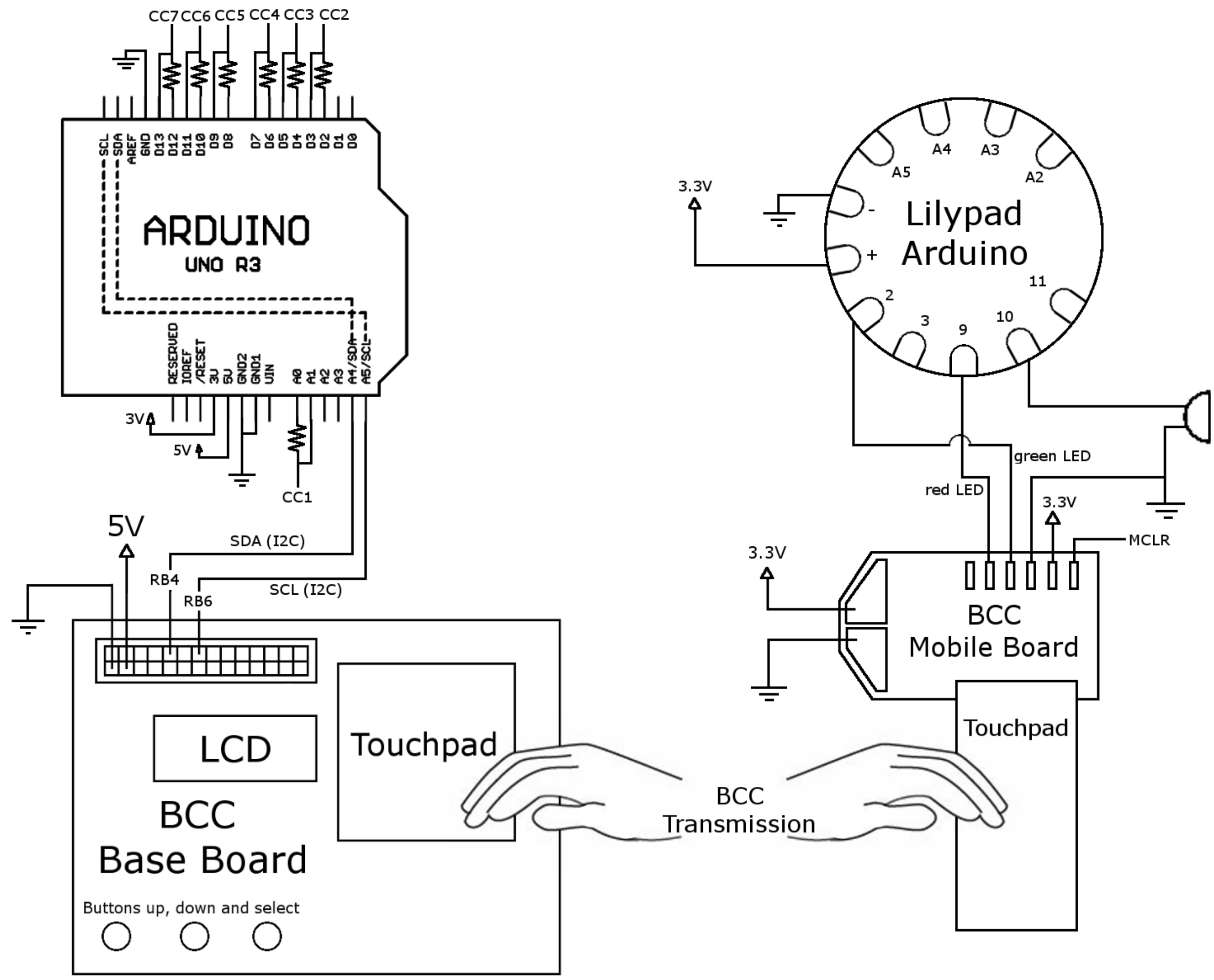

Figure 3.1.: Disposition of the final design. The Arduino Uno reads which capacitive component is being touched, and sends the corresponding note to the BCC base board. The base board will transmit the note via BCC to the mobile board and finally the mobile board will forward it to the Lilypad Arduino, so it can play the according tone with the buzzer.

For further information of the components and the software used in the project check the Budget chapter (5).

In the Appendix you can find simplified flow diagrams for all the microcontroller boards used.

3.1. First steps

My experience with BCC was completely inexistent when I entered the lab, so I was suggested to start by generating the Arduino application substituting the PIC controllers by a direct cable communication between the two Arduinos, considering the BCC transmission as a black box by the moment. I also needed to gain some confidence In programming the Arduino so I started from the basics, and as time went on, I could aim higher. This was the process:

- Make the first application of the blinking LED.
- Create simple transmission between the two Arduino using the Serial communication system..
- Make bidirectional transmission between the two Arduino allowing a confirmation message if the correct data was received. Still with Serial cable, in that case two wires with simplex transmission.
- Create libraries from the previous projects.
- Print some sentences in a oled display.

For the Serial communication system, the data from the registers is organized so it can be sent bit by bit, one after the other. It follows the norm established by RS232 to make possible the cooperation of receiver and transceiver. For that case, Arduino provides the SoftwareSerial library , which configures any pin of the board to act as a Serial emitter or receiver.

The oled display gets communication with the board with the help of the library u8glib. The communication applied is I2C, having one wire for clock and another for data. This transmission system will be further explained ahead in the project, as it is the same communication used between the Arduino Uno and the Base BCC board.

Now, it was time to start making what would be the definitive BCC application of the project. Taking into account what is mentioned in the point 2.4. and sticking to the importance of the human contact, the final decision was to program an Arduino to work with capacitive buttons, in an application where you can attach or detach the desired number of buttons to get different responses from the system. A capacitive button, can be any piece of conductive material disposed in a way that it detects when a human touches it. To add more complexity, one of this buttons would have the possibility to become a slider, detecting when you slide the finger over it and in which direction. To name this capacitive buttons or slider, the terms capacitive component or capacitive sensor will be used.

3.2. Capacitive Components

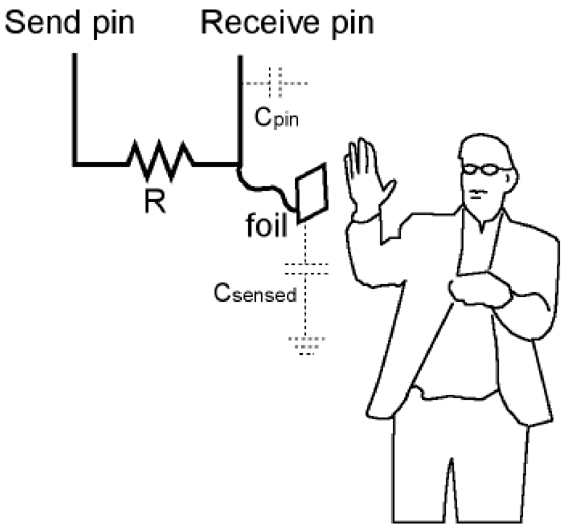

Figure 3.2.: Circuit model of a Capacitive Sensor. Image property of Arduino, released as Creative Commons Attribution ShareAlike 3.0.

