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Technologies That Motivate Healthy Toothbrushing Practices Through Social Translucence

MASTER DISSERTATION

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March | 2015

Acknowledges

I must express my appreciation and sincere gratitude to my advisor; Evangelos Karapanos who helped me achieve a life goal and make way for new opportunities. For your guidance, availability, knowledge, patience, enthusiasm, support and motivation during the course of this thesis, I cannot find words to show my gratitude.

To my family and friends, who have always supported me and encouraged to follow my goals. I am thankful for your presence and patience in all the moments of discouragements and successes during this journey.

Abstract

Fifty percent of the European Union's population suffers from an oral disease. Studies have repeatedly shown that while acquiring healthy toothbrushing practices early on in one's life is of significance, children and adults often fail to adhere to those. In this thesis we attempt to design and prototype interactive technologies that motivate healthy tooth brushing habits on individuals. Rather than focusing on the technologies' persuasive power over individuals, we tap on the social mechanisms employed by families. In this sense, we think of these technologies as social translucent rather than persuasive, whose goal is to raise awareness within the family on each other's habits and that aim at leveraging families' existing social mechanisms for behavior change, rather than replacing them.

More specifically, we aim to gain insights with respect to the following questions:

a) What are the drivers and barriers towards adhering to healthy tooth brushing behaviors?

b) Can we effectively measure toothbrushing behaviors?

c) How can technologies leverage family communication practices in motivating proper toothbrushing behaviors?

First, we present two studies about children and adults' tooth brushing behaviors and how these are influenced by social interactions within the family. Secondly, we present the design and prototyping of two systems that sense toothbrushing practices and provide feedback, using the Social Translucence Framework as a design lens. We conclude with an overview of lessons learnt from the prototyping of these systems supported by an analysis of the strengths and pitfalls of the developed technologies.

Keywords

Toothbrushing persuasive technology, families, social translucence, design guidelines

Resumo

Cinquenta por cento da população da União Europeia sofre de uma doença oral. Estudos têm mostrado repetidamente que enquanto a aquisição de práticas saudáveis de escovação dentária cedo na vida é de grande importância, as crianças e os adultos muitas vezes não conseguem aderir a estas práticas.

Neste trabalho, o nosso objetivo é desenhar e implementar tecnologias interativas que motivem os indivíduos a escovarem os dentes. Em vez de forcamo-nos no poder das tecnologias persuasivas sobre o individuo, nós optamos pelo estudo dos mecanismos sociais exercidos pelas famílias. Neste sentido, pensamos nas tecnologias como sistemas translúcidos cujo objetivo é aumentar a consciência dentro da família acerca dos hábitos de higiene oral e que visam engrandecer os mecanismos sociais existentes nas famílias para que permite uma melhor persuasão para mudança de comportamento.

Mais especificamente, pretende-se obter resposta às seguintes questões:

a) Quais são os motivos e barreiras que os indivíduos enfrentam quando tentam aderir a comportamentos de escovação saudáveis?

b) Será possível medir efetivamente os comportamentos de lavagem dos dentes?

c) Como é que as tecnologias podem aproveitar o papel da família induzindo comportamentos de boa higiene oral?

Primeiro, apresentamos dois estudos sobre os hábitos de escovação de crianças e adultos e uma análise de como estes são influenciados por interações sociais dentro do seio familiar.

Em segundo lugar, nós apresentamos o conceito e o desenvolvimento de dois sistemas que detetam práticas de escovação e fornecem informação acerca dos mesmos usando uma abordagem social. Concluímos com uma visão global dos resultados obtidos dos pontos fortes e fracos das tecnologias desenvolvidos

Palavras-chave

Escovagem, tecnologia persuasiva, famílias, translucidez social, diretrizes de desenho

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1 Introduction

Toothbrushing is a daily practice that impacts an individual's oral health and quality of life. Establishing a good oral health behavior from an early age can prevent serious illness (Savolainen et al., 2005). Despite being a relatively inexpensive behavior that does not require too much effort and which can easily be taught (Foundation, n.d.), individuals often fail to adopt healthy toothbrushing practices. Barriers to this may be a missing routine, lack of motivation, time constrains and lack of information regarding the importance of toothbrushing (Caraban et al., 2014).

With these challenges in mind researchers and practitioners have developed a number of systems to motivate individuals to attain good oral health. While existing prototypes have focused on motivating single individuals (See Morlarcropolis and the playful toothbrush, for instance (Soler et al., 2009) (Yu-Chen et al., 2008) in our line of work we attempt to motivate healthy toothbrushing habits through tapping into the social mechanisms of families. Grounded upon the theoretical framework of Social Translucence (Erickson & Kellogg, 2000) we argue that increasing the transparency of toothbrushing behaviors among family members will increase individuals' motivation and accountability in adhering to desired behaviors. Thus rather than thinking of technologies as persuasive we think of them as social translucence whose role is to raise and support the existing communication and coordination practices within families.

1.1 Motivation/Problem statement

During the last decades the number of individuals holding a poor oral health has declined significantly. In spite of such progress, oral disease is still prevalent and indicated as a serious public health problem that affects a large part of the population. In 2012, it was reported that 50% of the European Union's population suffer from periodontitis and 10% have a severe related disease. This prevalence intensifies to 70-85% of population of the age of 60-65 years old (platform, n.d.).

Currently, oral disease is the fourth most expensive disease to treat (Platform, n.d.) And even though resources needed to prevent disease are much lower than treatment, individuals do not recognize oral diseases as problems until late phases

(Emmanuel & Chang'endo, 2010). Tooth decay, toothache, bad breath, gum disease stand out among the common oral consequence of a poor oral health. However, accumulated bacteria resulting from a bad oral hygiene can origin infections in the rest of the body, engendering more severe problems as chronic and systemic diseases conditions and low birth weight. Also can reflects in impairments of daily life activities as chewing and to individuals' low-self esteem (Herreño et al., 2012).

Clinical recommendations suggest that prevention embraces owning a proper oral health behavior and a controlled eating habit (varied and balanced). To attain a proper toothbrushing behavior, an individual should adopt a recommended frequency, duration and performance. Frequency relates to the number of times per day an individual should brush his or her teeth. Frequency should be higher than twice a day and toothbrushing should occur after meals and followed by flossing. Duration refers to the time the individual should spend in toothbrushing his or her teeth, with professionals indicating that good toothbrushing takes at least two minute, to be able to remove the bacteria. Lastly, performance refers to the toothbrushing technique that it should be adopted, see Figure 1. Performance takes in consideration the mouth areas brushed, the toothbrush inclination and the strokes conducted (gentles and short).

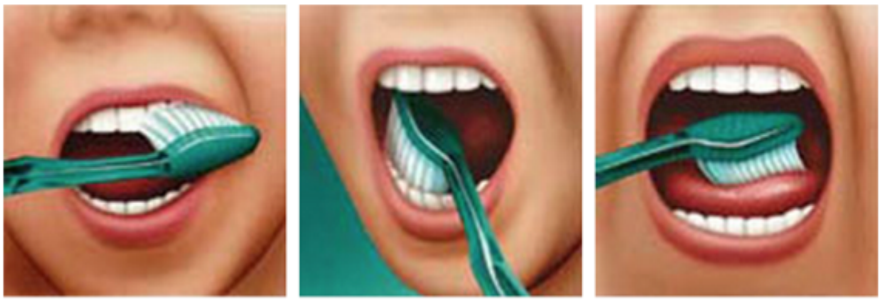

Figure 1 - a) Tilt the brush at a 45º degree against the gumline and sweep or roll the brush away from the gumline. b) Gently, brush the outside, inside and chewing surface of each tooth using short back-and-forth strokes. c) Gently brush your tongue to remove bacteria and freshen breath. (Colgate, n.d.)

Additionally, medical expert recommend adopting good oral hygiene practices from a young age, when interventions are more successful as in adulthood it becomes increasingly difficult to establish a proper oral behavior routine. (Aunger, 2007)

1.2 Contributions

With this work we provide two approaches for the design of persuasive system that aims at raising self and other family member's awareness to support behavior change towards proper toothbrushing practices. These approaches embraced insights and system description (software and hardware) for the development of these technologies.

We provide two studies that analyzed individual's needs towards adhering to a proper toothbrushing practice and analyzed how these are influenced by social interactions within the family.

We were able to present a paper at the Interaction Design and Children Conference with the insights obtained with this work (Caraban et al., 2014).

1.3 Thesis structure

In chapter 2, we first provide an overview of previous research efforts towards inducing proper toothbrushing practices. Through the analysis of previous work, we describe existing theories of behavior change and how they were adopted in these technologies. Moreover, we describe systems limitations and how this weakness could be addressed adopting social persuasion strategies in addition to persuasive systems. We concluded, describing the Social Translucence Theory and how the family role is important to motivate family members to adopt proper toothbrushing behaviors.

In chapter 3, reports two studies conducted that aimed understand individual's barriers and motivations towards adhering a proper toothbrushing behavior. The results collected, were refined and transformed to systems requirements for the design of a Social Translucence system.

In chapter 4, we describe the design and development of Smartholder, a toothbrushing holder that sense frequency and duration of family members' toothbrushing practices, and provides feedback about those behaviors to family members. We conclude this chapter, listing system limitations and describing how they could be address.

In chapter 5, we present Social Toothbrush, our approach for the design of a persuasive system that aims at raising self and other family member's awareness to support behavior change towards proper toothbrushing practices. We describe the design and development of toothbrush extension that sense family members frequency, duration and performance of toothbrushing behaviors and provide feedback through the extension and through a mobile application.

In the last chapter, we enounce some system limitations and the list future work ideas.

2 Literature Review

This chapter provides an overview about the current state of the art of theories and technologies for behavior change. First, we describe theories of behavioral change and their contributions to the design of systems that aim inducing proper behaviors on individuals. Secondly, we present persuasive technologies towards supporting individuals' toothbrushing practices. Finally, we present an overview related to Social Translucence theory and describe the role of family supporting these behaviors.

2.1 Encouraging Behavior Change

It is known how hard it is to change a behavior, especially when said behavior is nonresistant to change and is undesirable for the subject. For many years, researchers engage users to attain behaviors through psychology principles, focusing in understanding individuals' conducts and motivators. These motivators comprise the understanding of the individuals' intention to adhere to a behavior, how valuable it is for him to adopt it and his expectations to accomplish the desired conduct (usually they misjudge the effort and resources required) (Romero et al., 2010).

Nowadays, as technologies evolve and become more accessible, individuals often rely on external systems in order to help them achieve certain tasks and toothbrushing practice is no exception. With an increasing emphasis on behavior change technologies, interest in these has grown over time, including systems that stimulate individuals to attain good oral health. To help overcome bad oral health behaviors, different approaches have been developed to change toothbrushing behaviors and create engagement with users, making the practice more pleasurable. However, motivating individuals continues to be a complex task to achieve. As research efforts continue to progress, motivational theories continue to emerge and to be adapted to everyday problems, creating opportunities for persuasive technologies.

2.1.1 Fogg's Behavioral Model

Fogg's model for behavioral change proposes that in order for a behavior to happen, three properties have to come together as one, at the exact moment: the motivation to achieve the goal, the ability to perform it and a trigger to initiate the behavior (Figure 2). If one of these factors is missing, the behavior won’t happen (Fogg, 2009).

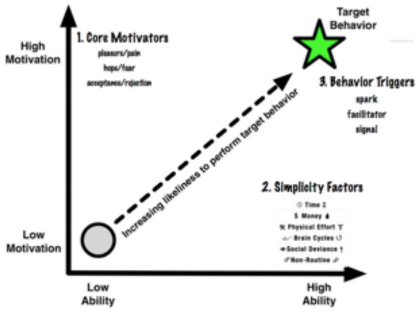

Figure 2 – Three attributes identified by Fogg’s for behavioral change (Kappe, n.d.)

Applied to our problem, motivation refers to the individuals’ desire to have good oral health. Ability refers to the resources and capabilities needed (for instance, the access to a proper environment, toothbrush/toothpaste) and individuals’ ability to perform it when the resources are available. Lastly, triggers taps on what can leverage the motivation to achieve the task.

An overview of existing commercial and technological solutions that aims at encouraging proper toothbrush habits, demonstrates how this theory has been applied. Currently, commercials products have been mainly designed to encourage healthy habits early in life, through playful approaches. Customizable toothbrushes (featuring different illustrations) and tasteful products (toothpastes/floss/rinses) have been some of the early solutions towards this goal, see Figure 3 and Figure 4.

Figure 3 - Tasteful toothpaste

Figure 4 - Colorful toothbrush

More recently, technological products that sense and provide feedback on individuals' toothbrushing habits have filled the market. For instance, Spinbrush, see Figure 5, Tooth tunes (Tunes, n.d.) and Squeaky Clean Teeth (Yanko, n.d.), see Figure 6 are toothbrushes that play a song while toothbrushing for the minimum recommended time (i.e., 2 minutes) with the goal of sustaining children's interest in the activity. Beam Brush (Beam, n.d.), see Figure 7. Also logs users' behaviors and allows them to review using a mobile app. Oral-B Smartseries 5000 (Oral-b, n.d.), see Figure 8 provides a visual display with feedback about time as well pressure control.

Figure 5 - Spinbrush toothbrush

Figure 6 - Squeaky Clean Teeth

Figure 7 - Beam Brush

Figure 8 – Oral-B toothbrush

Also, some mobile applications have been developed as educational tools attempt to help make toothbrushing fun and to teach individuals how to brush effectively. For instance, Aquafresh Brush Time (GSK, 2013), see Figure 9 and Plaque (Plackers, n.d.), see Figure 10. Attack and Molarcropollis, see Figure 11 aim to persuade individuals through the demonstration of cause and its effect through simulations.

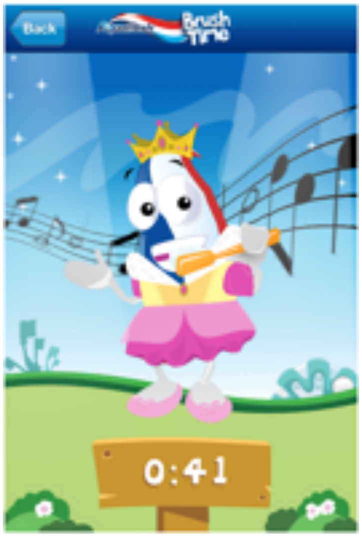

Figure 9 - Aquafresh Brush Time (GSK, 2013)

Figure 10 - Plaque Attack (Plackers, n.d.)

Figure 11 – Molarcropolis (Soler et al., 2009)

The vast majority of the technological solutions described have relied on providing just-in-time motivational feedback, with the goal of increasing adherence to desired behaviors or performance within. In line with Fogg's behavior model for persuasive design, they attempt to increase individuals' (especially children's) awareness and motivation for frequent or appropriate toothbrushing, to increase individuals (perceived) ability to perform the task, or to provide the triggers that encourage behavior change during appropriate moments.

2.1.2 Presentation of Self in Everyday Life

(Goffman, 2012) presents his "Presentation of Self in Everyday Life" theory with a metaphor of a theater, to depict the importance of social relations. To Goffman, the individual that is performing the activity is seen as an actor, who is on a stage and is being observed by the audience, see Figure 12. The actor adjusts his performance according to the situation, to what he wants to demonstrate to others or otherwise, what he wishes to conceal. In this way, individuals' actions are influenced when the individual is in immediate presence of others. As others can make inferences of the activity he is performing, the individual adapt his behavior.

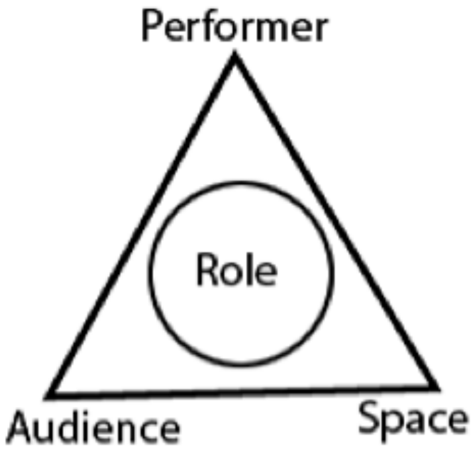

Figure 12 - Graphic representation of individual and environment in The Presentation of Self in Everyday Life (Kristinstollenwerk, n.d.)

We associate this theory with Nakajima work (Nakajima & Lehdonvirta, 2013). They proposed a virtual aquarium that motivates individuals to adhere to 3-minute toothbrushing practice. Feedback is reflected in the bathroom mirror and the user's behaviors are emulated by the representation of aquarium elements, which are likely to be seen by others, see Figure 13. Through simulation, they aim to persuade users to create an attractive environment while performing the activity. More time a person spends toothbrushing, the bigger the fishes get and prettier the aquarium becomes.

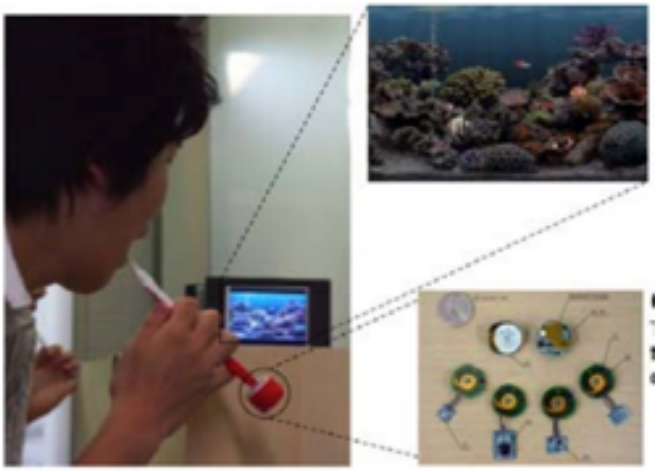

Figure 13 - Virtual Aquarium (Nakajima & Lehdonvirta, 2013)

2.1.3 Goal Setting Theory

This theory highlights the importance of predefined goals and how they affect individuals' performance. When an individual is committed to perform a proper behavior and sets a complex and specific goal, he is more expected to achieve it. This happens because the individual is pushed to define a set of strategies that help him accomplish the task - since the task is difficult; it requires more effort and dedication. Feedback related to the goal is desirable as to keep track of current practices and progression. In our work, goals may include, for example, toothbrushing three times a day, brushing for two minutes or attaining a proper brushing performance (Locke & Latham, 1990).

Chang, Yu-Chen work applies this theory to practice. Playful Toothbrush (Yu-Chen et al., 2008), see Figure 14 is an ubiquitous computing technology that attempts to assist parents in educating kindergarten children on proper toothbrushing practices. With the purpose of providing real-time visualizations about the children's performance, the prototype uses a vision-based motion tracker (located in the bathroom) that recognizes different toothbrushing strokes. Feedback, is provided through an interactive game, see Figure 15, which aims to induce the children to complete the task of cleaning a virtual group of teeth, highlighting the teeth that are yet to be brushed.

Figure 14 - Playful toothbrush practice

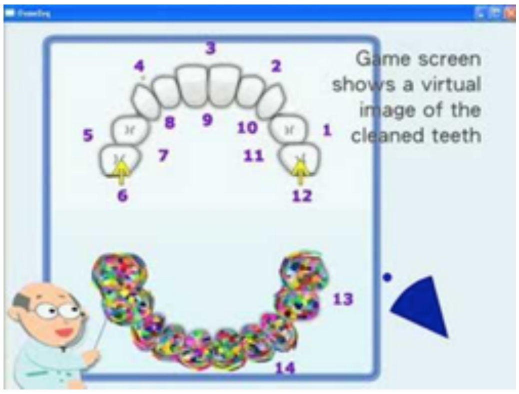

Figure 15- Playful tootbrush feedback

2.1.4 Social cognitive theory of self-reflection

This theory introduces self-regulation as a personal, behavioral and environmental process adopted to achieve particulars goals. Self-regulation is defined as a cyclical feedback process where an individual performs an activity and later on, insights of past performances (behavior feedback) are used as self-monitoring performances. This feedback allows the individual to identify deficits and make the necessary adjustments/corrections that will be applied to future practices. While individuals persist on achieving the objective, this cyclical procedure repeats since personal, behavioral and environmental elements are ever changing, see Figure 16 (Bandura, 2001).

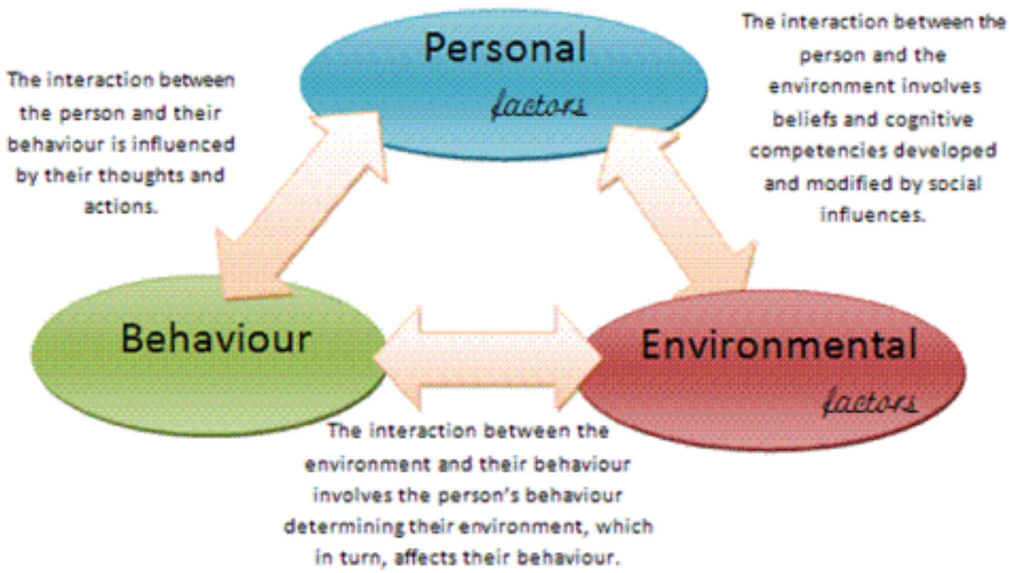

Figure 16 - The Social Cognitive Theory representation (motivation-project, n.d.)