For making the capacitive buttons there is an Arduino library called Capacitive Sensor. It takes two pins of the Arduino for each component. One pin will act as emitter of pulses and the other as a receiver. They must be connected via a resistor (in our case a 2.7 MΩ resistor is used), and after the resistor, in the receiver's side, there must be a cable connecting the capacitive sensor (metallic surface) to the main system. See the image in the left. The emitter pin changes its state periodically sending a train of pulses, so the receiver will also change following the pulses of the emitter. The change in the receiver can be delayed if there is a capacitor going from that pin to the ground. The capacitor in this case, will be the human touching the metallic surface and coupling it to the ground through the body, and the delays will be calculated by the Capacitive Sensor library, which will return its value in arbitrary units. In addition, for the final design of the prototype, there is the plan to build all the components on a wooden board and cover the back side of the board with aluminium foil connected to ground to serve as an isolating shield. The website of the library recommends using a small capacitor from the receiver pin to the ground to get better results, however, in our design, it has not improved the results, so it was discarded.

By using this method the capacitive buttons were made with no complications. Regarding the slider, not only the contact had to be detected, but also the displacement of the finger from one side to the other. Many different systems were tried to alter the capacitance or the power perceived by the receptor. The most efficient method turned out to be such a simple idea as to cover the slider with various sticky tape layers. On one side of the conductive line, there is only one layer of tape covering the metallic surface, and as you move to the other side the number of layers increases. That way the human body and the conductive surface are less coupled and the detected capacitance decreases.

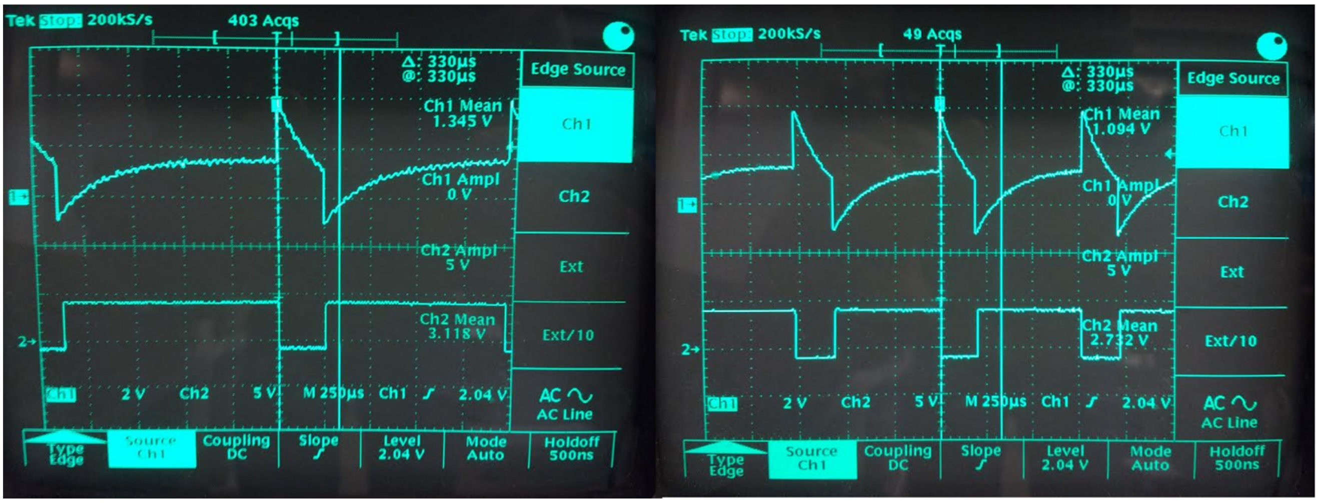

Figure 3.3.:Observations of Capacitive Sensor behaviour with an oscilloscope. In the Channel1 (up) the receiver pin, in Channel2 (down) the transmitter. In the left image, human is in contact with the sensor. The receiving pin takes about 1500us to reach the threshold when rising and 330us when going down. In the right image no contact is being made with the sensor. It takes about 700 us for raising and 250 for going down.
For this performance the small capacitor (150pF) from receive pin to ground was used despite not being used in the final version.

A calibration method was programmed for these components, so the thresholds would adapt to changes in the environment or user, however it could not be implemented in the final design. Instead, a standard threshold was chosen to decide if a capacitive sensor is being touched or not. Neither could be implemented the oled display, for it used the same communication pins that make possible the transmission to the BCC board. This two features will be no longer commented in the report.

A library was created for the Capacitive Components. It can tell if the capacitive component is a simple button or a slider. It gives the chance to change buttons to sliders or vice versa. It returns the value of the component: 1 for on and 0 for off in the case of buttons, and a scalar number from 0 to 9 in the case of slider. Finally, it gives the option to set an Id for each component.

The Arduino selected to be the controler of the Capacitive Components, and therefore, the transmitter, is the Arduino Uno. It is bigger and uncomfortable to be attached to the body. The Arduino Uno will stay on the table with the sensors, while the Arduino Lilypad will be in charge of receiving the information and taking the response action.

3.3. Buzzer

It was not enough to be able to read capacitive touch, but a reaction is needed for it. We must know that the transmission is being correctly made, and better if it is in an amusing way. So there was a buzzer added that would play a different tone for every button touched. If more than two buttons are touched, more variety of sounds will be played, and for the slider there is a whole array of tones.

The Arduino Uno, who is in charge of administrating the capacitive components, has a character array in which stores the notes that every button combination will play and another array for the slider. 0 means that no button is being touched and there must be no sound. Depending on the number of buttons connected the array will change:

- One button: “0a”
- Two buttons: “0fbD”
- Three buttons: “0abdDef”
- Four buttons: "0dacbgdaDECae"
- Five buttons: “0dfcaEeabwxagaaaDzyaFaaaC”
- Six buttons: "0decfwgaaGyaCaaabGAaxaaaEaaaaaaaDAaaBaaazaaaaaaaF"
- Seven buttons: "0cdveCwafaDayaaagaaaEaaaxaaaaaaaaaaaaaaaFaaaaaaaazaaaa aaaaaaaaaaabaaaaaaaaaaaaaaaaGaaaaaaaaaaaaaaaF”

The decision of these arrays was based on some study of chords and simple melodies. The strange combinations such as pressing three buttons at once will produce the ‘a’ note. The letters such as v, w, y and x correspond to a lower scale for f, g, a and b notes. As we can see the number of buttons is limited two seven dwe to hardware limitations.

The way to read this arrays is based in assigning power of two values to every button. So for the case of three buttons, if button number one is pressed, it will return 1 (2^0), thus we will read notes[1]=a. If button number three is pressed, it will return a 4 (2^2), thus notes[4]=D will be read. If pressing buttons one and three at the same time, we will get 1+4=5, and read notes[5]=e. With the power of two we can know exactly which buttons are being pressed for simple combinations of one or two.

The decided note will be sent to the Arduino Lilypad, that will relate that note with its appropriate period. The Lilypad has a buzzer connected in one pin (appart from ground), and will quickly change the output of that pin to high and low using the correct delay (half the period) to produce the tone ordered by the Arduino Uno.

3.4. Implementing BCC

At that point all the capacitive components were working well and the tones were played correctly and smoothly without noticeable delay and very little error. It was the time to change the serial data connexion by the BCC system.

The Microchip company provides a demonstration software, to allow the new users check the correct functioning of the boards and have a basis to start working with them. There is also a template software which served as model to add my code on it. That template, in its original version, worked depending on the three buttons attached to the base board (apart from the reset). Up button sets the board in touch mode (communication activated when touchpad touched), down button sets button mode (communication activated when third button is pressed), the third button activates o deactivates the communication if button mode is active. When the communication is active, the base board will search for any active mobile board by sending a broadcast ping paired. If there is any mobile board close enough to receive the data it will respond sending its own ID address. The base board will then print the received ID in its incorporated LCD display. For every message sent, the checksum system will be applied as a verification method.

My objective now was to change the code so the base board would send, not a Ping Paired, but a message with the note read by the Arduino Uno, and the mobile board would not only answer to the base board, but also forward the received note to the Arduino Lilypad. The base board has to be the transmitter as it is not designed to be weared, unlike the mobile board, so its place is on the table next to the capacitive components and the Arduino Uno.

3.4.1. I2C - From the Arduino Uno to the BCC base board

The first goal defined was to allow communication between Arduino Uno and the base board. The system Inter-Integrated Circuit (I2C) was chosen to make it possible. Other possibilities were observed such as making serial communication through the USART (Universal Synchronous/Asynchronous Receiver/Transmitter), but it did not give good results.

The I2C communication uses two ports of each connected device: one for the clock (SCL) and one for the data (SDA). One of the connected devices will act as master. This means that it will have control of the clock and every transmission will be begun by him, whether it is for delivering data or asking for it. Any other device will behave as slave. One master can have up to 112 slaves identifying them with 7 bit addresses. 10 bit addresses can also be used, but in our case 7 is enough. This following image will help to understand the coming explanation of the protocol:

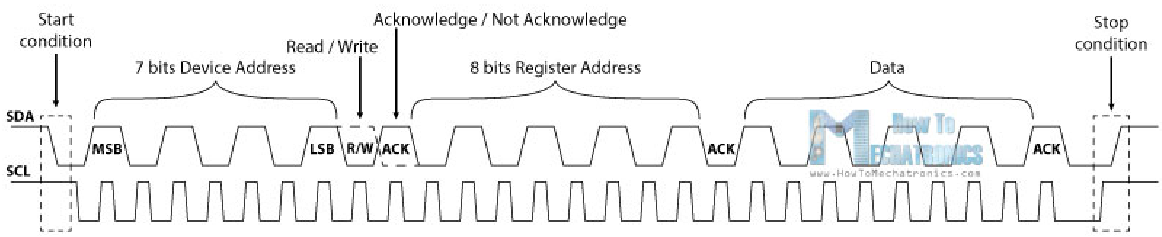

Figure 3.4.: Timeline for the I2C protocol.The upper line is for data (SDA) containing the data sent (in our case only address, read/write bit and data/note), including the confirmation bits (ACK). The lower line (SCL) is the clock used for synchronizing transceiver and receiver. Image provided by HowToMechatronics.com. Link to the source article in references.

When the master wants to initiate communication with any of them, it has to create the start condition. In the start condition, the SDA line drops while the SCL is still high. At that moment the clock begins working and the slaves synchronize with it. For every pulse of clock a bit will be transmitted. Now, the master must tell what it wants to do by sending a byte of data to the SDA bus. The first seven bits contain the address of the slave he wants to communicate to, and the eighth bit indicates if it wants to read or write. In that moment, the addressed slave will pull the SDA line down as ACK to confirm the data was well received. If the line keeps up, it means that the target slave did not receive the order correctly or could not react to it. This is understood as a NACK. In case of NACK, any controller can react in a different way. In our case, it will restart the communication in the next loop of commands. In case of ACK, another message should be sent before taking action. In this message there should be indicated the internal registers of the slave that have to be read or written. For our case it is not necessary, as the slave is an active component that has already been coded were to store the received data and which data to send when asked, so we can skip this step. Then comes another ACK. Now it is time to put the desired data in the SDA bus. The master in case of write and the slave in case of read will be in charge of putting the data, the other device will only have to read it. Here we have another ACK. Once the transmission is done, the master will end communication by setting the stop condition: SDA goes from low to high while SCL is high. This process will be repeated any time a data packet has to be sent or read. The data packets can be more than one byte, and until they are not all sent, the communication can still be on, if programmed correctly. Luckily, our system only sends one character at a time, so with one byte per transmission we are done.

For the implementation of I2C in the project, after some tests, it was decided that the PIC microcontroller would be the master, and therefor, the Arduino would be the slave. It took a long time to get it working as many things had to be taken into account. First of all, one must understand how the registers of the PIC16LF1829 work for setting the clock and reading and writing data in the SDA bus. All the information can be found at the datasheet of the controller. Setting the Arduino as slave was easier due there is a library that helps in the process. The library is called Wire.

Looking at the side of the PIC controller, BCC base board, it has to receive the notes and send them via BCC. So this I2C master will have to ask periodically to the Arduino to read the notes. The steps on the previously explained process can not be taken all at once here. If we set a loop that can not be exited until the note is received, there would be a high danger of getting stuck in there, especially for the base board has many interruptions programmed that could spoil the transmission. There should be a lot conditions regarding the states of the registers to ensure the correct flow of that loop. A better option is to use the main loop, and everytime the loop is run, an I2C step will be taken. This steps are controlled by a variable and executed by a function called I2CM_Handler(). Part of this function was already created for the communication between the PIC and the incorporated LCD. In the first loop the start condition is set. In the following loops the function will check the register that tells that the transmission is definetly started. When it is true, the address of the Arduino is sent into the SDA bus with the read bit set. In the following loop that it is detected that the bytes have been sent, the function checks if there is an ACK in the line to proceed and read the line to store the note in a local variable, that has been introduced to the function as a pointer. The function is entered again in the next iteration, and reentered until it detects that the transmission has been finished. Then it reads if there is an ACK or a NACK as a result. In case of ACK it closes the line. In case of NACK, the process will have to be restarted. A delay of 150 ms had to be added in the main loop because the time it takes the Arduino to read the notes from the capacitive components is far longer than the time of the BCC loop, and if it is asked twice to give a note while in the same period of reading it will give mistaken information.

For the side of Arduino, it has to be set an address and configured as a slave. To configure an Arduino or any other device as a slave, interruptions have to be created, so when the device address is referenced in any of the master's messages the Arduino has to stop whatever action it was doing and listen to the master. In that case, only the action of request is going to be needed, but also the action of receiving was programmed to make some verifications. Any time the request interruption is entered, the arduino sends the last read note to the SDA. Then, the Arduino's internal index to enter the notes array is returned to 0 to avoid misreadings.With the arduino we do not need to be so much careful in the process of interacting with the I2C buses as it has all registers controlled under the Wire library and other of its features.

To allow the correct performance of I2C, pull-up resistors are needed for SDA and SCL are active low. In our systems the resistors are already incorporated within the boards.