This theory is applied to Alonso work with Brush and Learn (Bruns Alonso et al., 2014), a prototype focusing on brushing duration and performance. An interactive toothbrush provides haptic feedback with the goal of learning to perform a complex toothbrushing technique. Users can check feedback about their behaviors displayed on the computer and reflect on their toothbrushing performance.

Also, Hachisu and Kajimoto (Taku & Kajimoto, 2012) proposed a solution that manipulates the auditory sensation of toothbrushing with the goal of augmenting the experience of progressive cleanliness to help individuals attain a proper performance.

2.1.5 Self-determination theory

This theory enunciates feelings that make an individual more likely to change his behavior: competence, relatedness and autonomy, see Figure 17. Competence taps in how confident and capable the individual feels to achieve a pre-set goal. Relatedness denotes the connection made and lastly, autonomy refers to the feeling of control an individual holds when attempting to adhere to the behavior. An individual feeling confident, capable and relatable to the behavior is more likely to reach an attainable goal. Moreover, this theory categorized motivations by two different orientations: intrinsic (within the individual) or extrinsic motivators (external to the individual). In our line of work, intrinsic motivators may tap into the feelings of fulfillment an individual obtains resulting from achieving a good toothbrushing behavior. Extrinsic motivators refer to an outside motivator, for example, social influence or social pressure, to adopt social norms (Deci & M. Ryan, 2011).

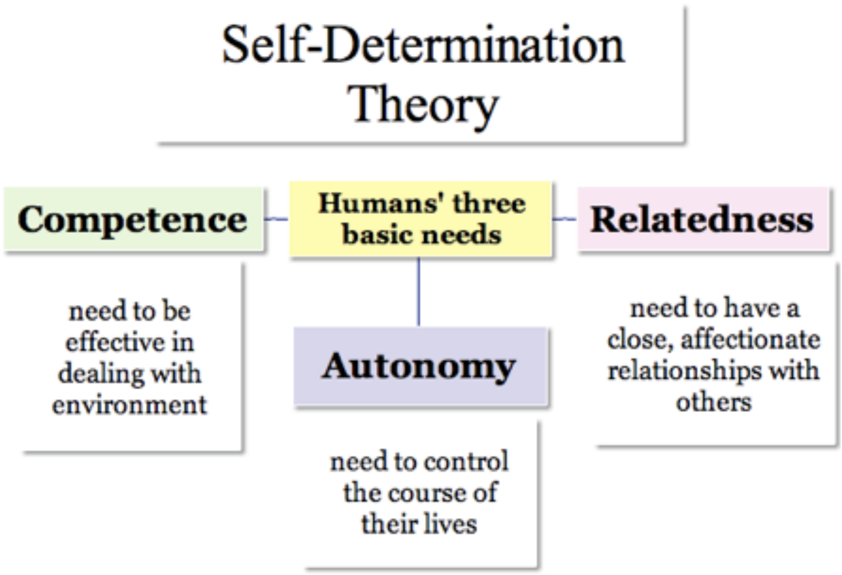

Figure 17 - Self-determination Theory diagram (Program, n.d.)

(Bozgeyikli et al., 2014) propose Cravy Brush, a system that aims to support parents in teaching proper toothbrushing behaviors. The system understands children's behaviors through mobile phone sensors inserted in a case attached to the children toothbrush. A mobile game aims to engage the child while the practice is conducted, helping them to achieve the recommended brushing time while an alarm feature is included to remind users to brush their teeth (See Figure 18). Parental influence is used as a way to monitor and rectify children's brushing motions, frequency and duration. Parental supervision can be identified as extrinsic motivators, while an intrinsic motivator is the fulfillment the child obtains when accomplishing the game goal (which reflects of time spent brushing their teeth).

Figure 18 - Cracy Brush extension and game application (Bozgeyikli et al., 2014)

2.1.6 The Transtheoretical Model

The Transtheoretical model defines and helps understand the five states of change (or process) through which individuals progress since they begin to engage/feel motivated to modify their behavior, to the moment they are able to keep them: precontemplation, contemplation, preparation, action and maintenance. Moreover, (Prochaska & F. Velicer, 1997) propose a set of advised strategies per stage, chosen for their relevance at each stage. This process of behavioral change is more likely to be cyclical since people often do not succeed achieving the desired goal (Prochaska & F. Velicer, 1997).

We assimilate this theory with (Gerling et al., 2010) and (Soler et al., 2009) work. They proposed serious games as educational tools in raising awareness of the importance of toothbrushing and educating children on proper toothbrushing behaviors. First one presents a system that attempts to help users to improve their brushing efficiency resourcing to a *WiiMote*. The system recognizes user activity through a gesture-based classification system and provides feedback through a game that also encloses a learning feature. Second one presents *Molarcropolis*, a mobile game with embed learning approach (See Figure 19). Rather than motivate through game simulation, the system aims to instruct children about the consequences of a poor toothbrushing practice. Elements of this theory are found through the informative feedback these systems provide. Response related to the user activity allows the user to acquire knowledge as he makes progress in their behavior.

Figure 19 – Molarcropolis game interface (Soler et al., 2009)

2.2 Creating opportunities for persuasive interactions

Nowadays, web, mobile and ambient technologies have been targets of wide adherence for persuasive interactions due to the way it can reaches users. Designing interfaces for persuasive systems is an explore field and several principles have been proposed for system that aims behavioral change. However, current approaches have weak results. In our approach, rather than inducing behavior change through self-monitoring or reflection, we want to leverage the role of the family providing technologies that best integrate with them rather than replacing them. Kukkonen's & Harjumaa's research about the design of persuasive systems better support our aim (Oinas-Kukkonen & Harjumaa, 2008). They suggest seven postulates for the design of these systems which relates to users, persuasive strategies and system features which are:

1. Information technology is never neutral
2. People like their views about the world to be organized and consistent
3. Direct and indirect routes are key persuasion strategies
4. Persuasion is often incremental
5. Persuasion through persuasive systems should always be open
6. Persuasive systems should aim at unobtrusiveness
7. Persuasive systems should aim at being both useful and easy to use

These postulates were translated into features that should be considered to design persuasive systems. As a result, his work embraces several design principles summarized in Table 1.

Table 1 – Kukkonen's & Harjumaa's principles description for the design of persuasive technologies

Feature	Principle	Description
Primary task support	Reduction	Target behavior should be divided in small tasks
	Tunneling	System should guide the user among the whole process
	Tailoring	System should provide custom-made information
	Personalization	System should provide personalized content
	Self-monitoring	System should help individuals track their performance
	Simulation	System should provide a recreation of current behavior
	Rehearsal	System should provide a way for practicing that behavior
Dialogue support	Praise	System should complement user about his behavior
	Rewards	System should provide rewards and credit when a user achieves the target goal
	Reminders	System should recap the user about the goal he is aiming to achieve
	Suggestions	System should provide advice/tips about certain behaviors
	Similarity	System should resemble users behaviors
	Liking	System should be appealing
	Social role	System should own a social feature
System credibility support	Trustworthiness	System should provide reliable information
	Expertise	System should support knowledge (providing information)
	Surface credibility	System should appear reliable
	Real-world feels	System should provide information about what supports the system (organization, people, etc.)
	Authority	*"System should refer to people in the role of authority"*
	Third-party endorsements	System should provide endorsements, approvals or/and certificates
	Verifiability	System should provide a way to verify how reliable is the content presented

Feature	Principle	Description
Social support	Social learning	System should allow the user to observe others individuals reaching (or attempting to reach) their goal
	Social comparison	System should allow users to compare performances with each other
	Normative influence	System should support peer pressure (for example through challenges)
	Social facilitation	System should inform the user about other users with the same goal
	Cooperation	System should allow cooperation
	Competition	System should allow competition between users

This framework describes systems features that should be adopted for the design of persuasive systems that aim behavioral change. One can notice that some of the previous research systems embraced some of these characteristics and that this framework provides interesting concepts relevant to the development of a system intended to induce good oral hygiene habits.

2.3 Persuasive Technologies for Healthy Tooth-brushing Practices

The earlier overview on behavioral change approaches provided some interesting insights/guidelines for the design of systems that aim to induce users to adopt new conducts. Moreover, it allowed us to understand explored research paths and possible opportunities left to be studied with the goal of promoting proper toothbrushing behaviors. Never the less, through a more thorough review one can notice common characteristics and approaches adopted. For a better understanding, we decided to cluster all systems based on six main categories based on the characteristics they retain and which we considered more suited to the scope of these types of systems.

These categories include detected behavior, type of feedback, feedback location, target population, intrusiveness and visibility. Detected behavior refers to focus the system attain to reinforce – frequency, duration or performance. Type of feedback refers to approach followed for the information intended to be display, feedback can be motivational or reflective/informational. Motivational feedback is attached to the information presented with the purpose of creating the experience more enjoyable/desirable. This can be done through simulations (showing abstractly and attractively to the user the relation between the current behavior and consequent effect) and stimulations (suggestions and rewards for achieved goals). Reflection however designates systems that tracks behaviors and allows self-monitoring in a later time. Feedback locations indicate the environment where the feedback is displayed. It can be displayed within-context (in the bathroom) while the practice is been conducted or out of context (outside the bathroom, for instance through a mobile application). Target population indicates if it is intended for children and/or adults. Intrusiveness describe if the system is seamless or intrusive. Lastly, visibility is the classification that refers to the feedback intention either towards a specific individual or to the surrounding individuals, as it's intended to be public or not.

Following is a classification table listing the mentioned systems and their respective properties, having commercials products been discarded in this classification.

Table 2 – Previous research systems taxonomy

Name	Motivational Vs Reflective	Within – Context Vs Out - Context	Population	Intrusive Vs Non - intrusive	Visibility	Detected Behavior
Cravy Brush	Motivational	In - Context	Children	Non - intrusive	Public	Frequency, Duration, Performance
Playful toothbrush	Motivational	In - Context	Children	Intrusive	Public	Duration, Performance
WiiMote	Motivational	In - Context	Children	Non - intrusive	Private	Performance
Brush and Learn	Reflective	Out - Context	Not limited to a target population	Non - intrusive	Private	Performance
Molar - cropolis	Motivational	Out - Context	Children	Non - Intrusive	Private	Aim to provide knowledge about the practice
Virtual Aquarium	Motivational	In - Context	Not limited to a target population	Non - Intrusive	Public	Frequency, Duration, Performance

This system categorization provided insights about different approaches followed to motivate healthy toothbrushing behaviors. As expected, systems intended for adults included more of a methodological approach, providing means for the user to track their performance (self-monitoring) in a later time, attempting to persuade the user through behavior reflection (See Figure 20). On the other hand, all systems designed for children engagement comprised a motivational approach, especially through games simulations.

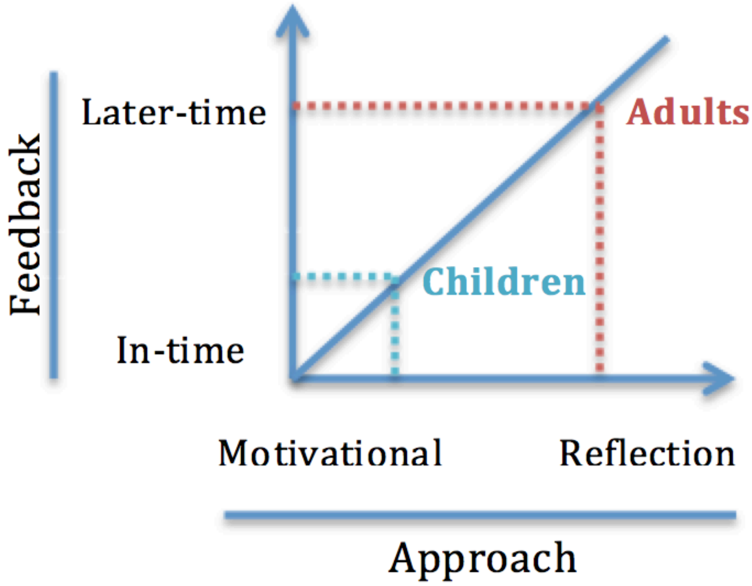

Figure 20 - Relation between previous research efforts

Although all of these systems focused in single users interactions, most systems aimed at children engagement support parents' supervision while the practice is conducted (within context). These systems take advantage not only of system persuasion but also from social persuasion when they make information visible and accessible to parents. Though persuasive systems help individuals obtain some improvements on oral health, adopting or reinforcing behaviors, these technologies fail to understand individuals' motivations. As a result, these systems become slightly less effective when the individual has no interest in changing his behavior. This is where social persuasion takes action, enhancing the effectiveness of these approaches to overcome lack of social persuasion and technologies limitations.

Through this section, we conclude that current approaches show some weak results. Technologies should not bypass existing social practices but rather best integrate with them. Rather than inducing behavioral change through self-monitoring and reflection, technologies should take advantage of social persuasion.

2.4 Families as Proxies to Behavior Change

An extensive body of work in behavior change applications has pointed out the strong influence that social ties, as family and friends, have in reinforcing or changing behavior (Consolvo et al., 2008) through social persuasion. For instance, Unger and Johnson mention the concept of social push, through which they identify the importance of social ties as triggers inducing behavioral change. They demonstrate how physical activity can be motivated by social activities encouraged by friends (Romero et al., 2010) reported the needs of individuals (older adults) having a social influence to maintain a physical routine. Additionally, relationship between workers also showed to have influence in inducing behaviors. (Huang & Fu, 2013) reveals that individuals feel more interested and determined to outperform when they are in presence of peer-workers and his conducts are visible to others. Furthermore, close social ties such as families, also revealed quite important influencing family members' behaviors. (Bauch, 1998) report that parents' support can improve children's performance about 86% when they are faced to children conducts while they are at school. It also has been observed that a parent dental behavior has a substantial effect on young children conducts (Klingberg & Broberg, 2007). However, it is important to notice that from all social interactions, family relationship proves to be the stronger social motivator. This is mostly due since family relations are longer lasting, which strengthens emotional closeness and increase trustworthiness among members (Carstensen, 1992). Family plays an integral role in an individual's live structure, starting with children's development process supported by their parents, which develop feelings of responsibility, and extended to all family members. This commitment is long lasting; families permanently try to ensure that all members reach their goals more effectively and as result, an individual's goal becomes a family goal. Moreover, desired conducts are mostly induced through effective and advanced strategies, such as playful nudging and maintaining an awareness of each other's behaviors, which enable families to develop common routines and establish social norms.

As such, technological interventions as toothbrushing systems may be more effective if they integrate with families' existing social practices. Despite some recent interesting systems on the topic of toothbrushing behavior, the domain currently lacks an understanding of the effectiveness of different approaches in motivating healthy toothbrushing behaviors through the role of family. Also, they reveal some pitfalls in raising self and mutual awareness making it difficult for family members to support others practices

2.5 Social Translucence Theory

One can notice that although families' interactions have a profound influence helping individuals' progress towards a goal, this occurs when individuals are provided with perceptible information. Only when the information is visible, these interactions can take action and likewise, providing feedback about an individual's conducts does not lead to changing behaviors without social interaction. The ideal scenario is an association between social cues to persuasive systems. Based on this idea, (Erickson & Kellogg, 2000) propose a model for the design of systems that provides visible information about others individuals' activities with the goal of encouraging interactions. This theory called Social Translucence, describes three vital properties, which should be represented, on a system that is intended to effectively support social interactions to induce behavioral change. These three properties are: visibility, awareness and accountability (Erickson & Watson , 2000).

Visibility refers to presenting significant information to be perceived, allowing users to see each other's behaviors and make inferences about others actions. It is important to reflect on the risks and implications when it comes to making information visible given that privacy concerns emerge. Although this is intended to increase transparency about conducts, it is not intended to make all information visible and it must be taken into account which cues will be disclosed and to whom (grounded on the context). (Barreto et al., 2013) (Leth Jespersen et al., 2007) refer the terms "covert surveillance" and "overt surveillance" where "covert surveillance" is no longer consider a persuasive technique (yet a hidden monitoring) since is not towards motivation but rather manipulation and punishment. This is why the term *Translucence* has a substantial significance

Awareness designates the perception an individual gains knowing his actions are public/being shared and that those can provide information to others. Insights obtained, brings coherent information to the table through which the interactions are sustained (Barreto et al., 2013).

Lastly, *Accountability* refers to the impact that the knowledge of visible information has on an individual. Since he knows that others know about his behaviors, he becomes responsible for his actions and therefore acts or inhibits some behaviors to gain others' approval (Barreto et al., 2011) (Erickson & Watson , 2000). These feelings make norms more effective since an individual is induced to follow the rules.

This framework provides a wide range of opportunities in design space when it comes to induce proper behaviors through tapping social interactions. Systems designed to support communication and collaboration between individuals have proven to be a resource to structure richer interactions and stimulate behavioral change through mechanisms as competition, comparison and public commitment (Barreto et al., 2013) in particular when family is involved.

In our line of work, we believe that a socially translucent technology can afford significant information about family member's toothbrushing behaviors (as frequency, duration and performance), through which individuals might be linked to. Making individuals more conscious about others members' behaviors can leverage families' existing social mechanisms of encouraging behaviors (as empowerment). Also, one may notice that awareness levels between family members are higher and this hardly raise privacy issues.

Rather than developing a persuasive system, in our approach we intend to take advantage of families multiple interactions, providing tools that allow individuals to draw inferences and act accordingly through feelings of personal accountability.

3 Understanding user's needs and practices

The following section presents two studies, a survey and a set of interviews, that tried to inquire into children's and adults' practices of toothbrushing (such as the perceived frequency and duration), the motives and the barriers towards adhering to desired practices, as well as how social interactions among family members affect individuals' toothbrushing practices.

3.1 Survey

A survey aimed at gaining insights into individuals' toothbrushing behaviors. A total of 61 participants completed the survey. Their mean age was 24 years old (min=7, max=59). Fourteen (23%) of the participants were children between seven and nine years old. Children completed the survey on paper and were recruited in a school with prior authorization (mean age=7, min=7, max=9).

To avoid memory biases we employed a similar procedure to the Day Reconstruction Method (Erickson & Kellogg, 2000), see (Gouveia & Karapanos, 2013) for an alternative. Rather than asking them to report on their typical behaviors, we asked them to recall the past day and report when and for how long they brushed their teeth, along with other information about these events.

The survey protocol can be seen in appendix 9.1.

3.1.1 Findings

Toothbrushing practices

Overall, individual's self-reported habits are better than expected. In fact, 97% of participants reported brushing their teeth two or more times a day, the minimum frequency recommended by experts (Colgate, n.d.) the average number in our sample was three per day. However, while participants' reported frequency of toothbrushing may be judged adequate by experts, the majority of the them (61%) reported that they would like to increase the frequency of toothbrushing by 1 time/day (43%) or 2 or more times/day (14%).

The median perceived duration was 2 minutes and 37 seconds; only 59% of participants reported brushing their teeth for 120 seconds or more, the duration recommended by experts (Colgate, n.d.).

We found that individuals with age lower than 18 years old (N=21, Mean=146 seconds, SD=108 seconds) spent less time brushing their teeth than adults (N=61, Mean=177.15 seconds, SD=216.19 seconds, t(79)=- 6.19, p=0.5). An even stronger effect was found in the perceived frequency of toothbrushing with children and teenagers displaying less frequent behaviors (N=21, Mean= 2.05, SD=0.740) than the adult participants (N=61, Mean=2.90, t(79) = -3.61, p<0.01).

As expected, children of nine or lower were not aware of the time spent brushing their teeth, but they were conscious about their toothbrushing frequency. Only 43% of the children reported a tooth frequency of twice a day (or more), the minimum recommended practice.

Barriers against healthy toothbrushing practices

We identified five primary barriers against adopting healthy toothbrushing practices: individuals' lack of motivation coupled with the unattractiveness of the task (39%), time constrains (blaming the frenetic lifestyles and rotating schedules, preventing the execution of the "task that in itself requires some time" - 21%), missing routines (17%) and the lack of information about health consequences (12%).

Intra-family awareness and influence

In total, 59% of survey respondents reported being aware of other family members' toothbrushing practices. They attributed this mostly to common routines (16%), such as leaving home at the same time and taking meals together. About 9% of the respondents reported this awareness coming through discussion as they attempt to remind each other to brush their teeth, while respondents reported that subtle cues such as the sound of toothbrushing as well as the toothbrushes being wet often raises this awareness.

Almost all of respondents (90%) reported that they often attempt to influence other family members' toothbrushing habits, with the primary practice (in 77% of the cases) being contextual reminders, such as reminding others to join them when brushing their teeth.

All children below nine reported that they brush their teeth accompanied by a family member. The majority of them (71%) admitted being forced by their parents to brush. However, when asked about the importance of oral hygiene, we found young children to be well informed about the reasons why one should maintain good oral hygiene.

3.1.2 Limitations

While this study provided some interesting preliminary results, one may note a possible self-selection bias, especially in our adult population. This might have affected the results, as individuals concerned about oral hygiene, and consequently more likely to adhere to healthy behaviors, could be more likely to respond to the survey.

3.2 Interviews

The interviews aimed at a deeper inquiry into children and adults' practices and the social interactions among family members. We interviewed a total of 29 individuals from 11 families, from which 8 were children (ages between 3 and 14 years old). We started by inviting all family members to complete a Day Reconstruction diary (Karapanos et al., 2010) one day prior to the interview. This diary asked participants to reconstruct all activities an individual performed during the past day, from the moment of waking up till the moment he or she went to sleep. This provided us with a rich, situated account of one particular day of the family and served as input to the interview. Interviews took place with all family members present and lasted approximately 20 minutes (See Figure 24). We ended by walking through a typical toothbrushing event in the actual space (See Figure 21, Figure 22 and Figure 23). The survey protocol can be seen in appendix 9.2.