3.4.2. From the BCC mobile board to the Lilypad Arduino

Assuming that the note has already been transferred from base board to mobile board through the body, now it has to be transmitted to the Arduino Lilypad to let the tones play. This step in the communication presented an added difficulty in the beginning because there are no SDA or SCL pins in the mobile board. According to the schematics provided by the Microchip company, the six pins provided are connected to MCLR (master clear), power supply (3,3V), ground, green led (pin for programming), red led (pin for debugging), and the last pin is apparently not connected to anything. The only option remaining to transmit data was to use the led pins. Even if they are configured for programming and debugging, while the chip is not in bootloader mode, they can be used as normal input-output pins. That way, a simple I2C based protocol is generated. The green led would set the start and finish conditions and the red led would transmit the data. In the Arduino, an interruption was created. When the green led, connected to its pin two, goes low, the Arduino starts listening to pin nine, where we find the red led. The red led is high for a determined time multiple of 50 us. The Arduino detects the length of that pulse, and depending on it, one or another tone will be played. All the tone semi periods are stored in an array called notes, so the delay for the current note will be accessed this way: note=notes[(duration of red led high in microseconds)/50]. It was also studied to send a train of pulses to take the average length value, however, it required a lot of coordination for both controllers, otherwise the Arduino would read just the first pulse and then read another random pulse that could not be identified, leading to misread values. In the final version, one single pulse is sent, showing no error up to the date.

The last received tone will be played continuously, stopping only when interrupted by a transmission from the mobile board, or when it has been playing during 3000 loops (about 6 seconds) without detecting any interruption. In this last case we consider that the BCC transmission has been lost.

3.4.3. BCC block

The objective in this stage is to transmit the read note from the base board to the mobile board. The communication between the mobile board and Arduino Lilypad has been previously established so we can check that the data transmission in the BCC block is correct.

The responsible of beginning the communication is the base board. The communication can be initiated in two different ways. The default way is by touch. When the base board feels that a body is making contact to its touchpad it will begin transmitting (see section 2.1.4. “Deeper insight in the technology” to learn more about the activation by touch). The other system is by button. The base board can be configured to start emitting by pressing a button, and make it stop emitting by pressing the button again. The button method is used to make the development and tests easier. When transmission is activated, the base board will send a broadcast message looking for any device. The structure of the messages is: one byte for command (echo request, echo response, ping paired…), four bytes for address, one byte indicating the data length and as many bytes as needed for the data itself. For sending a note we have enough with one byte of data. By default, the template code would send a ping paired, however it was manipulated to be an echo request with the note in its data. That way, any receiver programmed to understand this message will be able to recognize the note. Until this message is not received, the mobile board will be in sleep mode. Once the message is received with its address or the broadcast address (this is our case), the mobile board will wake up and store in a variable the note contained in the message. After that it will send an echo response to the base board with its own address in the address field, so the base board can acknowledge who has listened to it. For that response the base board also has an interruption configured, to be able to read the input data whenever the reception buffer is full. After sending the response, the mobile board will forward the note to the Arduino Lilypad following the method explained in the previous section.

3.4.4. Bringing all together

Separately, everything worked very well. When attached, some components showed incompatible configurations and some changes had to be made. The final actions of each device are the ones that have been presented in the previous points. So after all, the general action of the system is: Arduino Uno reads value from capacitive components (buttons or slider) and, whenever it is asked by the I2C master, sends the read note to the base board. The base board sends the note through the human body to the mobile board and gets a response from it. The mobile board after receiving the note and answering to the base, creates the start condition by pulling down the green led and sends a single pulse of a duration multiple of fifty microseconds with the red led, varying in function of the received note. The green led goes high again a short time after the pulse, as the ending condition. The Lilypad Arduino detects the length of this pulse and identifies the tone that has to be played by the buzzer. For a better presentation, the system was mounted attached to a wooden board. The lower side of the board was covered in aluminium foil connected to ground for a more reliable reading of the capacitive components.

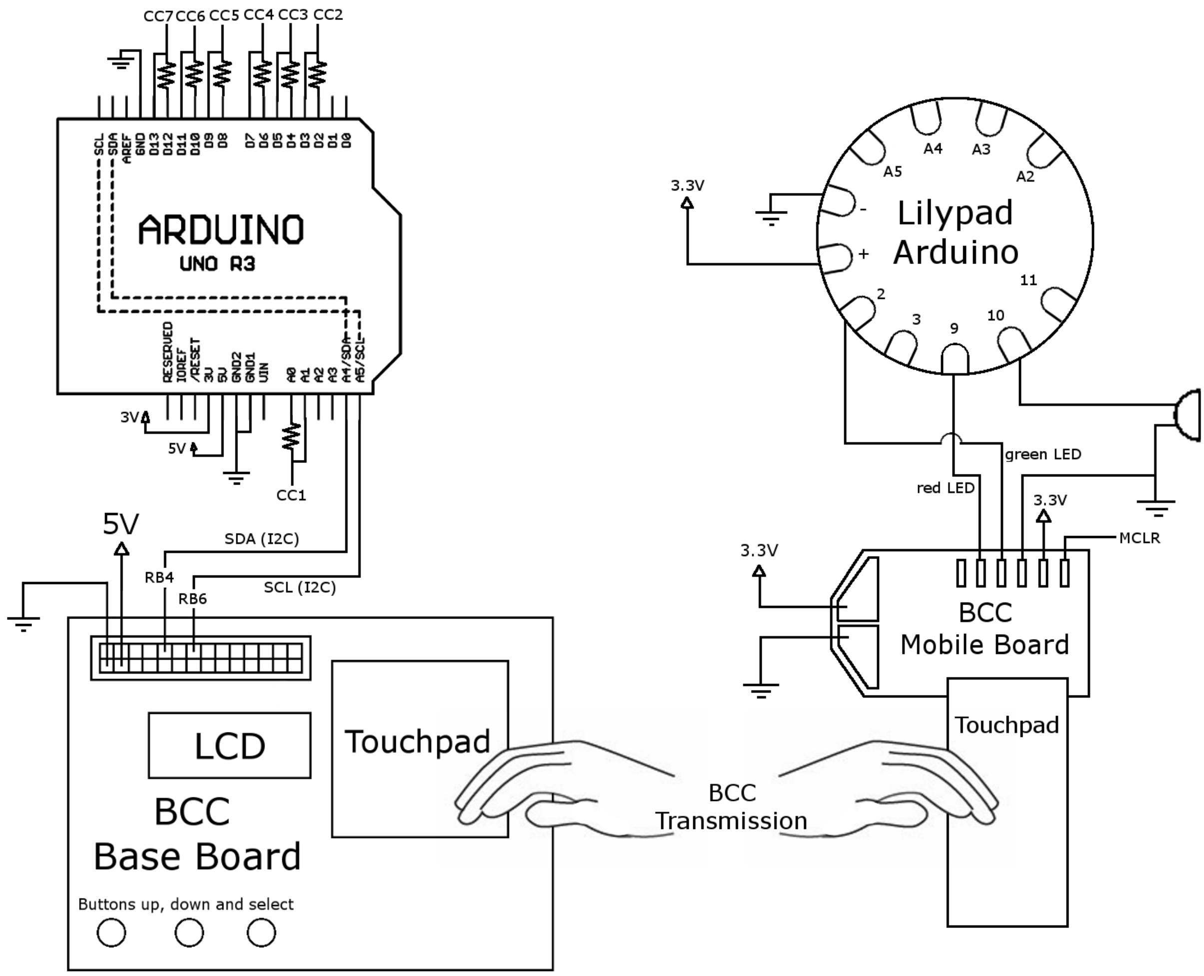

Figure 3.5.: Connection schematic of the definitive implementation system. CCn (in the pins of Arduino Uno) correspond to the Capacitive Components. The Arduino Uno detects which capacitive components are being touched and sends the corresponding note to the BCC base board. The base board sends the note via BCC to the mobile board. The BCC mobile board tells the Arduino which note it has received. And finally, the Lilypad Arduino produces the asked tone through the buzzer.