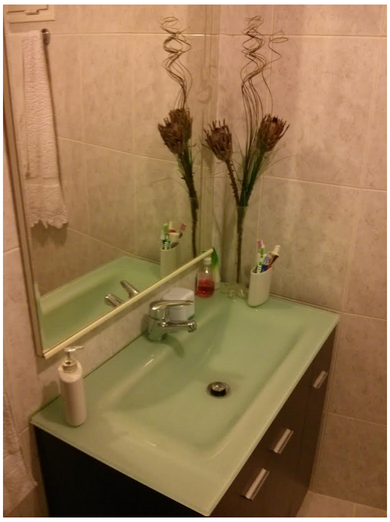

Figure 21 - Bathroom of a respondent

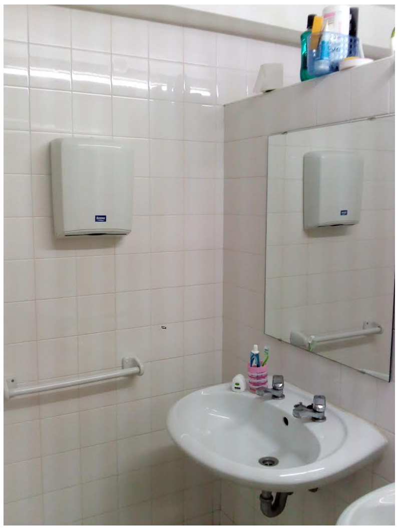

Figure 22 - Bathroom of a respondent

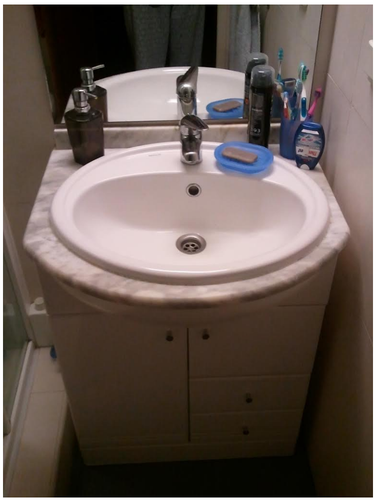

Figure 23 - Bathroom of a respondent

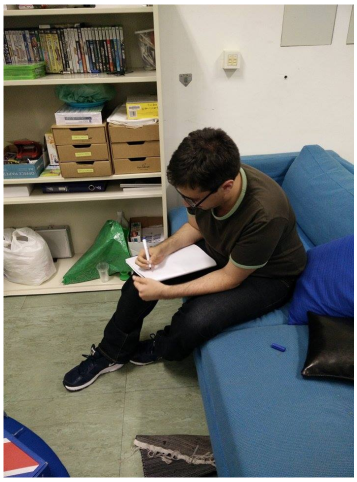

Figure 24 - One of the study participants interviewed

3.2.1 Findings

Overall, the interviews corroborated the findings of the survey with lack of motivation, time constrains and missing routine being critical barriers in individuals' adherence to healthy toothbrushing practices. While some individuals demonstrated lack of awareness on what constitutes a healthy practice ("[P22] I think I own a good oral health... I do not feel like brushing my teeth more than once a day, one is enough..." "[P7] I brush my teeth once a day. Perhaps my oral hygiene could be better"), the majority of participants knew what a healthy practice is, but often failed to adhere to it, attributing this to lack of motivation ("[P7] "People do not have patience, they can even have time to brush their teeth but have no motivation", "[P25] Sometimes I am too lazy to brush my teeth"), time constraints ("[P6] Sometimes people are always in a rush and do not give importance to brush teeth"), or the lack of an established routine ("[P5] I do not have a good toothbrushing routine but at this time I find difficult to change it. I use to try to brush more often but after a few days I tend to forget").

Parents reported employing a number of strategies to help them and their children engage with the task, such as listening to music ("[P6] I turn the radio on every morning and only turn it off when I am leaving home. I think it motivates me to perform my daily practices and I end up leaving home in a good mood"), providing incentives to children ("P[28] "Kids do not feel achieving something when brushing their teeth so we try reward techniques like: if you brush you can choose the movie"), making the task more playful for their children through selecting fun toothbrushes and toothpastes ("P[15] I have a toothbrush with some drawings that I like", "[P26] I like to brush my teeth because I have toothpaste that is very tasty. That toothpaste is cool to swallow" (4 years old), embedding the task in daily rituals ("[P20] "When we are almost done eating mummy asks what we should do next and then we scream brush our teeth!"), brushing their teeth at the same time with other family members ("P[26] I brush my teeth with my brother, it's more fun", "[P6] (...) When children are home, I brush my teeth and wait in the bathroom while they brush theirs."), or simply nudging them ("[P10] (...) with my son, I have to remind him every day. Sometimes he forgets but in others he is too lazy! He needs to get used to it while he is young".

3.3 Summary from the two studies

Overall, the results from the survey and the interviews revealed some interesting findings: toothbrushing is a behavior that can be accomplished more easily in the long term when grounded upon a strong, established routine. This proved to be a hard task and individuals try to incorporate means of playfulness to increase engagement, especially when children are involved. Despite the difficulty to keep supervision and being aware of others family members' behaviors (primarily with dual-income families and rotating work schedules) individuals exhibit concerns about others behaviors and feelings of accountability quickly manifest. As expected, this sense of responsibility showed to be stronger between families that possess a good family dynamic and feel comfortable in sharing their daily practices.

4 The design and prototyping of *Smartholder*

Smartholder was designed with the intention of motivating individuals and the whole family to keep healthy toothbrushing practice. Our intention was to develop a low technological solution that would fit in a normal toothbrushing environment and which could engage all family members through raising their awareness' of each other's practices.

In this section we discuss the design and prototyping of *Smartholder*, a prototype that senses the frequency and duration of toothbrushing practices and attempts to raise family member's awareness of each other's behaviors.

A number of interesting implications for design and concepts emerged from the studies. For effective behavior change the system should hold three main characteristics:

a) A playful, appealing system (visually and functionally) - a playful system is more likely to engage individuals in prolonged periods of time (Karapanos et al., 2010), (Lyra et al., 2013) than one that focuses merely on information presentation, helping to create a routine and joust lack of motivation.

b) Increases transparency – Rather than merely presenting information to individuals, the system should opt to make this information available and visible to all family members through comprehensive explanation about the current behavior, helping increase awareness among them, especially when families hold different schedules. We believe that individuals are more likely to become interested and care about their behaviors if they are faced often to them.

c) Enhances positive communication – Rather that inducing negative self-perceptions coupled with feelings of accountability and guilt, the system should induce positive and playful among family members.

We decided to incorporate an awareness system in a common object, visible to all family members without adding external resources to their environment. We decided to develop a functional toothbrush holder that senses families' toothbrush behavior and provides situated just-in-time feedback through visual cues and support families to communicate and coordinate on desired practices.

Based on our survey and interview results, firstly we decided to focus on frequency and duration as this was most often what individuals were concerned about, what families coordinated upon, and since we noticed that estimating the duration of toothbrushing was not an easy task for individuals. Secondly, we made interaction over the design taking in account the bathroom space and behaviors within, based on our interviews and activity walkthroughs with the interviewed families, leading us to different forms and feedback displays that were modeled into cardboard prototypes (See Figure 25 and Figure 26) as well as virtual 3D prototypes (See Figure 27 and Figure 28). Thirdly, we developed a first working prototype of *SmartHolder* using 3D printing, an Arduino platform and a set of sensors and actuators.

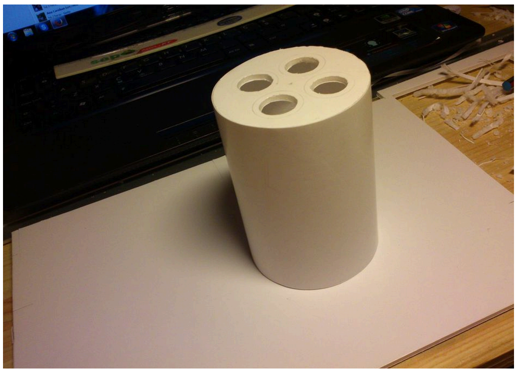

Figure 25 - Early conceptual design

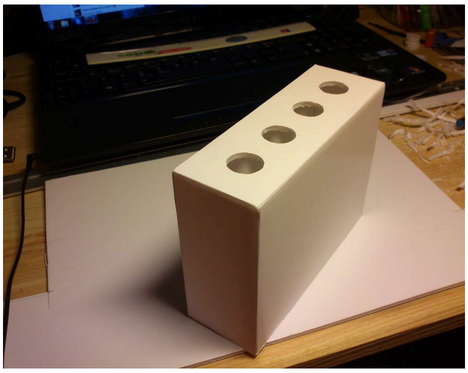

Figure 26 - Early conceptual design

Figure 27 - Rendered 3D holder concept

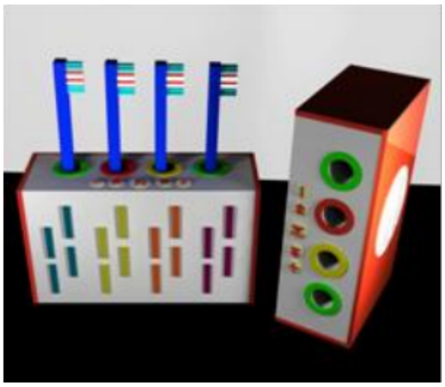

Figure 28 - Rendered 3D holder concept

SmartHolder is a usual toothbrush holder that senses when each toothbrush is (or not) present in the holder through infrared technology. This allows us to log when and for how long each individual uses his toothbrush and provide feedback accordingly.

Information gathered about individuals' is displayed in the holder using light feedback. On the top of the holder, a semitransparent ring that provides information about the user toothbrushing frequency surrounds each hole. On the front side of the holder four LED (Light Emitter Diode) lights per user provide instance awareness of toothbrushing duration; each LED lights up once 30 seconds of toothbrushing having elapsed, recommending a total duration of 2 minutes.

Music and micro-learning audio-clips are played throughout toothbrushing, according to users' preferences and time of the day, helping increase engagement and willingness in the practice of toothbrushing, as we found parents often resource to personalized music while teaching the practice to children to motivate them.

When no activity is detected (See Figure 29 left side), the system does not provide any feedback. After 32 hours the LED does not light up, assuming that the respective user is not in the household.

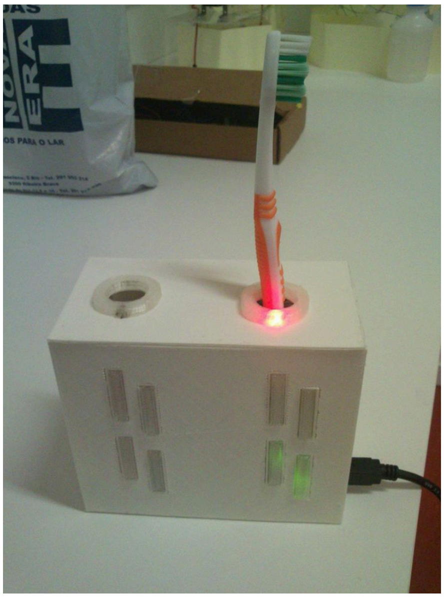

Figure 29 - Front view of Smartholder

4.1 Prototyping the form

This process began with the cardboard modeling. This allowed us to look at designs in various perspectives and quickly prototype different forms while transitioning to a 3D printed object. As a result, viability and realism of the form were tested before printing which allowed us to design a model that met the needs.

The access to a 3D printer allowed us to produce the intended design concept. The design was drawn using *Google Sketchup* platform (Sketchup, n.d.) and a SLT (STereoLithography) extension (SketchUp, n.d.) was installed to convert the 3D design in a format acceptable to the Ultimaker printer 3D. In the chosen design we adopted a rectangular shape and the representation of two family members (Figure 30 shows view the chosen design). It was decided to split the holder on different parts to help later in their subsequent assembly (See Figure 31, Figure 32 and Figure 33).

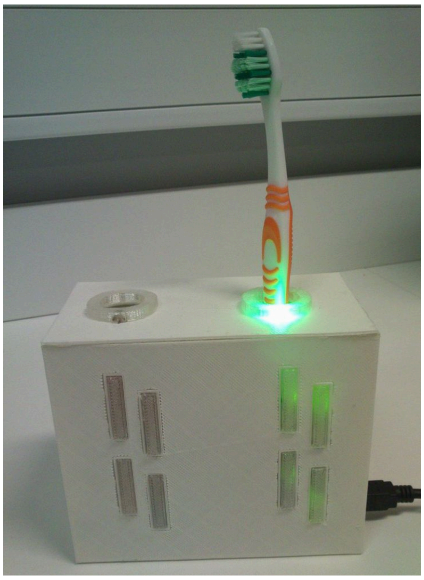

Figure 30 - Smartholder indicating the user of the right side had brushed at least twice for 2 minutes

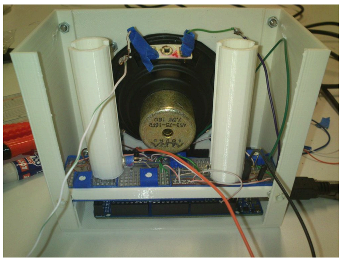

Figure 31 - Smartholder arrangement

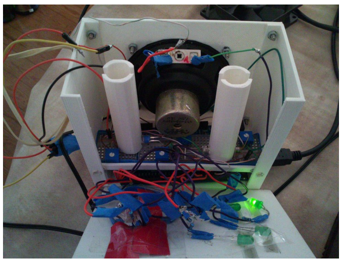

Figure 32 - Smartholder arrangement

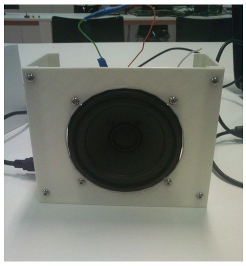

Figure 33 - Smartholder arrangement

4.2 Prototyping the function

We developed this prototype using the Arduino platform (Arduino, n.d.), an open-source physical computing platform that allows the rapid prototyping of interactive technologies that combines hardware (using a wide range of input sensors) and software. We choose this environment for its flexibility, cost and ease of prototyping. Of all models available, we chose an Arduino Mega as it contained more digital output pins than others models, which allowed us to directly, connect all the LEDs and components we needed (*Smart holder* uses on the whole 15 output pins) and allowing us to be able to simply add features in the future without recourse to other hardware components. To build this prototype, it was needed the following material to represent two users: Arduino board, RGB (Red, Green, Blue) LED, infrared pair, low power audio amplifier, speaker, resistors and MP3 Music Player (see more in appendix 9.3). Mounting the holder required screws, welding wire, soldering iron, glue and wire wrapping.

4.2.1 Sensing behaviors

To infer the presence of the toothbrush we considered a number of alternatives such as the use of a pressure sensor, a button and a piezo vibration sensor, however an infrared solution turned to be a simpler and more precise solution to detect the object. For this purpose we used an infrared pair (emitter and receptor) and defined a threshold of one and a half centimeter (which reflects the distance between the emitter and the receiver). This provided enough space to place a normal toothbrush.

Through placing the Infrared emitter and detector pairs, in the bottom of the holder, we were able to detect when the toothbrushes were or not in the holder, thus they acted as proximity sensors.

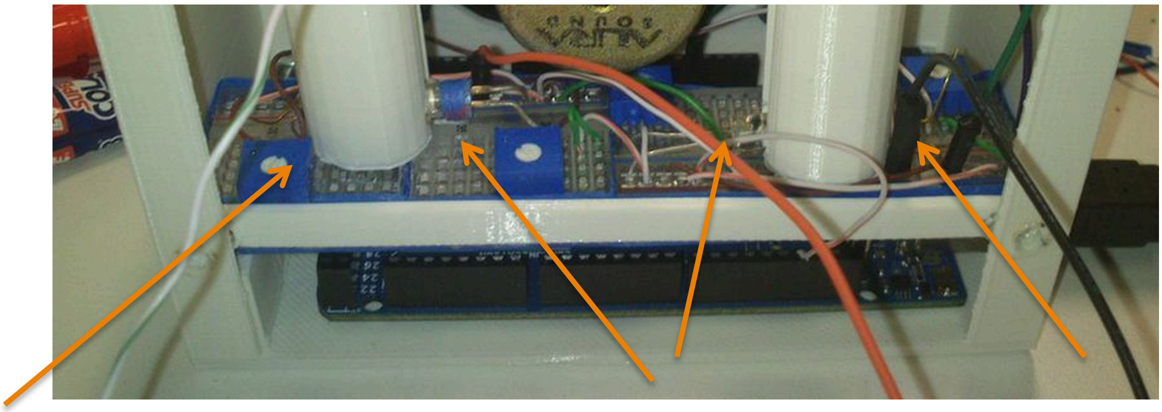

Figure 34 - Infrared pairs position indicated through the arrows

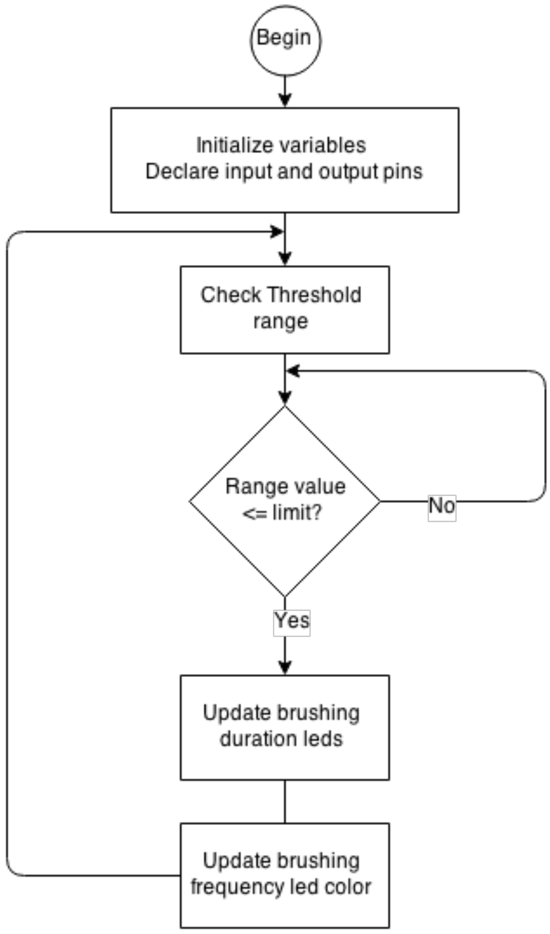

Figure 35 - Toothbrush detection operation

4.2.2 Providing feedback

We decided to provide glanceable information about users behaviors through light feedback. We provide feedback about users frequency and duration. Each user requires an RGB LED to represent his frequency and 4 simple LEDs (LEDs that provide only one color) to represent his toothbrushing duration. Frequency is represented through a ring situated around the toothbrush tube hole:

Three status indicators provide frequency feedback:

- Good frequency – User brushed at least twice for the last 24 hours. Color reflected in the ring is green (See Figure 36);
- Medium frequency - User brushed once for the last 24 hours. Color reflected in the ring is yellow;
- Bad frequency - User did not brushed on the last 24 hours. Color reflected in the ring is red. See Figure 37.

The reasoning for this process is represented in the following fluxogram, see Figure 38

Figure 36 - Good frequency reflected on the holder

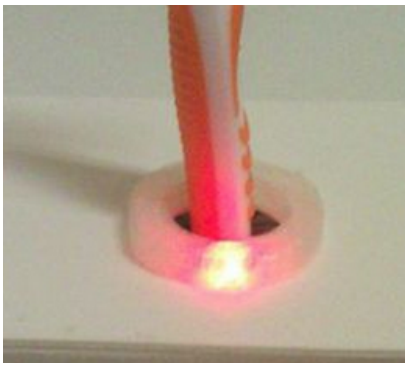

Figure 37 - Bad frequency reflected on the holder

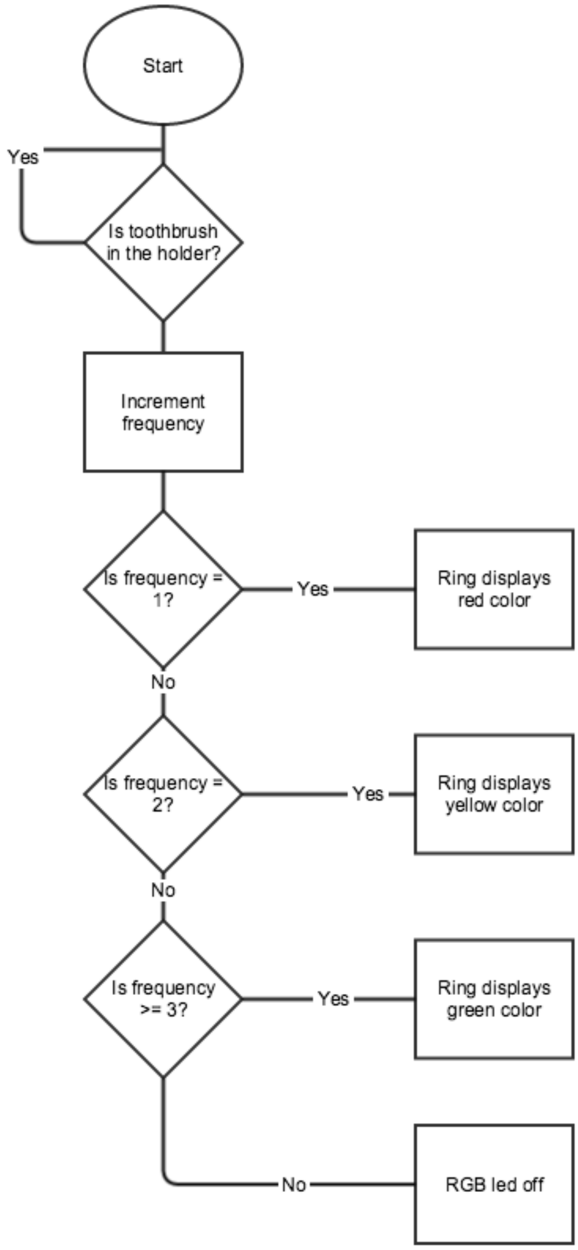

Figure 38 - Frequency operation logic

User toothbrushing duration requires 4 LEDs. Each LED represents 30 seconds that elapsed, making a total of 120 seconds, the two minutes toothbrushing duration recommended by professionals. While the interval time occurs, the corresponded LED blinks – if user is brushing for twenty seconds, the bottom LED blinks (see Figure 39) until time is lower than thirty seconds. If second LED (from the bottom) blinks, means that the time is between thirty seconds and sixty seconds. The same reasoning applies to the remaining LEDs. This information is reflected in the central region of the holder.

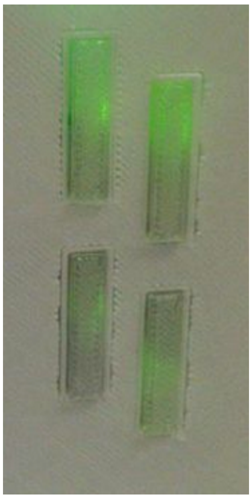

Figure 39 - Duration of at least 2 minutes displayed on the holder

The reasoning for this process is represented in the following fluxogram, See Figure 40.