4. Results

Some tests are done on the system to check how to improve its performance before mounting it onto a wooden board, that will be the final release. For this test we have the Arduino Uno communicating serially to the computer to tell us which note is being read from the capacitive components and which note is being sent to the BCC base board. This two parameters show an error around 1% when there are seven capacitive components attached to the system (it is the maximum number), as the value to send is restarted every time a transmission is made from the Arduino Uno to the base board, and this transmission might happen in the middle of a reading, altering the correct value. The correct BCC transmission is checked by comparing the notes displayed in the computer and the difference in the tones played by the buzzer of the Arduino Lilypad. There is no noticeable error. When the screen showed ‘0’, no tone was played. When the screen showed a high tone, the buzzer played high. And the same for a low tone. However the performance of the system is not perfect. The following lines explain step by step where the main errors can be found.

If the system is not touched there are no alterations and no error is showed. The Arduino Uno shows that no button is pressed at any time. As there is no button pressed nor BCC transmission, the other components neither react.

There is no distortion if only the capacitive buttons are pressed while no BCC transmission is active. However, the thresholds to consider a button pressed are very high to cope with future distortions introduced by BCC. For this thresholds, we get about one false zero for every four correct positives. We can say that when there is no transmission and buttons are being pressed we have an average error of 20%. The readings sometimes show better performance and a few times worse. This error does not affect much to the user perception, however is quite unacceptable. A good measure would be to lower the thresholds, but the next paragraphs are going to show us why it can not be done.

When only the BCC system is active but no capacitive component is touched, all the capacitive components keep the zero value and the buzzer stays silent. The red led from the mobile board blinks, telling us that BCC transmission has correctly been done. There is still no remarkable alteration in the system.

When BCC is active and the capacitive components are also being touched, there is when trouble comes. The noise value of the capacitive components in that case rises up to 5000 units approximately. In order to avoid reading this value as a false true, a new condition was added to the code. This condition regards that the capacitive components that are close to this value will be read as false. Trying other components with different sizes and tape layers, it was proved that the size of the capacitive component is a decisive parameter for its behaviour, providing different noise levels.. Also there is a wire longer than the others and with crocodile clips at its tips (used for connecting one capacitive component to its receptor) that helps to get a false positive. For the final prototype, all the capacitive components will be the same size and the wire connections made the shortest possible, all the same length. This will help for setting a common threshold that will lead to better readings. Also a shielding of conductive material connected to ground will be attached in the lower side of the board to polish the sensors perception. The cause of the distortion is that both, the capacitive components and the BCC devices, are repetitively sending pulses into the human body. This pulses interfere with each other despite working at different frequencies. However, once the level of distortion was detected, it was corrected. This way, the performance of the system is good, despite still showing a bit more than 20% error.

After considering the performance of the Arduino Uno readings, it is time to check the BCC transmission. To know when a successful transmission has been done, the red led from the mobile board or the green led of the base board can be checked as they will blink. When they blink we know for sure that the data received is readable, so the bits have suffered no big error. The checksum system is used to prove that. Whenever the checksum does not correspond to the received packet, the data will be discarded and the transmission restarted.

The tests have shown that when both emitter and receiver are in contact with the same arm of the user, the transmission will be successfully executed most of the times. The average value tells that for one minute there will be 46 correct transmissions and about three failed. In total there are almost 50 transmissions per minute, allowing an update every 1,2 seconds to the Lilypad Arduino. If we change the distance while staying in the same arm, no big changes are appreciated. When going to the other arm, however, the failure will imperate. Only a couple of messages will reach the mobile board. Must be said, though, that this values can vary a lot in different scenarios, or even in different realizations in the same scenario, both for transmissions in the same arm or different arms. In this case, after receiving just one packet in one minute, a whole burst of 31 messages was transmitted then without changing anything.

It has also been proved that multipath has a very negative repercussion for BCC. When transmitter and receiver are very close, they can couple without need of touching. In this situation, if the receiver is touched, there will be a multipath and the transmission will be far more erratic.

All this results lead to consider that Capacitive BCC is still an unstable technology that can be used only for transmissions that do not require fast data movement.But even slow, very interesting projects can be done with it, and will definitely mark a difference when it comes out from the laboratories.

Considering BCC applied with the capacitive components, it has been proved that the Capacitive Sensor library, though working well, is quite a rudimentary system, that works well by its own, but when it receives unexpected interference such as a BCC transmission, it easily collapses providing many errors. A far more efficient implementation for this project could be not to have the capacitive components connected to an arduino and the arduino connected to the BCC transmitter, but to make the capacitive components an entity by themselves. When capacitive technology is advanced enough, it will be possible to attach small BCC chips and batteries to this kind of sensors. We are not far away from making them small enough to be almost imperceptible thanks to the carbon printing and the improvements of nanotechnology. This would allow us to make, not sensors controlled by an arduino, but entities with their own id and containing information that would be transmitted by the touch. Wires would be eliminated and precision would be increased. This kind of tags are the ones that will make internet of things possible.

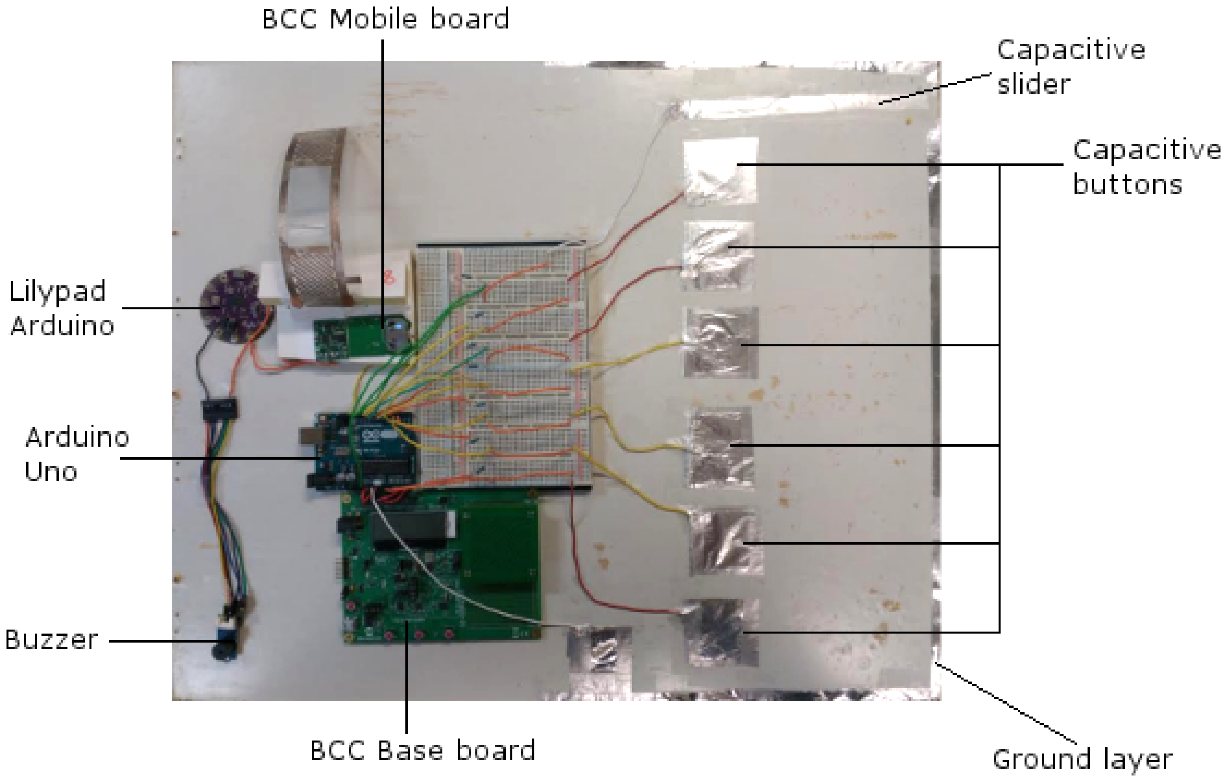

Figure 4.1.: Final demonstration system for the project. The Arduino Uno reads which Capacitive Component is being pressed and sends the according note to the BCC base board. When human contact is made, the base board will send the note to the mobile board through the human body. The mobile board will finally tell the Lilypad Arduino which tone to play, so it will make that sound with the buzzer.

5. Budget

5.1. Material

Material used in the final prototype:

Product	Characterístics	Price (€)
BodyCom development kit by Microchip	Includes only the development base board, equipped with PIC16LF1829, a 16x2 LCD, leds and buttons.	150
BodyCom development mobile board	Equipped with a PIC16LF1827 and leds.	2
PicKit 3	Microchip's bootloader cable for BodyCom development mobile board.	50
Arduino Uno	Microcontroller board using based on the ATmega328P.	20
Lilypad Arduino USB	Small controller board designed to be wearable. Uses the ATmega32U4 processor.	25
Buzzer for Arduino	Small grove-buzzer.	2
2,7MΩ resistors (x7)	Axial fixed resistors.	0.05 (x7)
Aluminium foil	-	2
Wooden board	Base to hold the system together.	5
Total		**206.35**

Table 5.1.: Budget of the material used in the final implementation.

Extra material, not used in the final design. This material was used in the beginning for some tests or was meant for applications that have never been done:

Product	Characteristics	Price (€)
Display for Arduino	Oled display 0.96".	14
Force Sensitive Resistor	-	18
Distance detector	Ultrasonic transductor	6

Table 5.2.: Budget for material not used in the final implementation

5.2. Software

Different softwares were tried for writing the code. The final choices were the following.

Software	Description	Price (€)
Microsoft Visual Studio 2017 (Community version) + visual Micro	Software for coding. The visual Micro extension for Arduino IDE was also installed.	FREE
MPLAB X IDE - v3.61	It also required the XC8 compiler in its pro version. A one month free trial has been used in that project. In case of needing it for unlimited time the price is indicated.	30
BodyCom development Kit software	Software provided by Microchip including guides, a demonstration program to see the features of bodyCom boards, the bootloader software and demonstration codes.	FREE

Table 5.3.: Budget for the software used during the project.

5.3. Hours of work

Hours dedicated to each stage of the project:

- Gathering information about the technology: 60h
- Gathering information about the history and SoA: 55h
- Gather and evaluate information for orienting the prototype purpose: 30h
- Gain confidence with Arduino coding and do minor test projects: 40h
- Coding Arduino Uno application (must be taken into consideration that the final code has experienced many changes due to constant changes in the limitations every time a new board or component was attached): 100h
- Coding Arduino Lilypad application:50h
- Coding BCC base board software:70h
- Coding BCC mobile board software:45h
- Assemble the system together: 10h
- Make last corrections: 50h
- Write reports (project plan, critical design review and final report): 20 + 5 + 70 h
- Total hours: 605h

Considering a salary of 8€/hour, the cost of the work would be: 4840 €

5.4. Evaluation of costs

The total cost of this project would have been approximately 5077€ (taking the worst case and not considering the material that was not used in the end).However, once the research has been done and only the material has to be bought it would be 236€.

For being such a new technology, it is relatively cheap. Most of the material price comes from the base board, and another big part comes from the pickit 3, and only one of it is needed for configuring as many systems as desired. Within a few years the budget will have probably been dropped to less than 50€. After all, the system is no more than a few microcontroller based boards with a touchpad attached and correctly configured to be able to read and transmit from it. To all this, we have to add that a simple BCC system could run just with mobile boards, that are about 2€ right now. This leads to a feasible budget of 4€ for a BCC system (not taking into account the salaries of workers).

For any enterprise, adding BCC in their products would suppose a great expense. In addition, within short time, the system will be made much smaller. BCC will bring a great enhancement to low range transmissions just with small and cheap modifications on some products. It can easily awake interest in communication and electronic companies in general.

6. Conclusions and future development:

In this project one can learn that BCC has silently been around for over twenty years, fruit of the research by T. G. Zimmerman, and has been improved by many different companies and research labs.

There are three different systems to transmit the data: Capacitive BCC, Circuit BCC and Wave-Guided BCC. They are respectively: Transmit the data through the body and use the earth ground as return path; Transmit the data and use a wire as return path; Use two electrodes in each side to create a transmission line with two ports out of the body. Of all this three, Capacitive BCC and Wave-Guided BCC are the ones with a brighter future, giving special importance for Wave-Guided as it is still in a very primary stage of development and, potentially, offers better characteristics.

For deciding what implementation to do, some research was done. With all the conclusions of these research, shown in point 2.4., one can see that BCC has a great potential. It can really make a difference in medical, security and gaming fields. And just for mentioning three. It has a very bright future, but for the current available technology many of those applications will have to wait for some time. Many other simple applications can be done by now, if they do not need fast and uninterrupted data transmission, such as identification for unlocking doors, or transmitting the data stored in sensors.

The implementation made consists in having some capacitive components, that can be just a piece of aluminium foil, and are meant to detect human touch. Depending on which component is touched a tone or another will be played in a buzzer. However, capacitive components and buzzer are separated, and the communication between them is made via Capacitive BCC. With the implementation I could witness myself that Capacitive BCC works well, but will not provide fast transmission and collapses easily for multipath or environment variations. It was also noticed, too late, that the capacitive components react negatively with a BCC transmission, altering their recognition of touch (BCC will continue working while capacitive components might provide some mistaken readings). A great improvement for the system would be made by having a small, unic BCC system for each capacitive component. But as many other things, it is not possible by now.

In some years, Body Coupled Communication will have much smaller receivers and transceivers. It can really be motivated by the application of graphene printing and the size reduction of batteries. In a few years there is great chance that whole BCC systems will be reduced to something just a bit bigger than a small tag. Undetectable in clothes and hidden in phones and everyday objects. It also needs to be cheaper. Once a BCC transmitter is as small as mentioned and with an reasonable price for being used in simple system, it might really populate all hoses and be present in many different working fields.

The final idea contained in the project is that BCC is a young technology and needs time to grow. And when it does, it will overcome all of its current competitors, for it has great potential.