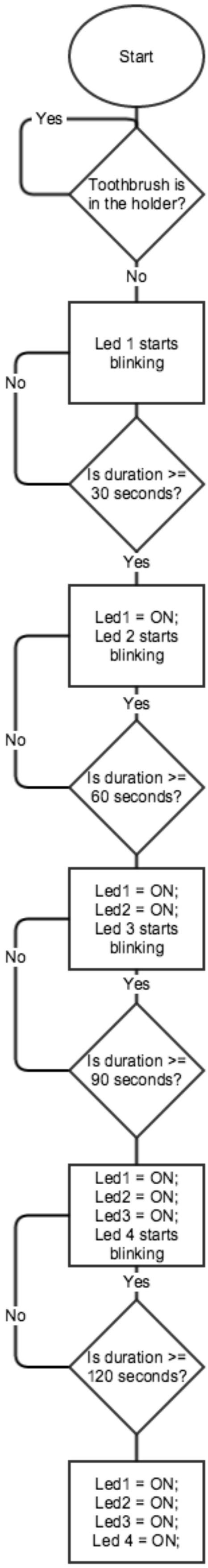

Figure 40 - Duration representation process

To include music and micro-learning clips in the prototype, we decided to adapt an MP3 player chip instead of adding a music player shield since they provide similar features and the chip was more affordable. As the sound output was low, we build an amplification circuit to increase the volume of the sound; this was controlled directly by the MP3 interface. The audio content was controlled through a SD card. The connection between the MP3 player chip and the speaker/amplifier circuit was made using an audio jack.

For a clear understanding, we provide following schematic of the designed circuit along with the final result achieved (see Figure 41 Figure 42).

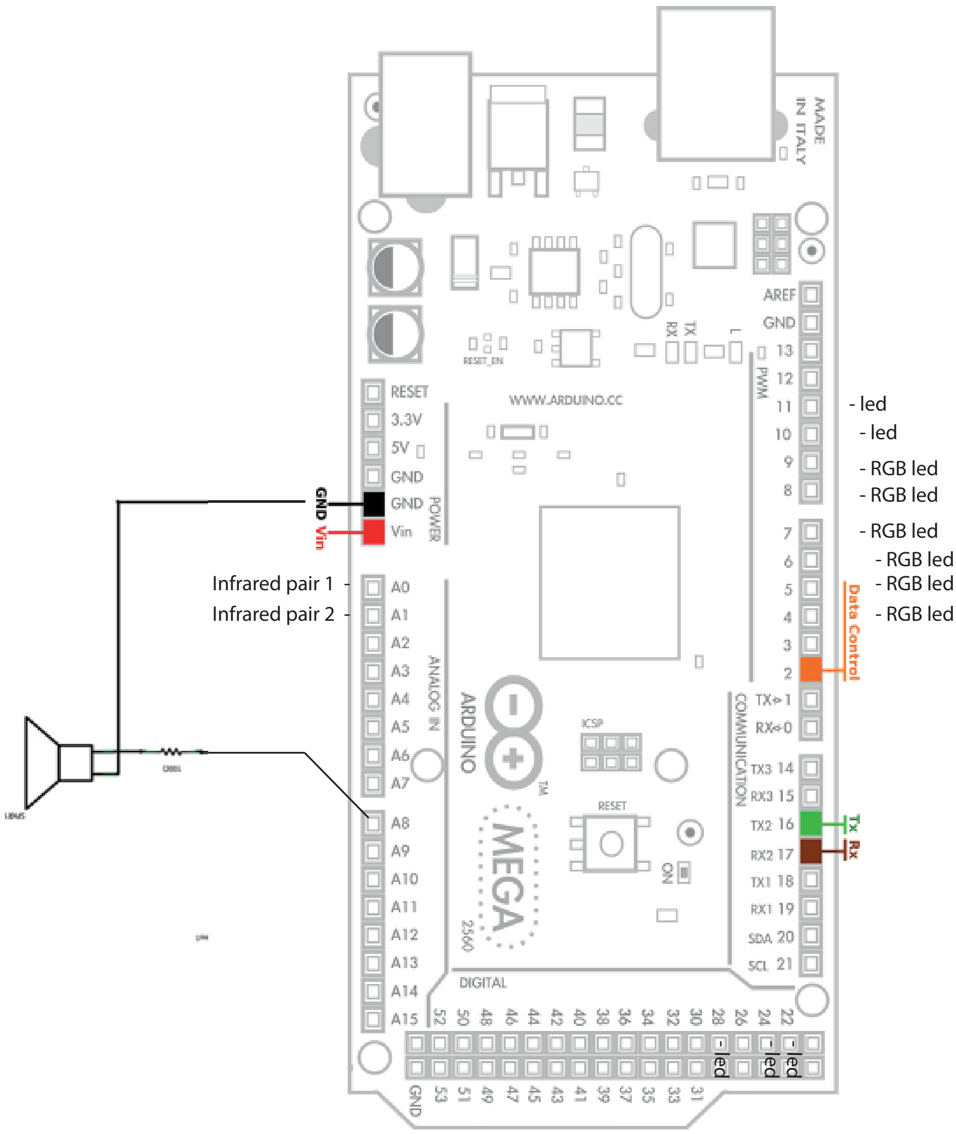

Figure 41 Smartholder schematic -

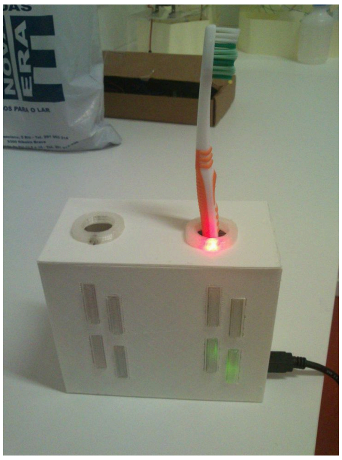

Figure 42 - Front view of Smartholder

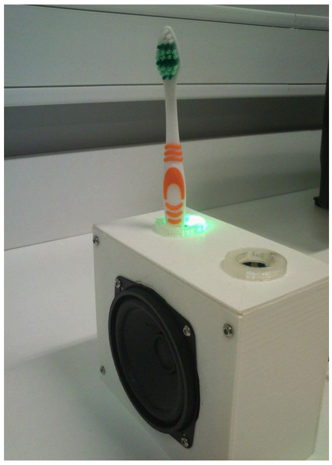

Figure 43 - Back view of Smartholder

The following scenario describes a possible use-case of the Smartholder system. “It's 8 pm, Maria enters the bathroom she notices a yellow light around her son's toothbrush. She realizes that her son only brushed his teeth once today. She checks for how long he brushed his teeth, the two lights that remain turned on, warn her about his poor practice today. She seeks him to encourage him to brush his teeth. Feeling empowered by his mother's words, Joao goes to the bathroom and while practicing he choose his favorite song, which will play until the toothbrush holder lights stop blinking”.

4.3 Discussion

In this chapter we described our first approach to the design of a persuasive system that aims at leveraging families' existing mechanisms for behavior change.

Firstly, we analyzed individual's needs towards adhering to a proper toothbrushing practice. This analysis provided insights about what kind of information individual's link to, when talking about toothbrushing behaviors. This allowed us to define a goal statement: the design of a system that raises awareness about the frequency and duration of toothbrushing among family members.

Secondly, we proceeded analyzing the context where the approach could be set in order to conceive the conditions that the system should support. Based on these outcomes, we defined the system requirements. This step was intended to evaluate what would be the best way to provide information that supports interactions; what kind of system could meet user's needs and how the system could be deployed by defining the strategy addressed for the design process.

Thirdly, we proceeded to the prototype development and further evaluation to estimate it efficiency. We developed a toothbrush holder able to reflect the frequency and duration about users behaviors, creating awareness thereon. The prototype evaluation allowed us to observe how interactions could be supported through the feedback provided in the environment. Although the requirements were translated and covered in the prototype design, the evaluation provided valuable feedback on technical issues. For example, the system had no way of knowing whether the inserted brush was from another user. This could lead to misinterpreted information if family members exchanged their toothbrush positions in the holder (for tampering or unconsciously). Also, the holder did not support different toothbrushes, such as the electric toothbrush. Though the prototype could be adapted to overcome these barriers, we considered that users no longer would use it since the electric toothbrush charges the internal battery with their own holder.

However, the recognition of these issues/needs allows us to reach at a better concept, to design a toothbrush extension to each family member. This evaluation also lead to new emerging ideas and revealed an unseen opportunity, by taking advantage of the toothbrush extension to evaluate users toothbrushing motion performance in addition to the frequency and duration.

5 Social Toothbrush: Sensing duration, frequency and performance

Through the previous prototype we acquired substantial knowledge about the pitfalls and advantages of the Smartholder approach. This resulted in the refinement of the design requirements, since while the evaluation was conducted some opportunistic ideas emerged. As the idea of the toothbrush extension shown to be capable of fixing the existing problems, we explored how this could also be tapped to better represent individual's toothbrushing behaviors. Due this information, we made a more in-depth research about the predictors for oral cleanliness. We found out that despite the importance of frequency and duration, toothbrushing performance revealed to be an important factor, especially due to the difficulties individuals face in identifying and adapting a proper brushing motion. This lack of proper performance proved to reflect substantially in individuals' oral hygiene deficit (Harnacke et al., 2015).

Based on this knowledge, we decided to take one step further and include the ability to infer toothbrushing performance by the technology. With the goal of helping individuals' acquire, change or improve also their toothbrushing technique, we aim to identify individuals' toothbrushing capabilities and styles to display information there on (in real time and through reflection). Thereby, we wanted to provide a learning system that could provide not only comprehensive information to encourage discussions among family members but also support individuals in times of absence of family interaction with a persuasive system. Focusing on individuals that lack a proper or suitable practice, our goal was again raise their awareness of individual's performance to adhering to proper behaviors. We wanted to provide a learning system that could not only provide information that could cue discussions within the family, but also support individuals in times of absence of family interaction.

5.1 Design

Through the analysis of the refined requirements, a new need was identified: identified unequivocally each individual's toothbrush. As a result of concepts emerged, the developed system embraces a toothbrush extension that track users' toothbrush practices and specifically with regard to their frequency, duration and performance. This extension includes a number of electronic components, such as motion sensors, a bluetooth module, a real time clock and is attached to a regular electrical toothbrush. It makes use of the electric toothbrush charger to recharge the extension battery. Toothbrushing behaviors are logged through the extension piece providing visual cues both in the toothbrush extension and in a mobile application. This hardware communicates with Bluetooth with a mobile app, which provides detailed feedback to individuals and others family members.

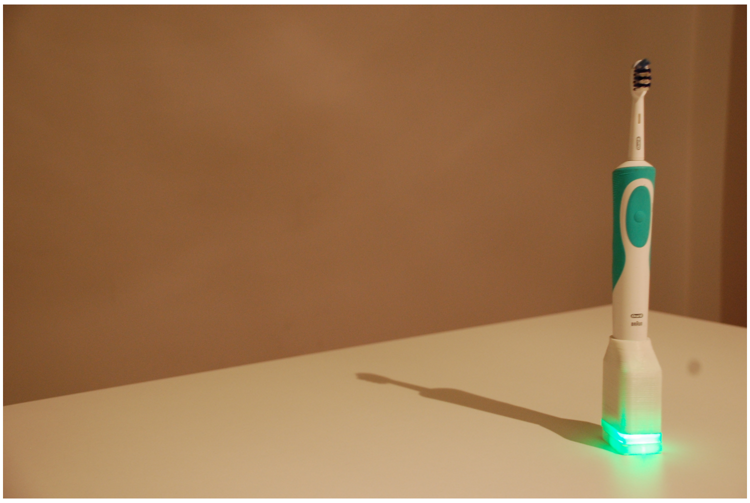

Figure 44 - Social Toothbrush

5.2 Development

The toothbrush extension system monitors and reflects users toothbrushing behaviors through feedback from a toothbrush extension and a mobile application. Through just in time, reflection and ambient feedback we aim to motivate individuals to adhere to a healthy oral practice.

For the development of the prototype, the main system was divided in two different subsystems that communicate between them, the extension and the mobile application. The extension is intended to track users performance, duration and frequency and the application aims display just-in-time information about individual's practices.

The extension required the development of a toothbrushing pattern classification. Through this information, we can track for how long individuals brushed and identify if the user was able to achieve a good a proper performance. The system also required the hardware implementation of the toothbrush extension so that it could met our needs (mostly in terms of operation and size).

5.2.1 Sensing users' behaviors

Our toothbrush extension collects information of a wide range of sensors through which we use to sense users' behaviors. Through an accelerometer and a gyroscope we were able to sense toothbrushing movements and identify the areas of the mouth that were brushed. This allowed us to infer user performance, along with the corresponded frequency and duration of toothbrushing practices. Behaviors were logged and communicated to the application when the smartphone was in range.

5.2.1.1 Tracking Performance, patterns classification

We combined information from a 3-axis accelerometer and a 3–axis gyroscope. This means, to infer that it was possible to calculate the angles in three dimensions and process fusion algorithms (which combines readings from different sensors to obtain a more reliable result) as movement detection (Leds&Chips, n.d.). Our goal was to calculate angular displacements (rotations around a fixed point measured, in degrees) of the toothbrush and match this information with the mouth areas.

Our first goal was to identify the mouth structure, in particular, how many regions could be distinguished and in with what accuracy. A clinical classification for mouth regions was performed for this purpose. This classification divides the mouth in four quadrants. Two for the upper teeth (right maxillary and left maxillary) and two for lower teeth (right mandibular, left mandibular). Sixteen regions (in the four areas) are also classified as it can be observed in Figure 45.

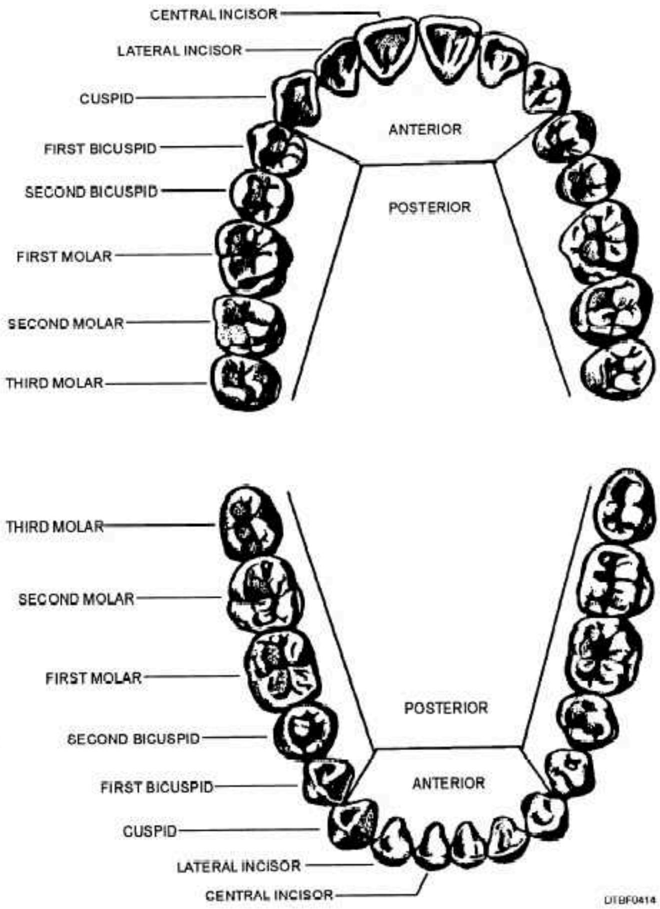

Figure 45 - Mouth classification

For our own purpose we decided to divide mouth regions with this classification presented in Figure 45.

Our second goal was to detect the toothbrush movements. We used Arduino for data acquisition and computation. Also, processing (Processing, n.d.) for the 3D visualizations. The communication between the sensors module and the Arduino was done through the I^2C (Inter - integrated Circuit) protocol (Sparkfun, n.d.) and communication between both Arduino IDE (Integrated Development Environment) and Processing IDE was made through serial port. For the region recognition, our goal was to map the information to the relative of the toothbrush to the mouth area. To simplify this relation, we aligned the coordinated frames of the toothbrush and the sensors module. For a more clear understanding (see Figure 46) on which the sensors module is represented in the toothbrush by the red color shape. The orientation of the sensor module in relation to the toothbrush is represented in Figure 47 and it can also be observed in Figure 48.

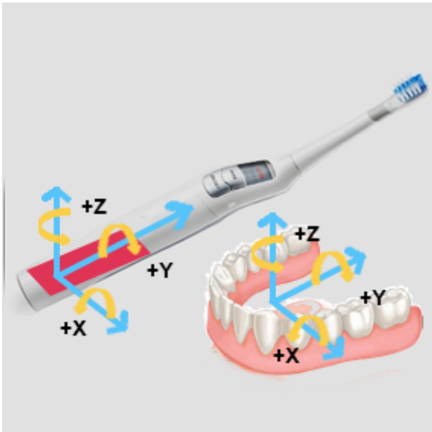

Figure 46 - sensor, toothbrush and earth (represented by the mouth) references axis

Figure 47 - The position in which the sensor is located in the toothbrush

Figure 48 - Sensor attached in the toothbrush initially for testing -

In order to confirm that the coordinated frames (reference axis) were aligned as desired and to check if data provided matched with the observed movement, a 3D toothbrush representation was designed and displayed in the Processing environment. This also allowed us to observe the drift of the gyroscope, which is an important problem as data ceases to be reliable on the long-term. We verified that over time, the drift increases and do not go back to the initial position when this situation is notice. Accelerometer instead, presents errors at the beginning of the representation but then stabilizes. However, both showed faults in some inclinations transition, which causes the representation to disappear since it cannot find data.

5.2.1.2 Data acquisition and filtering

Initial measurements obtained from the sensors module provided unstable data. A filter was then needed for stabilization specially. Considering the accelerometer and gyroscope limitations, errors in the short term (from the accelerometer) and long term (from the gyroscope), the best solutions was to adopt a *Kalman* filter to obtain reliable data for the angular position of the toothbrush. A *Kalman* filter is a sensor fusion algorithm highly endorsed for orientation tracking systems, since it combines the inputs of different sensors for accurate information about position and orientation (Corrales et al., 2010). This filter improves stability and performance, by estimating neglected measures that occurs while data is being read, predicting current values of interest. This is done through a set of mathematical equations which recursively can estimate data regarding current and priori measurements and target errors statistics (Welch & Bishop, 2006).

Since the chosen microcontroller allows mathematical calculations as trigonometric functions, and is additionally capable of computing floating-point math, it was possible to adopt it for the project. To this purpose we used Kristian Lauszus library (Lauszus, n.d.). The filter used, corrects transition faults and removes the drift from the gyroscope (since it verifies when the drift is wide and resets the value to the original position). In the following image, one can assess the impact of the *Kalman* filter (den-uijl, n.d.). Smoothing the sensors readings reflects in a lower ripple. On may notice on the top wave of Figure 49 the differences between the black line (*Kalman* filtered) and the light blue line (no filter applied). The same happens in the lower wave. The sensors specifications set can be seen in appendix 9.6.

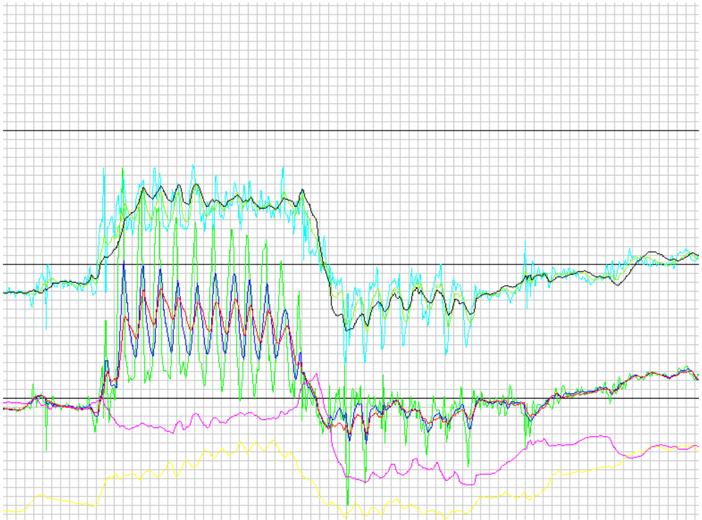

Figure 49 - Comparison between sensors reading after a kalman filter is applied. Black line represents Kalman x, red line represents Kalman y. The remaining lines represents non-filter values: yellow represents gyroscope x-axis, green represents accelerometer x-axis, purple represents gyroscope y-axis and the light blue represents accelerometer y-axis.

5.2.1.3 Toothbrush movements classification

The orientation is defined by the angle in which the toothbrush bristles against a fixed coordinate frame (reference axis) defined.

For an initial categorization, we defined four toothbrush positions, which refer to the orientation the toothbrush bristle is pointing: up, down, left and right (See Figure 50, Figure 51, Figure 52 and Figure 53 (Lee et al., 2012).

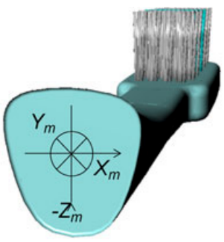

Figure 50 - Brush UP

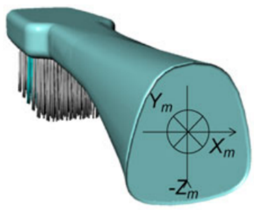

Figure 51 - Brush DOWN

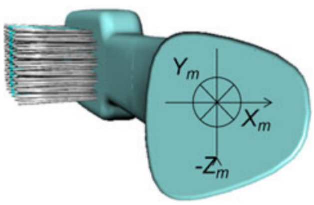

Figure 52 - Brush RIGHT

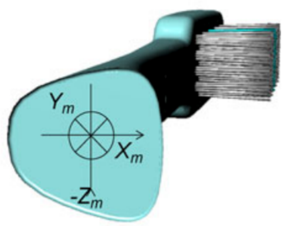

Figure 53 - Brush LEFT

In order to interpret the relation between values in different axes, we decided to analyze them and group them in certain range of values. We displayed the waveforms of sensor readings using Processing (during a simulated toothbrushing) and based on our thresholds, we obtained and identified position patterns. Figure 54 shows the waveform of the angular position through the x and y-axis. In Figure 54 electric toothbrush acceleration is not presented but was considered when intervals were defined.