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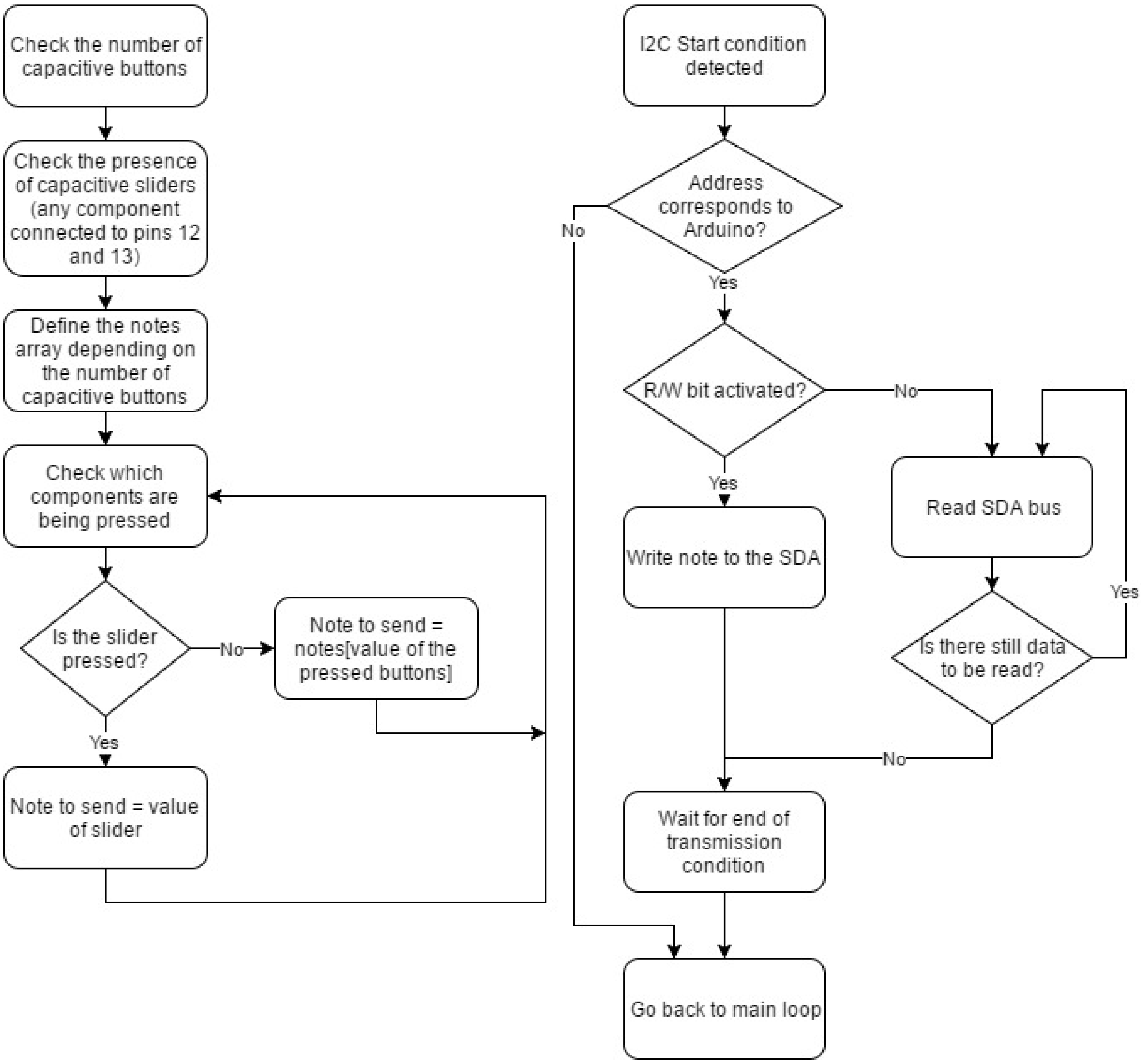
Appendices

Simplified flow diagrams

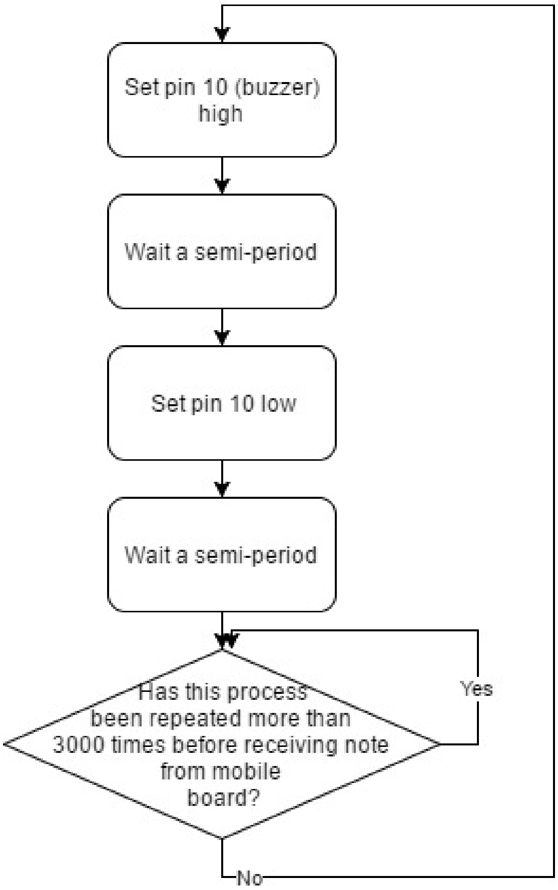
Arduino Uno

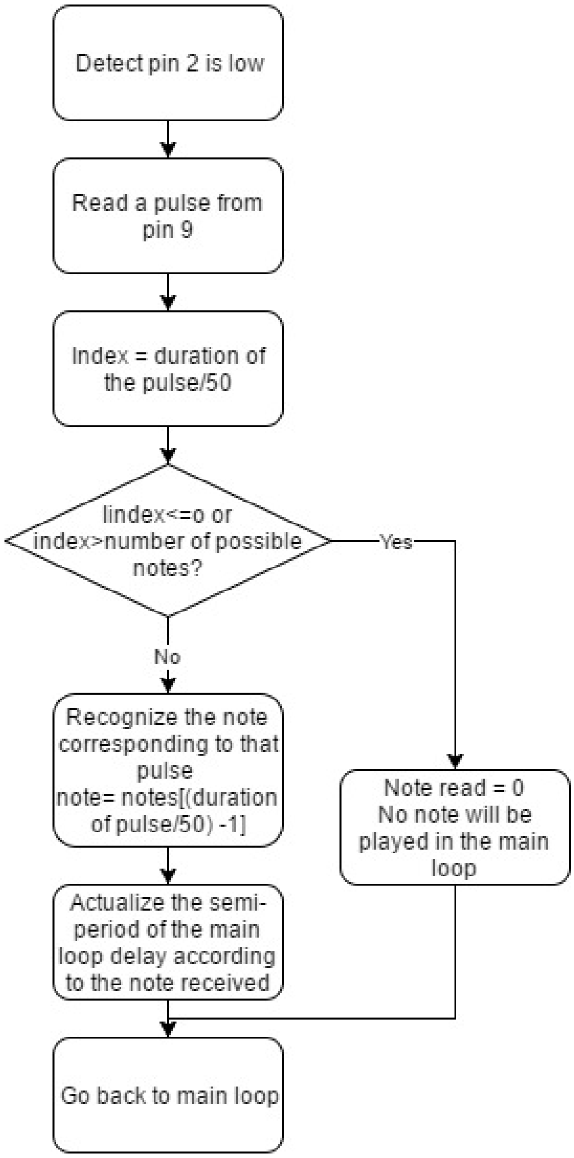
The left diagram shows the main loop. Diagram in the right shows the interruption caused by an I2C transmission.