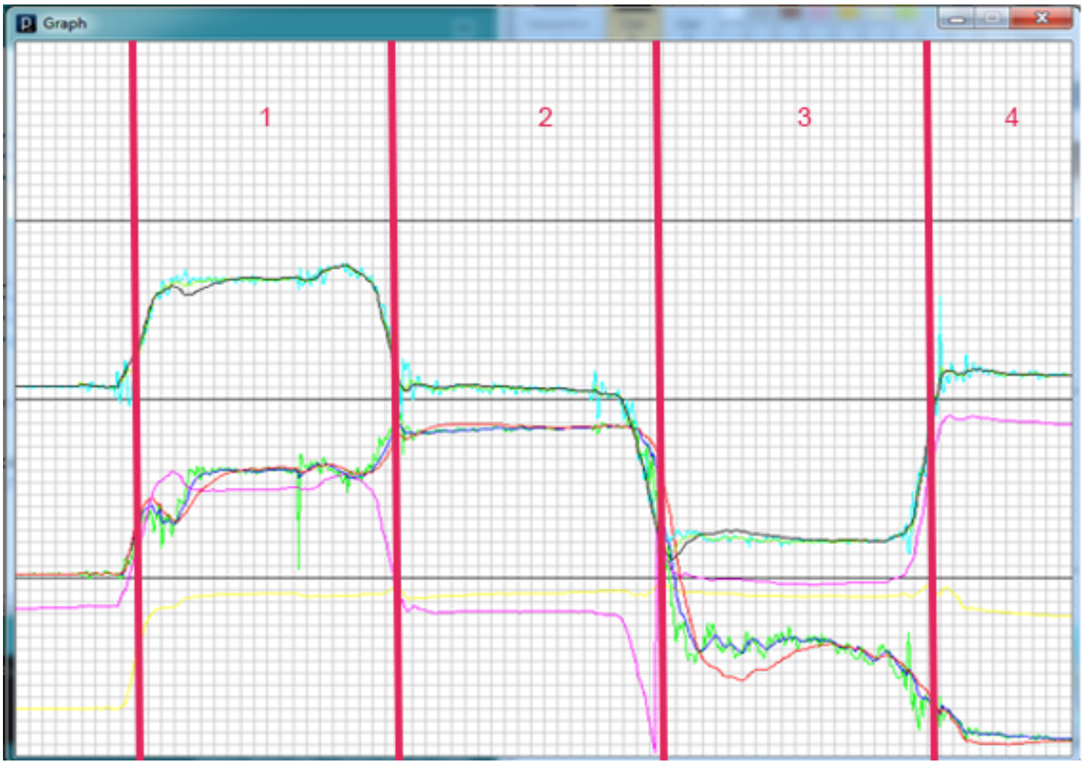

Figure 54 - Sensed waveform of the sensors data. 1 correspond to left, 2 to up, 3 to right and 4 for down. Black line represents Kalman x, red line represents Kalman y. The remaining lines represents non-filter values: yellow represents gyroscope x-axis, green represents accelerometer x-axis, purple represents gyroscope y-axis and the light blue represents accelerometer y-axis.

These position patterns were defined by intervals covered by the parameters as shown in the following table:

Table 3 - Region position variables threshold

Kalamn x – Kalman y	**>= 100**		**< 100**		**< 100**
Kalman x	< -35	>= 35	> 20	<= 20	<=20
Kalman y	-	-	-	< 80	>=80
Value	‘	0	2	1	4
Posture	Left	Down	Right	Up	Initial

In the Table 3, *KalmanX* and *KalmanY* stand for the mentioned axes angles. *Value* refers to the unique identifier of a specific pattern and *posture* refers to the position where the toothbrush is pointing.

Toothbrushing practices are susceptible to many movements/transitions and consequently, different patterns identifiers could be presented in a short time while a brushing action is being performed. To avoid noise from the transitions (for example, when the toothbrush position changes from up to down), the toothbrush position was only considered if the pattern identifier was constant for at least 1.3 seconds; this was done with a constant comparison between the current value and the previous value.

5.3 Validation of the approach

To test at to what extents each of these classifications are efficient with others users, we asked seven individuals to brush their teeth with the sensor attached on their toothbrush. Toothbrushing behaviors were video recorded. Simultaneously, we logged the graph patterns, the recognized position, brushing movements (in a text file), and we took pictures every three seconds (see Figure 55, Figure 56).

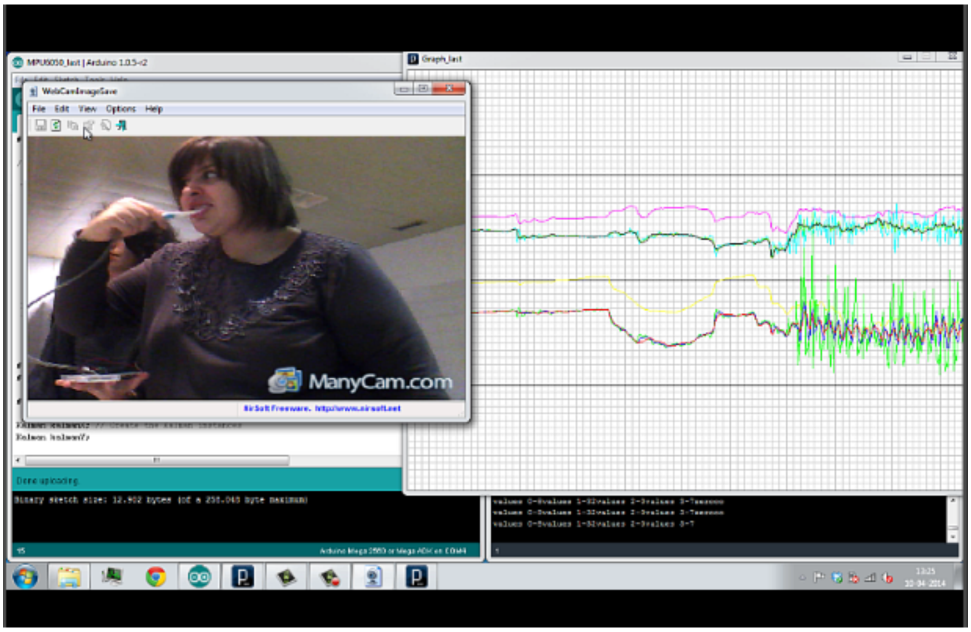

Figure 55 - User toothbrushing an upper mouth area

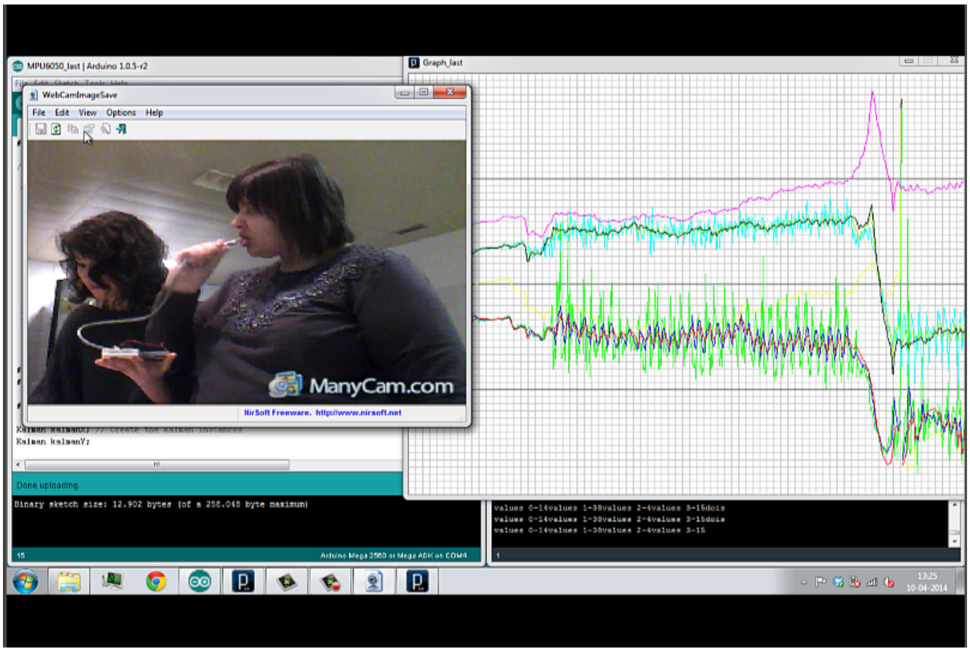

Figure 56 - User toothbrushing the right side of the mouth after brushed the upper side

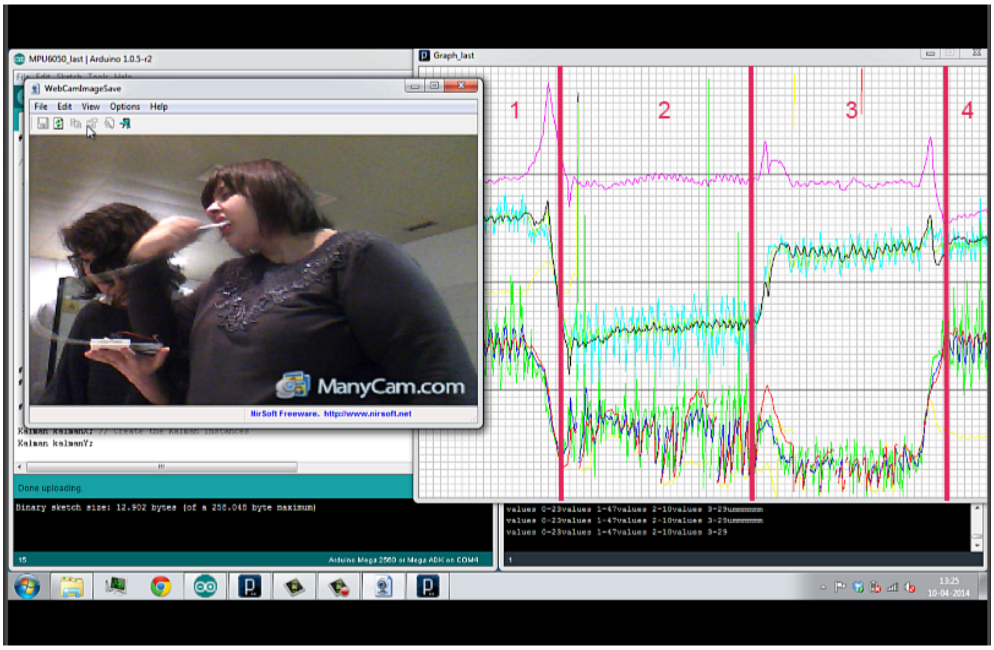

Figure 57 - User toothbrushing behavior, 1 represents left, 2 represent right, and 3 represent bottom and 4 represents up

To measure toothbrushing styles and performance, it was also important to analyze the inner mouth areas. For the inner recognition we needed to measure the left and right toothbrush positions and to observe the differences in the y-axis. The outer areas proved to be easier to classify than the inner areas - some ambiguity was noticed in the inner regions of the mouth. Despite the complications in distinguishing these areas accurately while the toothbrushing practice is performed, we were able to collect some insights. What follows is our early attempt to analyze them:

Kalamn x	**15 < x < 65**	**X < -15 && x > -65 < 100**		**X >15 && x < 65**		**X < -15 && x > -65**
Kalman y	Y	Y && <= 30	Y && x >30	Z && x <160	Z && x >= 160	Z
Value	4	5	8	6	90	7
Posture	Upper	Upper	Upper	Down	Down	Down
Orientation	Right	Left	Right	Right	Left	Left
Side	Outer	Outer	Inner	Outer	Inner	Outer
y = x <100 & x > -100 z = x < -100 & x > 100						

Through combinations of these insights we manage to categorize altogether ten areas: up left out, up left in, left, up right out, up right in, right, bottom left out, bottom left in, bottom right out and bottom right in. However in latter version of the prototype we took into consideration initial position, up left, left, bottom left, up right, right and bottom right since provided more accurate and reliable data.

5.4 Logging user behaviors in the extension

As the toothbrushing practice is being performed, we logged the time the user spent brushing in each mouth area. The performance is classified into one of three categories - good, medium and poor- based on the time the user spent brushing each area. A good performance is accomplished when the user brushed each area for at least the minimal recommended time, thirty seconds since the mouth was divided in 4 areas. For example, if the user brushes for at least thirty seconds all four areas, it is considered that he accomplished a good performance. However, if he brushes one of these areas for twenty-nine seconds or less, he achieves a medium performance. If the user brushes any mouth area from ten to thirty second, it is automatically considered that he accomplished a medium performance. Lastly, if the user brushes any area for less than 10 second, he achieves a bad performance.

The system performs a continuous comparison of the current position to the initial position, as soon as the positions are identified as different from each other, for at least seven seconds, we consider the user is brushing his teeth and a timer starts. We decided to allow this timeframe for the user to add toothpaste. This counter is also used to measure the total duration of the practice. The comparison between current and initial position, allows us also to detect when the user stops using the toothbrush (based on the assumption that is left on the charger). When the practice is over, meaning that the toothbrush is placed back in the charger and it is in the initial state, the data is logged. This happens when the system detects the initial position for at least four seconds.

All in all, the system logs when, for how long, and the overall performance of each toothbrush on a given day. Log file is stored in the SD card. The reason for that is that the frequency value needs to be incremented bases on preceding toothbrushing in the last 24 hours.

5.5 Hardware

5.5.1 Standalone circuit

As in the case of *Smartholder*, we designed and 3D printed our extension model based on the designed circuit measures. To achieve this, we used Inventor 3D since proved to be a more powerful tool to draw certain characteristics necessary in this system than *Sketchup* (Sketchup, n.d.). We decided to develop the extension for an oral b electric toothbrush (reviews, n.d.). We split the piece in three components to facilitate the assembly.

In order to create a more stable extension, minimize the prototyping cost, size, and create a circuit that best suits the needs of the project, we decided to not use an Arduino board as we did in the *Smartholder*. Instead we created our own Arduino compatible circuit with the microcontroller ATMEGA328p and the Arduino environment, platform tutorials and recommendations were followed. To transfer the code to the microcontroller we boot loaded the *Atmega* chip using an Arduino Uno board. For each extension we used the components listed in appendix 9.4.

The standalone Arduino construction was based on the circuit showed on Figure 58 (City, n.d.).

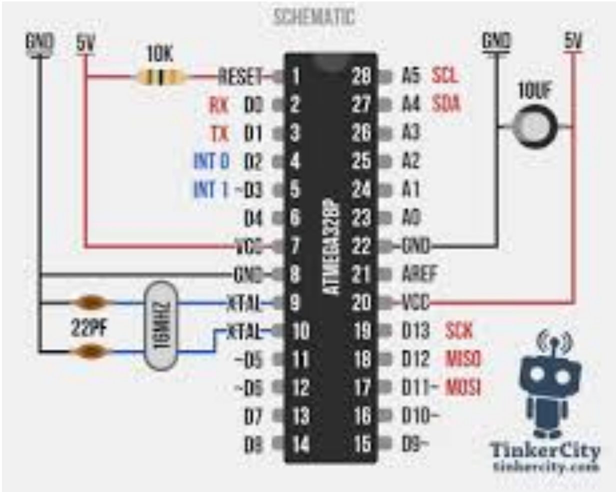

Figure 58 - Breadboard Arduino circuit

However, some changes were made: to provide stability/robustness we replaced the breadboard by soldering the parts to the PCB (Printed Circuit Board), expecting that the prototype will be subject to quite a few movements. We also replaced two capacitors and the crystal by a resonator since they perform the same actions, which resulted in having fewer components for welding, which facilitated the prototyping. We obtained the following circuit; see Figure 59 and Figure 60.

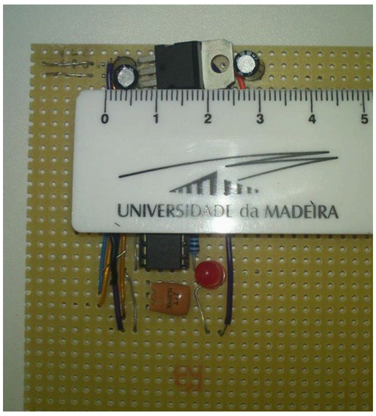

Figure 59 - Constructed circuit and its measurements

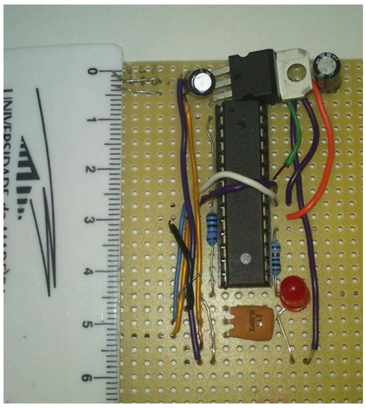

Figure 60 - Constructed circuit and its measurements

The sensors and actuators were tested and attached individually to this circuit: triple axis accelerometer & gyro, Bluetooth module, SD (Secure Digital) Card module and RTC (Real Time Clock).

The SD card module is used to log information about users' behaviors and ensure that no data will be lost the case the battery drains out. The following two fluxograms reflect the logic of reading and writing operations (See Figure 61 and Figure 62).

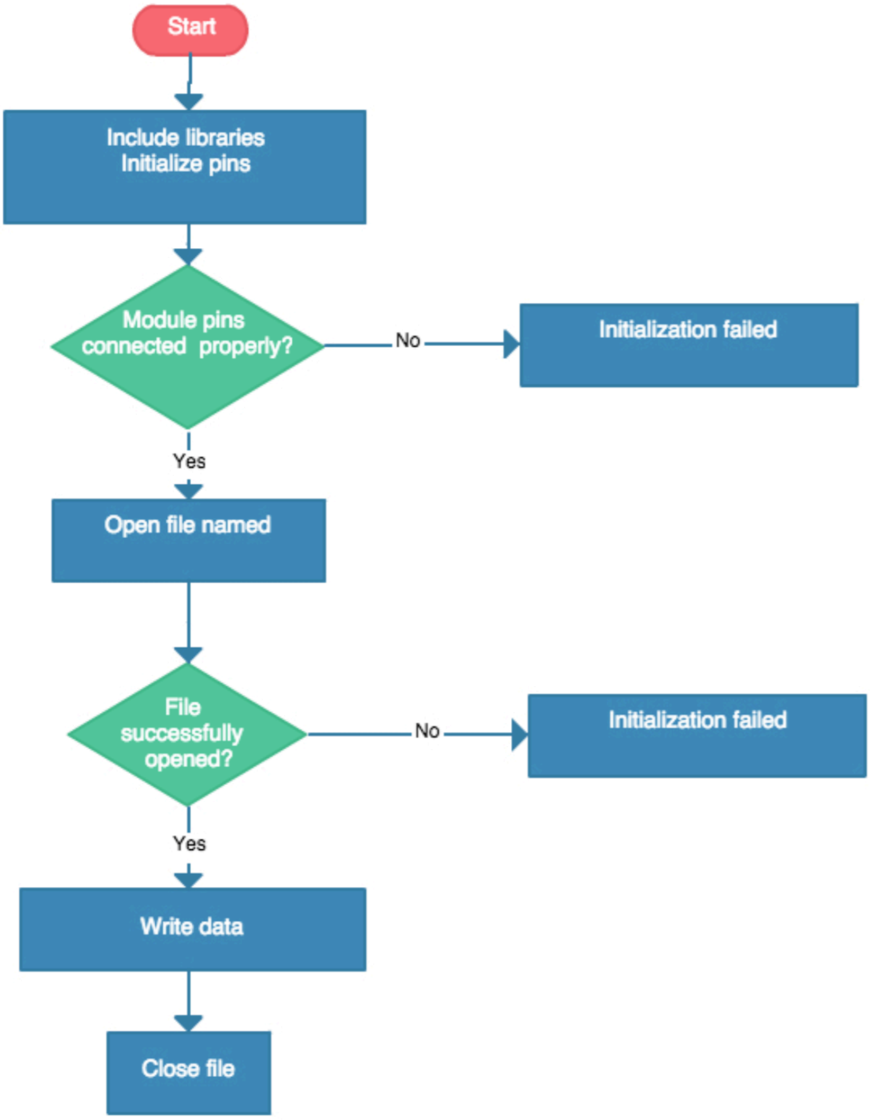

Figure 61 - Writing operation logic

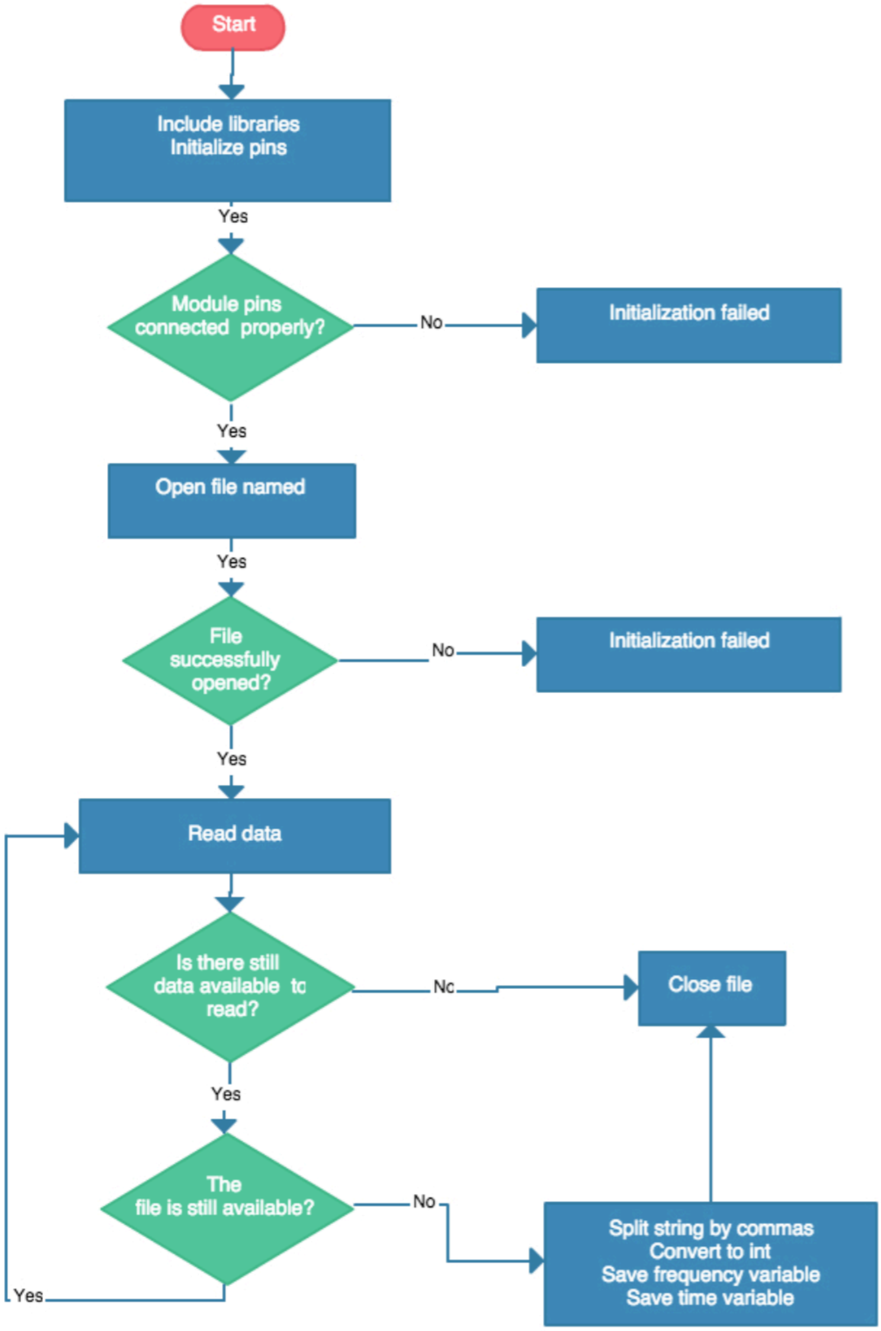

Figure 62 - Reading operation logic

To deliver accurate information about date, time and interval between user behaviors we use a real time clock. A Bluetooth module allows us to establish the communication between the extension and the mobile application, through the communication channel generated data is broadcasted and updated in real time. In Figure 63 follows its behavior:

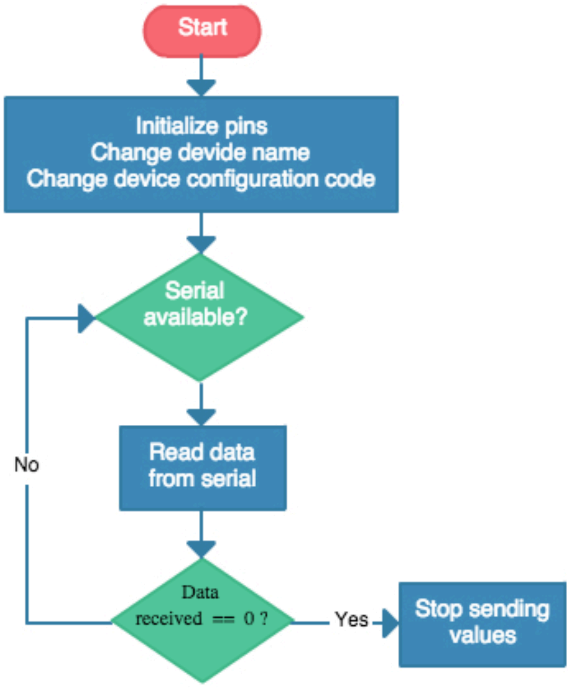

Figure 63 - Bluetooth communication fluxogram

For a clear understanding of how these components connect, we present the schematic into Figure 64.

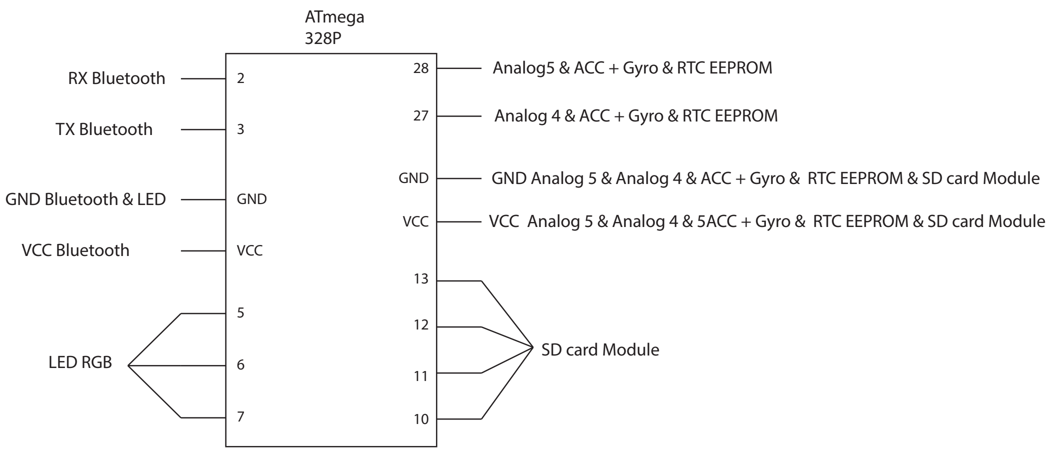

Figure 64 - Schematic with the required components

One may however notice that the regulars input pins for the clock and the MPU, match, since they both have the I^2C address 0x68, and this precludes the sensor reading. As the RTC clock address is unchangeable, the MPU address was modified (either by hardware and software) to the I2C address 0x69. To do this, instead of connecting the MPU VCC to the circuit VCC, this pin is not connected to the circuit and instead we attach the AINT0 pin to VCC. Another solution could be to use a multiplexer, but this requires an extra hardware component.

5.5.2 Power Supply and Charging

As most input and output modules requires being powered by 3.3V, we decided to power supply the circuit with a lower voltage - a 3.7V– instead of 5 to 9V. This was possible since the operating voltage for the microcontroller is from 1.8V to 5.5V and therefore instead of using a voltage divider at the output of Arduino we adapted the circuit to receive 3.7V at the entrance. This was possible by replacing the voltage regulator for a low-dropout regulator, from 5-V to 3.3-V. This enabled us to reduce power consumption and to not waste much power since all of it is consumed. It also helped us to handle all sensors and actuators properly guaranteeing that they will not be damaged. See Figure 65 for a better understanding

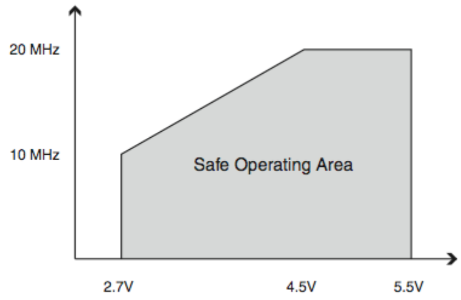

Figure 65 - Safe operation area of the needed sensors

To increase the system autonomy, we power supply the chip with a 3.7V battery creating a portable system. As the battery consumption is high, the battery charging was a mandatory requirement. The recharging is done inductively (wirelessly) through the charger from the electric toothbrush when the extension is placed on top. There were three main reasons that led to this decision, first is to take advantage of existing resources; secondly to create a wires free system, and lastly, to isolate the circuit as much as possible. Since the extension would be in constant contact with water, exposed contacts would be an issue. Some disadvantages however arise using this approach: some heat is wasted; the charging process is slower and increased the complexity in prototypes building (Wikipedia, n.d.).

5.5.2.1 Inductive charging

Inductive charging allows electricity to flow between an emitter (primary coil) and receiver (secondary coil) through an electromagnetic field without the need of any kind of conductive component (Powermats, n.d.). The toothbrush charger contains the primary coil, responsible for creating the electromagnetic field by an alternating current, the energy that is provided by the power supply. This induces a voltage in the secondary coil, located in the electric toothbrush. These two coils as a whole form a transformer (works, n.d.).

For our own use, we needed to replicate the circuit that lies on the toothbrush: a secondary coil and a wave rectification circuit to convert the power coming from the primary coil to electrical power.

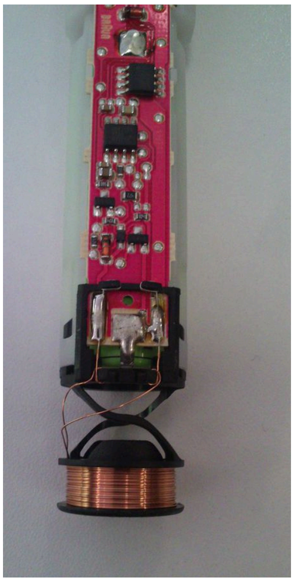

Figure 66 -- Interior of an electric toothbrush where the secondary coil can be observed

5.5.2.2 Secondary coil

As we wanted to extract a voltage output around 5V - more than what it was needed, such that, in case there were losses it would guarantee that output voltage remains adequate - we needed to replicate a step-down transformer. Such transformers decrease the voltage from the main/load to the secondary coil applying fewer turns in the secondary coil than in the primary coil.

The relationship between the voltage and current needed to analyze in order to obtain the intended result. In a transformer the voltage is directly proportional to the number of turns of the coils and the current passing through coils of a transformer is inversely proportional to the voltage in the coils. On this reasoning, the formula to calculate the number of coil turns is obtained by (BBC, n. d.):

$$\frac{Vp}{Vs} = \frac{Np}{Ns}$$

where V_p is primary voltage, V_s is secondary voltage, N_p is the number of turns on primary coil, and N_s is the number of turns on secondary coil.

As we did not know exactly the number of turns on the primary coil, we constructed an experimental coil based on the wire and coil properties (wire diameter, coil length, coil diameter and DC output current) we were able to compute it through a calculator (inc, n.d.) and obtain an estimate of the number of turns needed to obtain an output between 5 and 9V. This result was not 100% correct but it gave us an estimate of the turns required, these were corrected through measurements with a multimeter and through the previous mentioned formula. We attained an 8V output; we opted to keep this value since it was recommended to attain an output voltage higher than the one actually desired. A voltage regulator limits this value later on.

5.5.2.3 Wave rectification circuit

To rectify the signal from AC to DC two options were considered, the half-wave rectification and the full-wave rectification. We decided to adopt the full-wave rectification because it leverages the output signal as the wave has considerable less ripples than the half-wave rectifier, see on Figure 67.

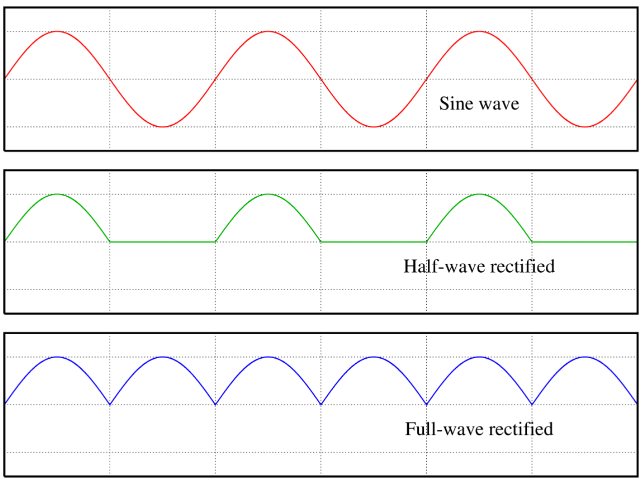

Figure 67 - Differences between the signal before the rectification, with a half-wave rectification and finally, with the full-wave rectification

This full-wave rectifier circuit (See Figure 68) is built on a rectifier bridge that splits the wave in half transforming alternating electric current (AC) to DC (Figure 69). The entries of the rectifier bridge, which in Figure 68 comes from the left side, are connected to the previously constructed coil ends.

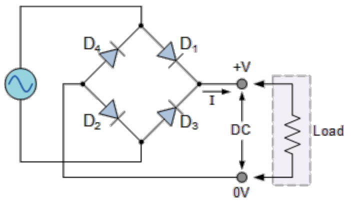

Figure 68 - Rectifier bridge schematic representation. Red represents the VCC output (positive) and blue represents GROUND

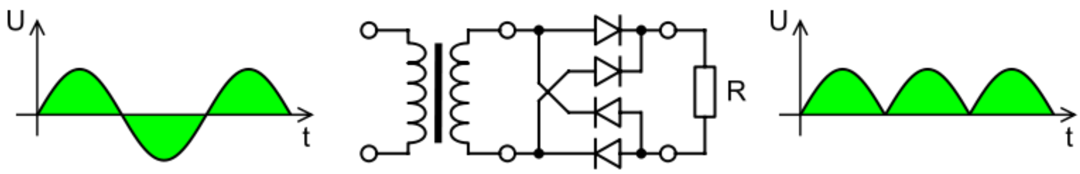

Figure 69 Alternating current converted to DC

To ensure that the output voltage is continuous and constant, a filter was incorporated to reduce amplitude disparities, this filtering is done with a capacitor with 4700uF capacitance (See Figure 70 for a better understanding).

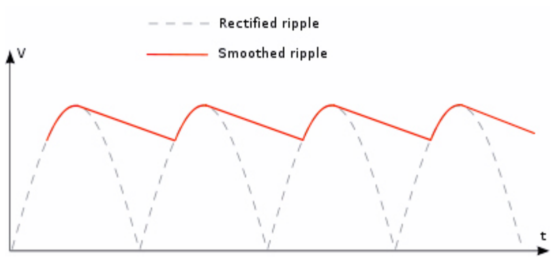

Figure 70 - Capacitor reducing the ripple form the DC wave signal. Final result of the constructed rectification circuit

5.5.2.4 Battery charging circuit

For battery charging we followed the battery charging circuit presented in appendix 9.10). Material that can be seen 9.7

The input voltage is delimited at the entrance of our standalone circuit with the voltage regulator to 3.7V. As previously stated this is done since is the voltage of the battery and the voltage supported by our build-in Arduino circuit.

The second part of the circuit is used as an indicator when power is being supplied to the circuit by the toothbrush charger. When the LED is on, energy is being transmitted. The resistor, placed sequentially, is used to limit the operating parameters to correct values, and prevent injuries on the LED.

The last part of the circuit manages to where the energy is addressed. If the voltage coming from the power supply (charger) is bigger than the battery voltage, then the circuit is only powered by the charger. Meaning that the energy is forwarded to the battery (recharging it) and to the circuit (supplying to it the necessary current). This prevents the electricity from the battery to unjustifiably drain, as it would otherwise discharge and need more charging cycles, decreasing the battery life cycle.

On the other hand, if the voltage coming from the power supply is insignificant or null – meaning that the charger is unplugged or a mains failure happened – is the battery that powers the circuit, taking the load without delay.

This management is accomplished using diodes that convey current only in one direction. This is verified in the last part of the circuit where battery power only flows to the circuit, it can never power the LED since it is unable to return back.

The resistor value was calculated to limit the battery charging speed, through the choice of a target current.

Although it works, this circuit presents some limitations since it does not detect when the battery is charged and may cause overcharging if the user always leaves the extension in the charger. See complete charging circuit assembled to the constructed standalone Arduino in Figure 71.

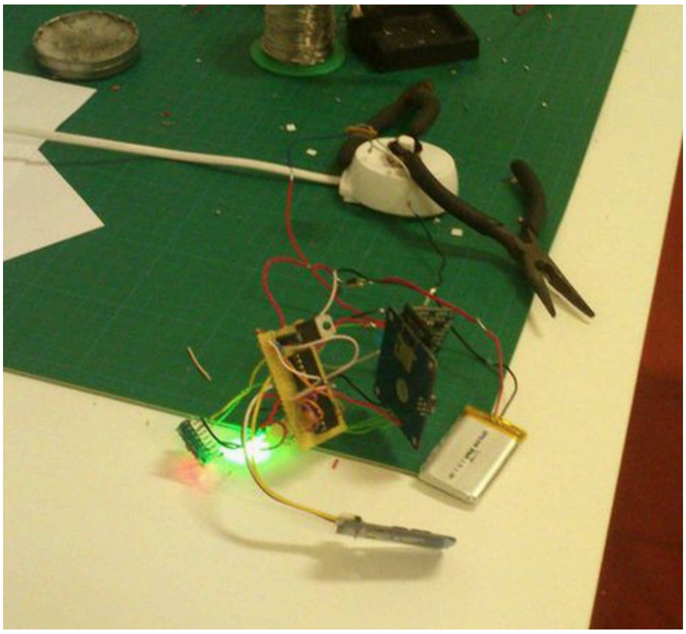

Figure 71 – Extension components assembled

5.6 Feedback

5.6.1 Ambient feedback

RGB LED in the extension is employed to provide ambient feedback. Users' behaviors are reflected in the extension using a LED light color combination displayed in the bottom of the extension. A transparent material surrounds the LED area in order to better reflect the color. When the system identifies that a user brushed her teeth properly, the extension lights up a green color (Figure 74), otherwise the reflected color is yellow (Figure 72). This information is visualized for four hours; thereafter the performance color is replaced by the color red (Figure 73) (identifying that no activity was recorded in the last hours). When we mention "brushing properly" we refer to a user that spent at least 30 seconds brushing each of four mouth areas (upper right, upper left, bottom right and bottom left) making a total of the two minutes recommended by professionals.

Figure 72 - Extension identifying that the user did not brush properly

Figure 73- Extension identifying that the user did not brush in the last 4 hours

Figure 74 -Extension identifying that the user brushed properly

5.6.2 Mobile application

In order to support users' interactions with the toothbrush extension and provide more detailed information, we opted to make collected information available through a mobile application with the goal of providing self and collective awareness (others family members) about toothbrushing practices. This decision was grounded upon the knowledge that persuasive systems can effectively improve communication when they share information among users, enhancing social support. Thereby, through this system, besides sharing users' behaviors, we want to provide a control mechanism during the process of tooth brushing.

The application, developed for Android devices, was set in two modes: real time and past reflection - relying on the simulation and self-monitoring principles previously mentioned (See Figure 75). In both approaches, the interface displays insights about frequency, duration and performance. While the activity is conducted, advices, tips, cues and encouragement are presented through textual feedback.

The design process of this application had several iterations, leading to various designs and interfaces, which can be seen in Appendix 9.11. During the firsts iterations, the development was done using Phonegap Framework (Phonegap, n.d.), however due to some limitations of the bluetooth pluggin (did not work on all devices) this option was discarded.

Figure 75 -- First screen of the application with two modes available

5.6.2.1 Real-time

This mode is intended to provide live visualization about user ongoing toothbrushing practice (see Figure 76). We provide detailed information about users toothbrushing duration and performance, as well as frequency information. Through this feedback, user can obtain a clear understanding of the context while interacting with the system, which can be used to evaluate and act upon the content that is provided. For instance, if user attempts to brush all his teeth in 45 seconds, the mobile application informs him that his performance is below the expected.

For the real-time design, we followed (Kukkonen & Harjumaa, 2008) Framework and included the following principles: simulation, suggestion, trustworthiness, reduction, surface credibility and self-monitoring, social learning, social comparison, social facilitation. Simulation was adopted since we allow the user to observe the connection between cause and its effects of his toothbrushing behavior, this approach also leaded to the self-monitoring principle. If the user does not brush his upper teeth, the system identified those areas as the most likely to lead to consequences (as cavities). Suggestions were provided to motivate users to achieve a better time. We do it while the practice is performed, since we consider is the most opportune moment to encourage users. So the system could be viewed as trustworthy, we did not present ambiguous information (therefore we omitted the inner and outer mouth areas representations since they are more susceptible to mistakes). The principle of reduction was chosen with the complex goals division in mind (dividing the two minutes long toothbrushing to smaller targets of thirty seconds). Surface credibility principle was used since we only provide reliable information for oral hygiene, as it is what the user expects. Lastly, social principles were used as we present oral hygiene information for all family members.

Live representations are done through Bluetooth communication between the Android device and the toothbrush extension. To each user is assigned a Bluetooth address of their toothbrush extension to create an automatic process. The app initializes and finishes the communication through two different codes. Thereby, the extension does not send data unnecessarily, and is hampered to send values to another device, which would not be able to interpret. When the communication is made, the application starts showing feedback to the user. When user finishes toothbrushing, tapping the screen will end the communication.

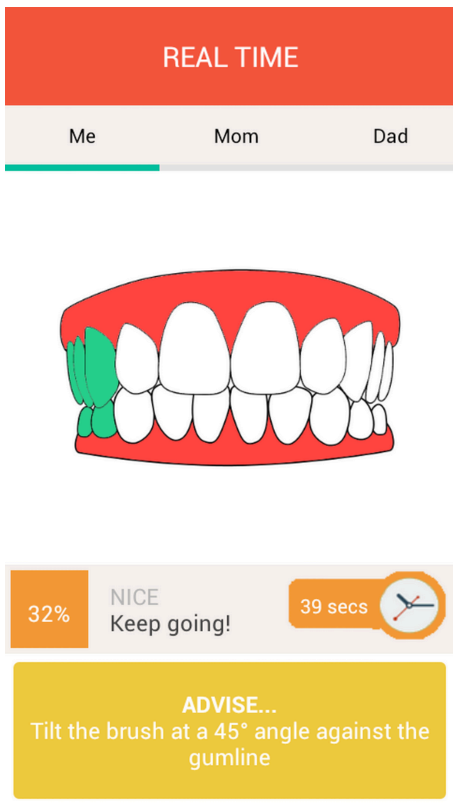

Figure 76 - Real time feedback, where the user can see live performanc

5.6.2.1.1 Frequency feedback

Feedback about how often individuals brushed their teeth is provided at the top of the application and under the name of each individual.

Toothbrushing frequency is categorized in three classification levels, see Figure 77.

· Good – user has brushed at least three times during the last 24 hours. Status is represented by the green color in the bottom of the name.

· Suitable – user brushed twice during the last 24 hours. Status is represented by the yellow color in the bottom of the name.

· Poor – user brushed once during the last 24 hours. Status is represented by the red color in the bottom of the name.