Lilypad Arduino

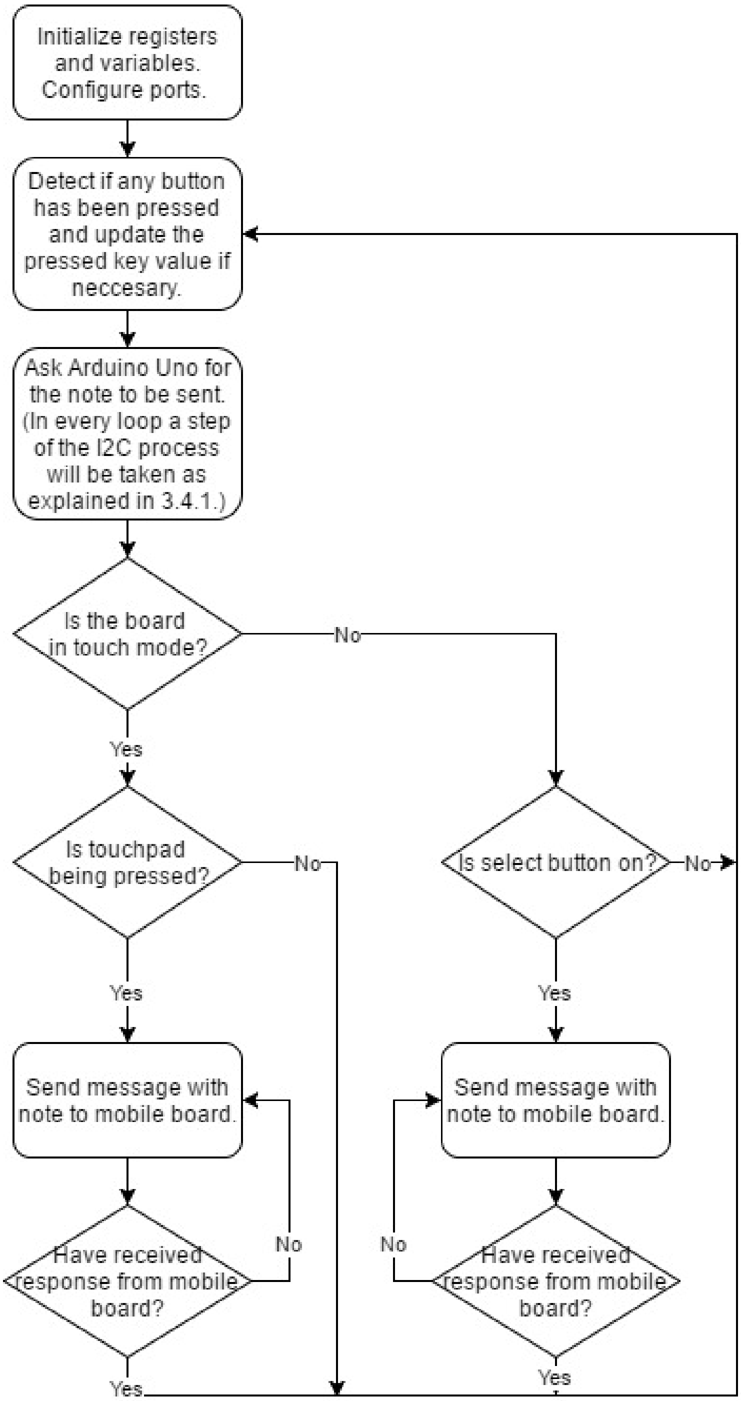
The left diagram shows the main loop. The right diagram shows interruption caused by the transmission of a new note.





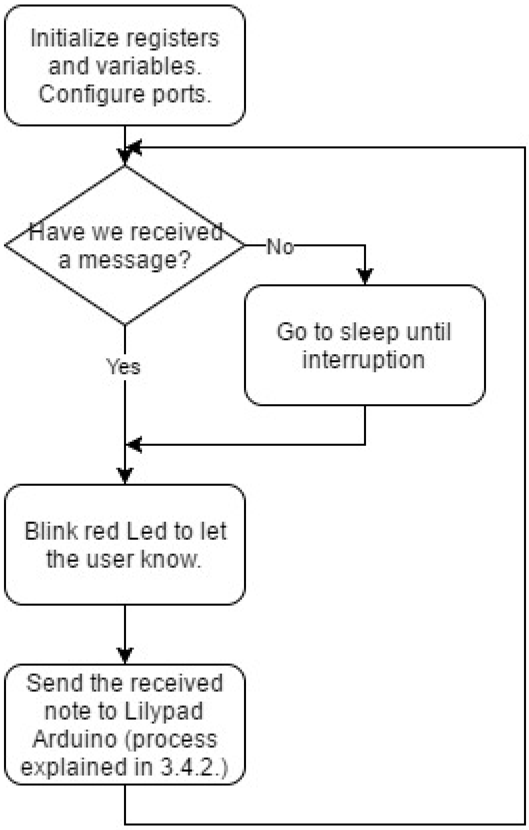
BCC Base board

In this case only the main loop is shown. The configured interruptions are for reinitializing parameters after a transfer, handling timer's overflows and make the led blink after receiving a BCC message.



BCC Mobile board

In this case, also, only main loop is shown. In the interruptions, we can find the case that a BCC message is being received or has to be transmitted. The received message will have priority over sending.



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Glossary

A list of all acronyms and the meaning they stand for.

Abbr.	Spell-out	Explanation	Context
BAN	Body Area Network	Interconnected devices attached to the body forming a small network.	Network formed by the studied technology: BCC.
BCC	Body-coupled communication	A communication scenario using the human body or clothes, etc., attached to the body as signal transmission channel.	Framework for this whole project.
I2C	Inter-Integrated Circuit	Transmission system consisting in two bus lines. One for data (SDA) and one for clock (SCL).	It is the system used to make communication between the Arduino Uno and the BCC base board.
IoT	Internet of Things	The idea of having all objects of daily life interconnected in a network. Any object might be able to connect to internet and interact with other devices.	This project aims to take a step towards IoT. BCC is a technology that can set a milestone in IoT.
KAIST	Korea Advanced Institute of Science and Technology	Important technological university in Korea.	The university has contributed with important progress for BCC.
MIT	Massachusetts Institute of Technology	Important technological university in the USA.	The university has contributed with important progress for BCC.
NFC	Near Field Communication	A new Radio Frequency transmission system, with short range of action, consisting in a chip implanted inside the human body.	Direct competitor with BCC. Must think of what differentiates BCC from NFC.
NTT	Nippon Telegraph and Telephone	Japanese telecommunication company with great investments in research.	The company has contributed with

			important progress for BCC.
PAN	Personal Area Network	Interconnected devices near the human body. Devices should be at a reachable distance.	Network formed by BCC.
RCID	Resistive Capacitive IDentification	Lock opening system implementing identification via BCC. Commercial product by Kaba.	Working example of an implementation of BCC.
RF	Radio Frequency	Electromagnetic waves compressed in about 3kHz and 300GHz. Generally used for data transmission.	The most important wireless transmission method by now.
SCL	Serial Clock Line	The clock line used to synchronize I2C communicated devices.	I2C makes the communication between the Arduino Uno and the BCC base board.
SDA	Serial Data Line	Line used by I2C to transfer data.	I2C makes the communication between the Arduino Uno and the BCC base board.
SoA	State of Art	Current development state of the studied technology, including its implementations.	Background information. Will let us know which is the latest and better model BCC.