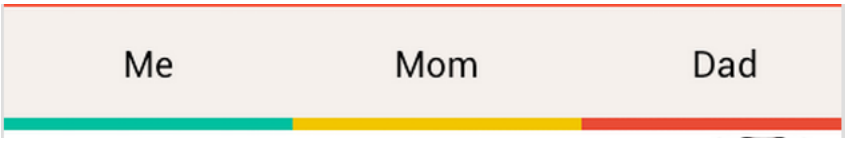

Figure 77 - In the top bar is represented that I brushed at least 3 times during the last 24 hours. Mom brushed twice and Dad brushed once

If the user did not brush his/her teeth during the last 24 hours, no feedback is presented about its frequency since it is assumed that the respective user is not in the household (same reasoning used in the first prototype) Figure 78 - Only the left user was in the household during the last 24 hours -

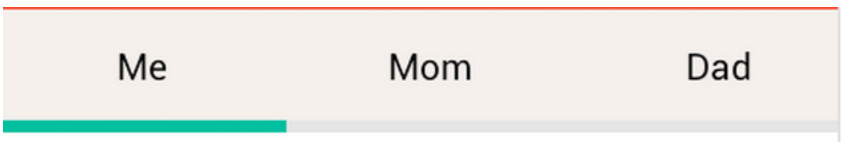

Figure 78 - Only the left user was in the household during the last 24 hours -

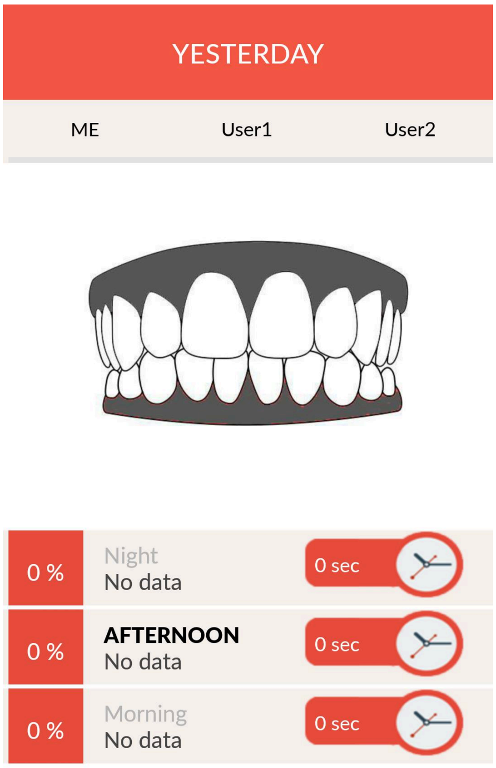

Figure 79 - Interface when user did not brush during the last 24 hours

5.6.2.1.2 Performance feedback

Performance is displayed to provide to users immediate knowledge about their toothbrushing motions/performance, which we assume the not to possess.

To display performance we decided to use representative images of the mouth areas in order to make the correspondence between the feedback and the user mouth areas more easy and straightforward. As we considered this the most important piece of the application, this section occupies the main area of the screen.

Users' toothbrushing motions were reflected as they were completed. We did not notice any significant delay while the data was received and displayed.

Initially, the mouth area was represented by two different illustrations: upper and bottom teeth. The images are shown based on the inclination of the toothbrush: if the toothbrush is pointing upwards the application visualizes the upper teeth, otherwise the lower teeth.

Upper and lower teeth images were split in four areas in order to hold the information about the inner and outer areas. In the beginning of the practice, we covered all areas with yellow color. As the toothbrushing performance improves, the areas become white. For instance, Figure 80 represents the image-displayed case where the user brushed properly the outer areas but missed the right inner area.

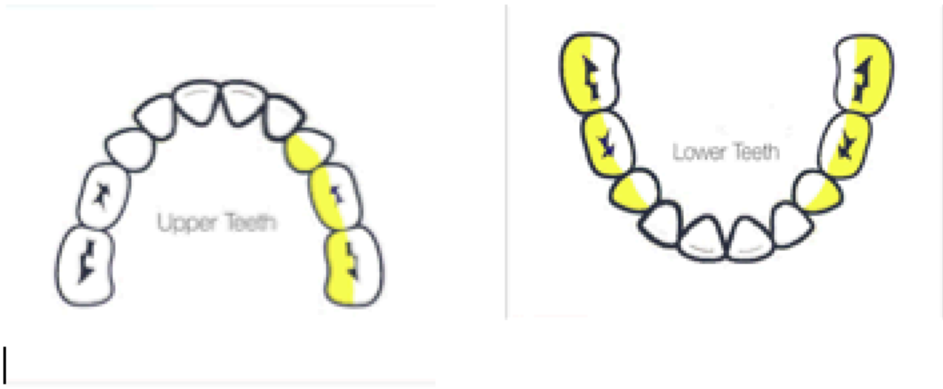

Figure 80 - Areas which were not washed properly are marked in yellow

One limitation of this approach is that the user is not aware of the remaining time. Also the same feedback is given for different performances and the user would not feel rewarded if he had completed a better time. Driven by this situation, that could discourage the user, we decided to represent performance across multiple color scales base of the time they spend toothbrushing:

· Orange – Initially, all areas are represented with orange color. Until the user does not reach ten seconds while brushing a specific mouth area, this color will remain. As represented in Figure 82.

· Yellow – If a user reached a brushing duration between eleven and twenty-nine seconds, in a given area, the color of this area is represented with yellow.

· Green – In case the user reaches at least the recommended time, the color changes to green. As represented in Figure 81.

We believe that this approach provides a better understanding about the user and his family performance behaviors. Also we consider that by providing this information it will lead the user to commit and to accomplish the recommended time in each mouth area. Furthermore through small, targets we believe the user reaches the targets more easily.

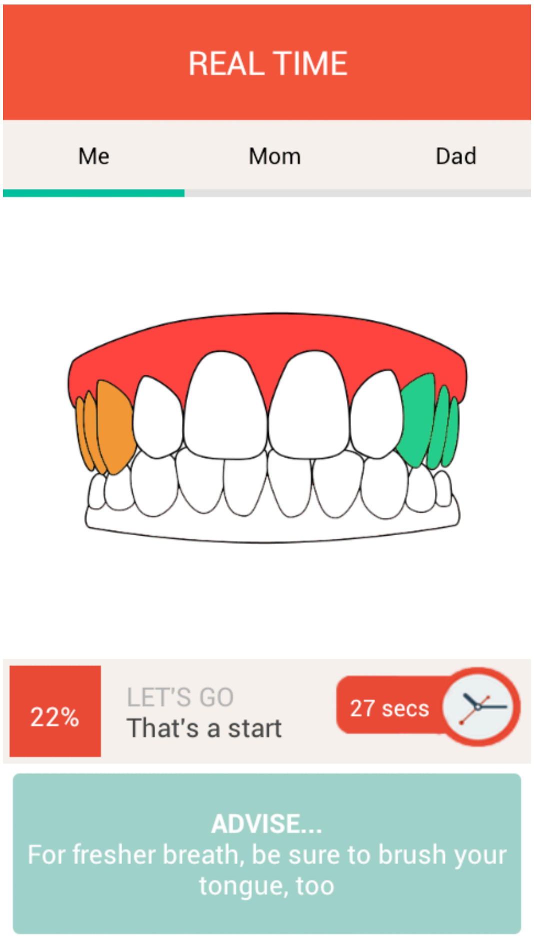

Figure 81 - User brushed properly the upper right area, however did not brush properly yet the left upper area

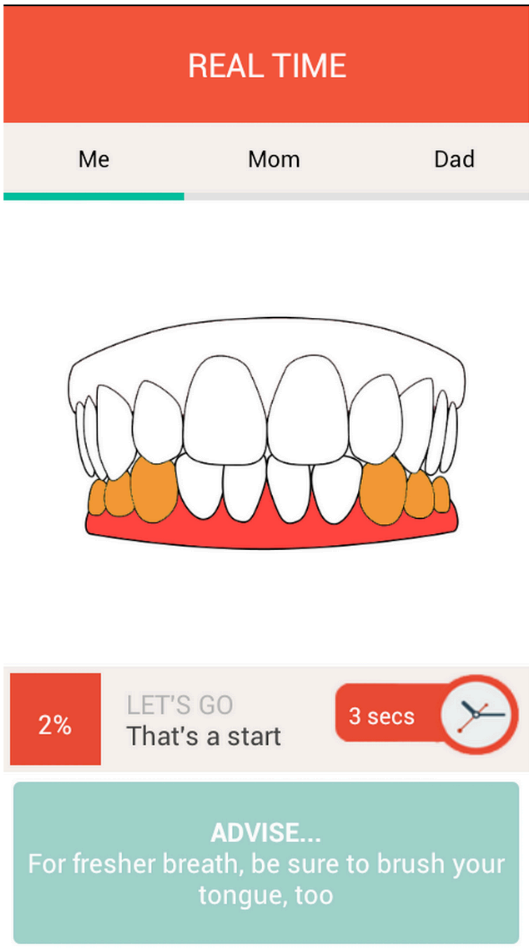

Figure 82 - User just started brushing his teeth and the areas are colored by orange

Posteriorly, we added a mouth-closed representation. We did it first, to be able to identify when the user was brushing both upper and lower teeth at the same time, and lastly and more important, to notify the user about an improper toothbrush inclination. An inadequate inclination denotes when the toothbrush is not tilt at a 45º angle against the gum line. A proper toothbrush inclination is presented in Figure 83. Figure 84 denotes an inappropriate toothbrush inclination and lastly, Figure 85 shows how this information is displayed to the user.

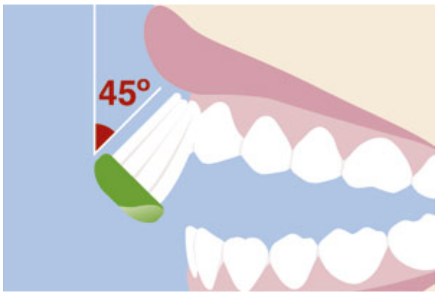

Figure 83 - Proper toothbrush tilt (Which, n.d.)

Figure 84 improper toothbrush tilts - (Clinic, n.d.)

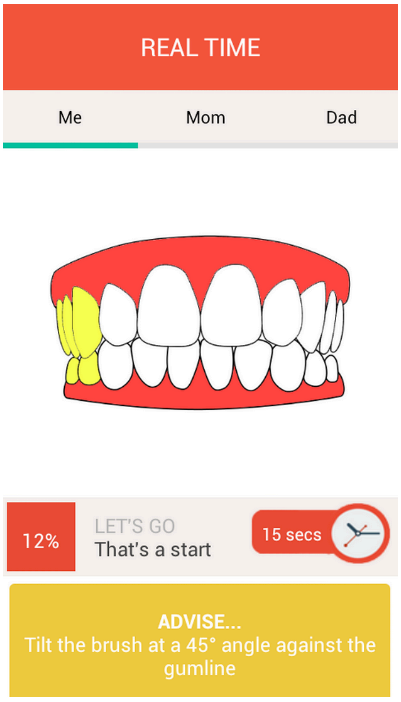

Figure 85- Advice provided to the user to adjust toothbrush inclination

Additionally, we added a small vibration for when this situation occurs. We aim to convince the user, while he has the device in his hand, to tilt the toothbrush otherwise the phone will not stop shaking.

Through the development process, we examined different mouth representations and how they were interpreted. At the end, we choose the mouth closed representation since images appeared to be better understood by users and since we decided to disregard the interiors mouth. Figure 86 illustrates the final representation of performance.

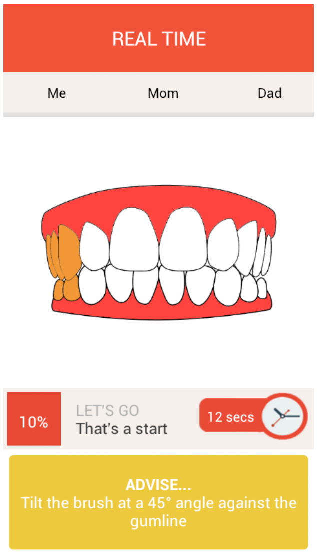

Figure 86 - Final representation of performance

5.6.2.1.3 Duration feedback

Duration feedback is provided using a timer on the right side of the bar, reflecting the time a user has so far spent toothbrushing. The ratio of the time achieved so far in relation to the time recommended by experts is represented on the left side. We decided to include this ratio since it is a better indication of toothbrushing duration. As the time increases, different messages are presented which aims to motivate users to brush for more time. These messages allow us to provide self-knowledge and motivate users.

We divided the recommended time in different levels, following the same approach we did for the frequency and duration. Levels classification:

· Level 0 – User has been toothbrushing for less than thirty seconds. Color red is displayed and percentage value is between 0% and 25%. Examples of messages displayed during this time are “That’s just the start!” “No hurry”, “Take your time” and “C’mon!”(See Figure 87).

· Level 1 – User has been toothbrushing between thirty and sixty seconds. The color displayed is orange and the percentage value is between 26% and 50%. Examples of messages displayed during this time are “Don’t give up!” “You can do it!” “Keep the effort!” and “Let’s go!” (See Figure 88).

· Level 2 – User has been toothbrushing between sixty-one and ninety seconds. Color yellow is displayed and percentage value is between 51% and 75%. Examples of messages displayed during this time are “Almost there!” “You are so close”, “Keep going!” and “Nice progress!”

· Level 3 – User has been toothbrushing between ninety-one and hundred and twenty seconds – 2 minutes. Color yellow is displayed and percentage value is between 76% and 100%. Examples of messages displayed during this time are “Good work!” “Good effort!” “Nice accomplish!” and “Well done!” (See Figure 89).

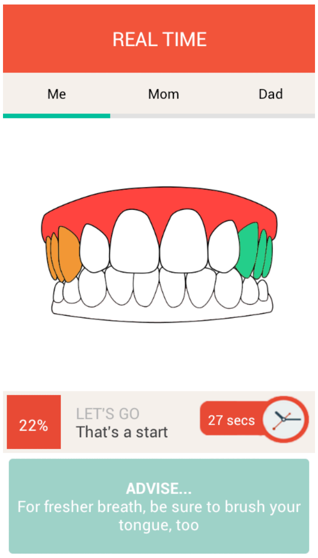

Figure 87 – Duration classified with level 0

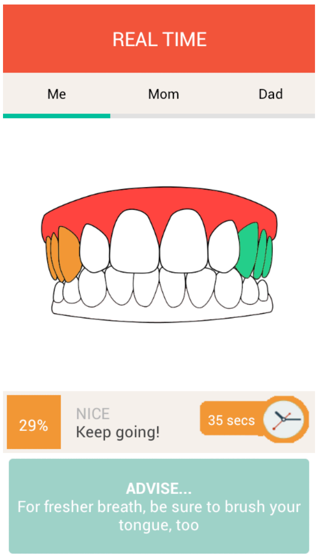

Figure 88 - Duration classified with level 1

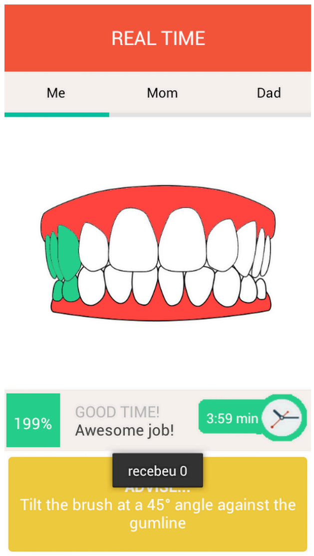

Figure 89 - Duration classified with level 3

5.6.2.2 Reflection

During reflection, the application displays the data in a historical manner. A reflection of user’s behaviors through the past seven days is provided and family members can compare and identify their own versus others progress and setbacks. This is possible because all the information collected in the application is made accessible to all family members when the device is connected to the network. Reflection mode reflects user behaviors during the last 24 hours per each screen.

The navigation between days is made through swipe gestures (swiping left would go to previous day).

On the top bar, rather than just showing the frequency of other users - as happens in real time - is possible to select other users and see their behavior. The same interface is shown for all users.

Contrary to what happen in real time mode, performance of all mouth areas is shown simultaneously (upper and lower teeth) in reflection mode, allowing users to compare mouth areas (See Figure 90).

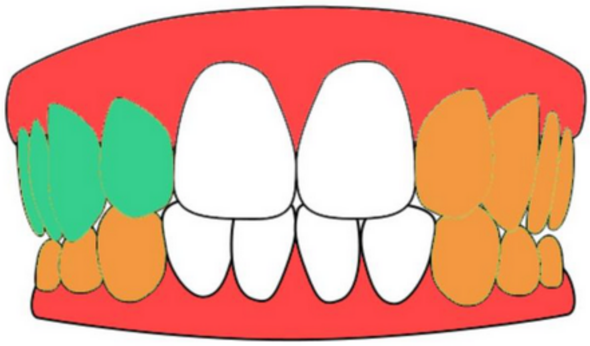

Figure 90 - Combination of all mouth areas performance

Duration however adopts a different approach. Rather than presenting only information about the last toothbrushing duration, is addressed to navigate among the various performance of the day acting as a timeline.

To accomplish this, toothbrushing durations were split in three-day times base on the hour of the day:

· Morning – Between 6am and midday;

· Afternoon – Between midday and 7pm;

· Night – Between 7pm and 6 am.

For example, if the user launches the application at 3pm the interface will show the duration and performance of the last toothbrushing. However, if the user clicks on the duration bar, a dropdown list will appear with the current and the previous time of the day (in this case, only shows morning) and the corresponded brushing duration. If user clicks on the morning label, the performance representation of that specific time of the day will be displayed. The same happens to different daytimes and users.

The bottom screen is used to display informative messages to the user and to notify in the event of a mishap (Two examples are presented in Figure 91 and Figure 92).

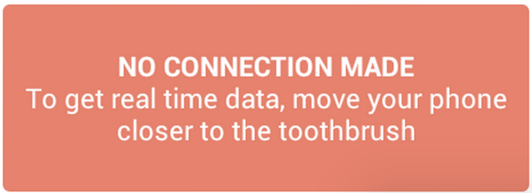

Figure 91 - Message displayed when the user did not made any connection with the app

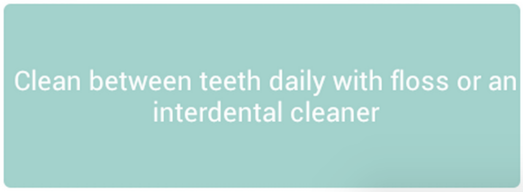

Figure 92 - One example of the messages displayed to the user

An informative message includes advices, cues, tips and repercussions about how certain toothbrushing behavior affects individuals in long-term. Thirty-two messages are presented randomly; these can be seen in Table 4. Every time the user interacts with the application (either tapping or swiping) the content is updated.

Table 4 - Cues, tips and recommendations shown to the user

Number	Message
1.	About 1 person in 10 has a tendency to accumulate tartar quickly
2.	Spending extra time brushing the teeth near the salivary glands may slow the development of new tartar
3.	If you have teeth that are sensitive to heat, cold, and pressure, you may want to try a special toothpaste for sensitive teeth
4.	Brush your teeth at least twice a day. When you brush, don't rush. Take enough time to do a thorough job
5.	Use the proper equipment. Use a fluoride toothpaste and a soft-bristled toothbrush that fits your mouth comfortably
6.	Remember to brush the outside, inside and chewing surfaces of your teeth, as well as your tongue
7.	Keep your equipment clean. Always rinse your toothbrush with water after

	brushing
8.	Know when to replace your toothbrush. Invest in a new toothbrush or a replacement head every three to four months
9.	The size and shape of your brush should fit your mouth allowing you to reach all areas easily
10.	A worn toothbrush won't do a good job of cleaning your teeth
11.	Make sure to use an ADA-accepted fluoride toothpaste
12.	Place your toothbrush at a 45-degree angle to the gums
13.	Gently move the brush back and forth in short (tooth-wide) strokes
14.	To clean the inside surfaces of the front teeth, tilt the brush vertically and make several up-and-down stroke
15.	Brush your tongue to remove bacteria and keep your breath fresh
16.	Clean between teeth daily with floss or an interdental cleaner
17.	Eat a balanced diet and limit between-meal snacks
18.	Proper toothbrushing takes at least 2 minutes. Most adults do not come close to toothbrushing that long
19.	To properly brush your teeth, use short gentle strokes, paying extra attention to the gum line
20.	Gently brush your tongue to remove bacteria and freshen breath
21.	You should replace your toothbrush when it begins to show wear, or every 3 month, whichever comes first
22.	Is very important to change toothbrushes after you've had a cold, bristles can collect germs that can lead to reinfection
23.	Oral health is more important than you might realize, health of mouth, teeth and gums can affect your general health
24.	Without proper oral hygiene, bacteria can reach levels that might lead to oral

	infections as tooth decay and gum disease
25.	Risk factors for oral diseases include an unhealthy diet, tobacco use, harmful alcohol use and poor oral hygiene
26.	The most common oral diseases are dental cavities, gum disease, oral cancer, oral infectious diseases, and hereditary lesions
27.	Worldwide, 60–90% of school children and nearly 100% of adults have dental cavities, often leading to pain and discomfort
28.	Decreasing sugar intake and maintaining a well-balanced nutritional intake can prevent tooth decay and premature tooth loss
29.	Consuming fruit and vegetables that can protect against oral cancer
30.	Stopping tobacco use and decreasing alcohol consumption to reduce the risk of oral cancers, periodontal disease and tooth loss
31.	Visit your dentist regularly for professional cleanings and oral exams

For this feedback, in addition to other principles mentioned above, we also supported praise through the motivational messages in the duration bar and linking by the minimalist interface.

5.7 System architecture

The application required that toothbrushing behaviors were logged in order to provide feedback about past behaviors. We did so storing all the information on a local *SQLite* database (within the device). However, since we wanted to make all this information available to all family members, we chose to have an external database. In this way, when the user connects to the Internet, his behaviors are sent to the online database. This is done automatically when the user enters in the application.

The communication between the application and the server was made using *JSON* and *PHP* technologies since Android is unable to communicate directly with a *MySQL* database (To see how the communication is done see Figure 93). In appendix one may find the *PHP* scripts created for reading and converting data. All in all, the application used the following *HTTP* requests:

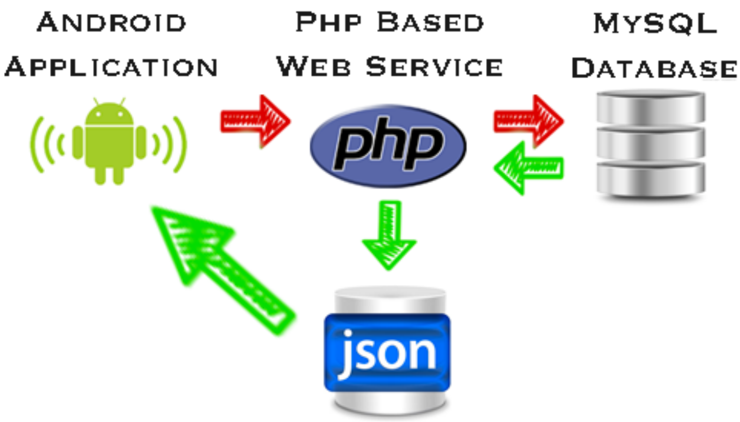

Figure 93 - Interaction between a Remote MySQL Database an the Android Application (back, n.d.)

Entity/relationship diagram presented in Figure 94shows the structure designed to store all data related to users behaviors:

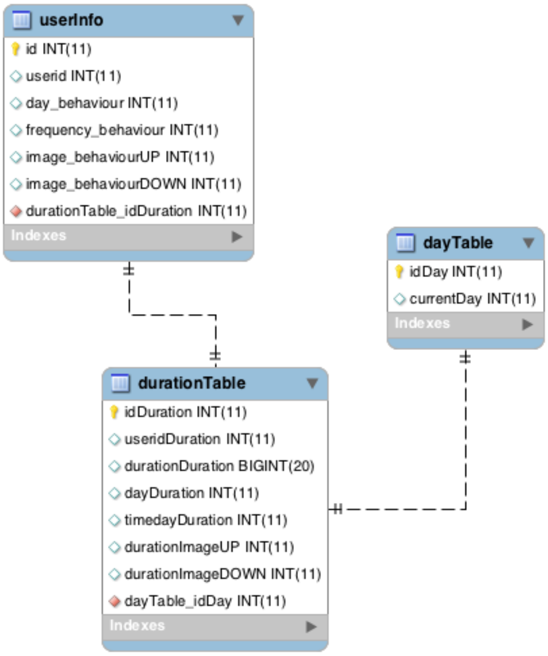

Figure 94 - EER diagram

The behavior and communication of the system is represented in image Figure 95

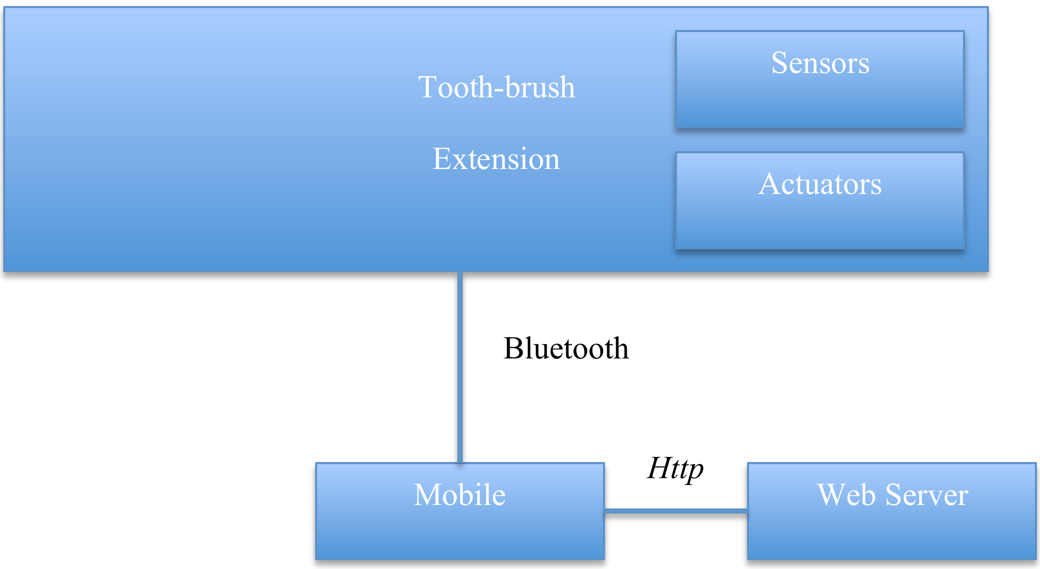

Figure 95 - System architecture

5.8 Discussion

In the previous chapter we described our final approach for the design of a persuasive system that aims at raising self and other family member's awareness to support behavior change towards proper toothbrushing practices. Initially, this approach had the main goal of overcoming the previous prototype's limitations. Yet, while the evaluation process of Smartholder was conducted, we were able to identify a missed opportunity, which was to track individuals' toothbrushing performance. Through a further analysis we were able to observe that this information could positively complement the feedback provided to family members in the previous system, and also identify its importance in oral hygiene practices. Although performance could have been indirectly improved with Smartholder, since it attempted to increase the overall brushing time of family members, we realized that it was not the best approach to follow, since it did not suggest individuals to distribute the brushing time for the mouth areas. Thereby, we developed Social Toothbrush - a toothbrush extension able to infer properly toothbrushing performance, frequency and duration behaviors and provided understandable feedback about those behaviors, which could allow individuals to act upon it.

The deployment of this system allowed us to not only to solve previous technical issues, but also to optimize the system operation (since now it can sense individuals' performance) and maximize the feedback provided to family members. We now can raise self and mutual awareness through the toothbrush extension and moreover, through a mobile application. This allows us to take advantage of a set of persuasive design strategies that aims at persuade and support discussions among family members to achieve better behaviors.

6 Conclusion

6.1 Limitations

One may however notice the existing limitations in this prototype. Although we can identify properly several toothbrushing patterns, we cannot properly infer all mouth areas brushed and some clinical classification for mouth regions were discarded in our approach (anterior and inner posterior areas). Nonetheless, we propose three different approaches to overcome this setback. First solution could be adopting (Lee et al., 2012) algorithm for toothbrushing region detection, which propose a mouth region detection system for monitoring toothbrushing activity using two sensors: a three-axis accelerometer and magnetometer sensor. Where the accelerometer is used to gauge information about toothbrush orientation while the magnetometer is used to detect orientation of the toothbrush. The combination of the sensors readings allows them to distinguish sixteen different mouth areas. This combinations can be seen in appendix 9.8.

The second approach is to use a vision-based motion tracker to infer the position of the brush through (web) cameras located in the bathroom. This information however had yet to be related to another algorithm for detecting the toothbrushing motions. Lastly, a more simple way to obtain individuals performance would be to develop a system in which the user manually identifies the mouth areas he is brushing.

From the previous approaches on may notice the potential that the first approach takes compared to other and how meets the needs of our project. However, before we developed the toothbrush extension we did not have knowledge of this approach, even though we explored several options to infer individuals motion behaviors. At the time, as we did not wanted the user to manually insert his performance, the only plausible option was to include a camera in the environment. Because this option made the system intrusive it was also discarded and thereby we proceeded with our own approach.

Another limitation of this work is the lack of evaluation of the developed prototypes. Although we emphasize the importance of the study to validate our approach, we underestimated the development time required, in particular, for the last prototype. As more time in prototyping in prototyping, this did not allow us to carry out the study, even though we developed 13 prototypes for this purpose (See appendix 101).

However, this allowed us to make additional iteration on the concepts and prototypes. Through these iterations it was possible to change and improve concepts, analyze usefulness of the development prototypes and understand how the ideas could meet the predefined goals towards the deployment of a successful design. As a result it was possible to obtain more trustworthy prototypes and gain some useful insights towards the design of Social Translucence Systems.

6.2 Future work

Our future work aims principally at conducting a longitudinal field study of the Social Toothbrush.

Through the study we want to understand the strength of Social Toothbrush as a Socially Translucent technology. Firstly, we want to understand if Social Toothbrush can induce behavior change through attaining proper toothbrushing practices, how and why. Secondly, we want to understand how Social Toothbrush can affect family communication and coordination practices around toothbrushing and how this affects family members' behaviors. Lastly, we want to understand if Social Toothbrush can sustain users' engagement over time.

We also aim to improve Social Toothbrush. We consider further iterations could bring new approaches to the table providing new concepts, new goals, which could be exploited for the development of other systems intended to have social persuasive interactions.

7 Discussion

With this thesis we have been able to understand the current state of the art of systems that aims inducing proper toothbrushing practices. Through the literature review we analyze the set of strategies that been comprise to motivate individuals to attain to a proper oral health. As previously identified, these strategies mostly attempt to encourage individuals through persuasive systems and do not take advantage of social influence. Although the emphasis of social persuasion strategies has been growing over time, we notice that an aspect missing on existing applications is the role of the family in inducing behavior change on toothbrushing behaviors. While some systems allows parents to intervene, they do not provide means to acquire knowledge about how others family members practices are conducted and do not attempt to induce proper toothbruhing practices focusing in frequency, duration and performance as a collection of steps that are required to achieve good oral health. We believe lack of a proper toothbrushing behavior is an issue that has not been completely addressed.

This thesis identified the main problem encountered on previous systems and provides some reflections to address this problem. We believe there is a need to afford insights to family member's toothbrushing behaviors, which could be used as tools to raise and support the existing communication and coordination practices within families.

Based on these results, we describe a set of design guidelines for the design of a persuasive system that aims supporting coherent discussions between family members and present Smartholder and Social Toothbrush, two systems derived from the stated guidelines.

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9 Appendix

9.1 Survey

1. How do you judge in overall your oral health?

2. On a typical day, how often you brush your teeth?

3. What motivate you to brush your teeth?

4. Think of yesterday. Can you recall when and for how long you brushed your teeth? For each one, can you reflect why you did so?

5. Often, individuals fail to adhere to healthy habits like toothbrushing. What do you consider this is due?

6. Does your family have any knowledge about each other's toothbrushing habits?

7. How many people live with you?

8. Other family members may sometimes influence the frequency or duration of one's toothbrushing behavior. Do you see this happening in your case? If so, can you elaborate as to how?

9. What is your age?

9.2 Interview

This interview is part of a project of Madeira Interactive Technologies Institute.

Goals: Interviewee insights will towards the design of technological solutions that help individuals in attaining healthy toothbrushing habits.

Technique: The interviewee respond freely to the questions asked if it is intended.

Duration: Total time between 20 to 30 minutes.

Record: If it is authorized, the conversation will be recorded (audio)

Questions:

1. What is your current age?

2. How many people live with you?

a. How would you describe the dynamics with the person/persons you live with?

b. Do you usually brush your teeth alone or with some of them?

c. Does your family have any knowledge about each other's toothbrushing habits? If so, how?

d. Other family members may sometimes influence the frequency or duration of one's toothbrushing. Do you consider this happen to you? If yes, how?

e. How comfortable are you in sharing your daily practices with your family? Can you expose why?

3. Think of yesterday. Can you recall when and for how long you brushed your teeth?

4. What motivates you to brush your teeth?

5. Overall, how good do you judge your oral health?

6. Ideally, how frequently would you like to brush your teeth?

7. On a typical day, how often do you brush your teeth? For how long you brush your teeth?

8. Often, individuals fail to adhere to healthy habits like toothbrushing. What do you consider this is due?

9.3 - Components required for the development of a Smarthholder with two users

Quantity	Component
1x	Arduino
2x	RGB LED
8x	LED (one color)
2x	Infrared pair (emitters and receptors)
1x	LM386 low power audio amplifier
1x	8 ohm speaker
14x	220 ohm resistors
1x	USB cable
2x	Potentiometers
1x	Stereo 3.5mm Jack Audio Cable
1x	MP3 music player USB with Micro SD
1x	100 ohm resistor
1x	Breadboard
Nonspecific quantity	Jumper wires, solder, glue, screws and welding wire

9.4 - Components needed for the construction of a breadboard Arduino

Quantity	Component
1x	Printed circuit board

1x	7803 voltage regulator
1x	LED
1x	220 ohm resisor
1x	110 kohm resistor
2x	10 uF capacitor
1x	Resonator
1x	ATMEGA328p microcontroller

9.5 List of the components for the toothbrush extension

Quantity	Components
1x	Breadboard Arduino (adapted)
1x	Coil
1x	Rectifier bridge
1x	Lithium battery 3,7v 1200mAh
1x	4700 uF Capacitor (confirmar o valor amanha na UMa)
1x	Triple axis accelerometer and gyroscope
1x	Bluetooth module
1x	SD Card module
1x	RTC module

9.6 Specifications on of the accelerometers and gyroscope sensors

Component	Specification

Accelerometer	Programmable full scale range of ±2g, ±4g, ±8g and ±16g. Set Full Scale Range to ±2g
Tri-Axis angular rate sensor	Sensitivity up to 131 LSBs/dps and a full-scale range of ±250, ±500, ±1000, and ±2000 degrees/s. Set Full Scale Range to ±250deg/s

9.7 - Components needed for the battery charging circuit

Quantity	Component
1x	7805 voltage regulator
1x	LED
1x	330-ohm resistor
2x	1N4007 diodes
3x	10 ohm resistor
1x	3,7v lithium battery

9.8 Tracking Toothbrush positioning

The domain of oral health has attracted the attention of researchers in the design of more efficient methods for evaluating quality of toothbrushing practices. Lee et al. propose a mouth region detection system for monitoring individual's toothbrushing performance. This system is an electrical toothbrush with several sensors able to detect individuals brushing styles, determined by brushing movements (Lee et al., 2012).

For this purpose, the system required two motion sensors: a three-axis accelerometer and magnetometer sensor. The accelerometer was used to gauge information about posture – brush left, brush up, brush right, brush bottom– through information of inclination (using pitch and roll angles) and activity level of toothbrushing. In turn, the magnetometer was used to detect orientation of the toothbrush through the heading angle with respect to the North Pole.

In their work, they distinguish sixteen different mouth areas categorized by the following mouth regions: inner and outer tooth surfaces of molar, anterior buccal and chewing surfaces of the teeth. The areas identified for the upper teeth are maxillary right molar buccal, maxillary right molar occlusal, maxillary anterior buccal, maxillary anterior lingual, maxillary left molar buccal, maxillary left molar occlusal, maxillary right molar lingual, maxillary left molar lingual. For the lower teeth are mandibular right molar occlusal, mandibular right molar buccal, mandibular left molar occlusal, mandibular left molar buccal, mandibular anterior buccal, mandibular right molar lingual, mandibular left molar lingual and mandibular anterior lingual. See Figure 96 .

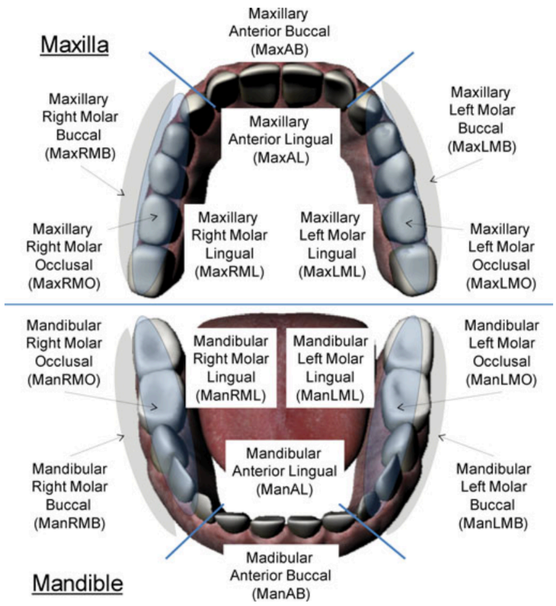


Figure 96 - Mouth categorization (Lee et al., 2012)

9.9 Prototypes developed

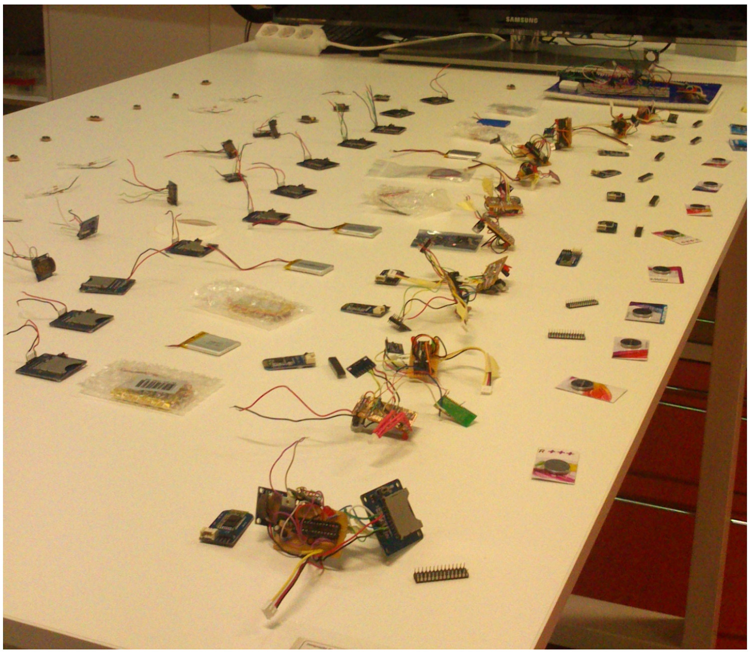


Figure 97 - Prototypes materials

9.10 Battery charging circuit (Mohankumar, n.d.)

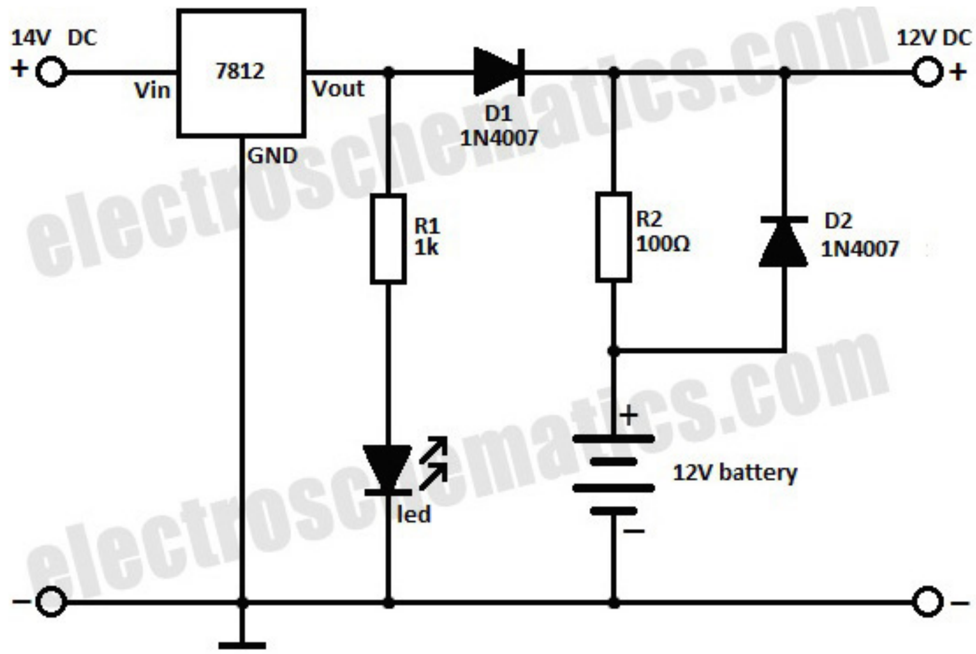


Figure 98 - Backup battery circuit

9.11 Previous Designs of the mobile application

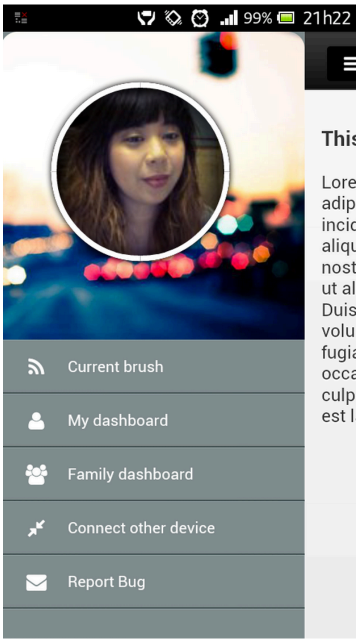


Figure 99 – First design of the application

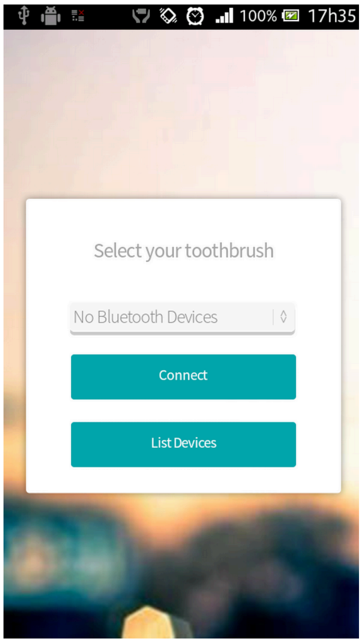


Figure 100 - First design of the application

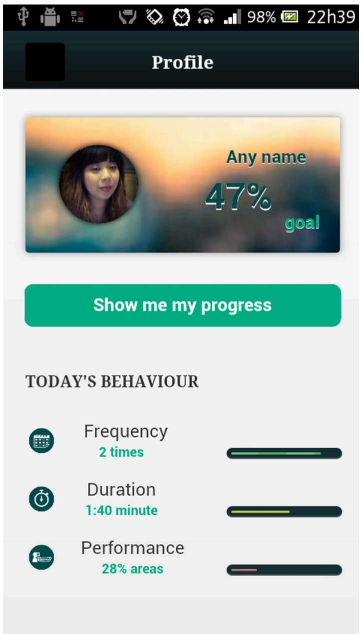


Figure 101 - First design of the application

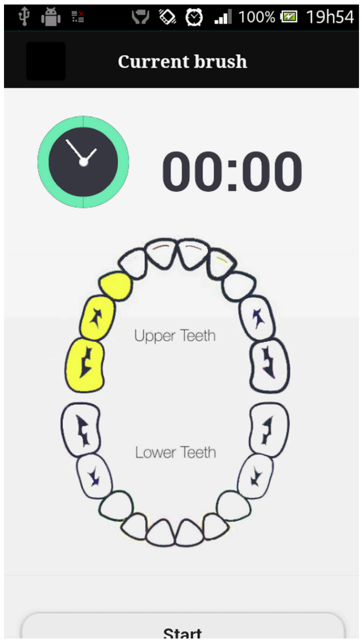
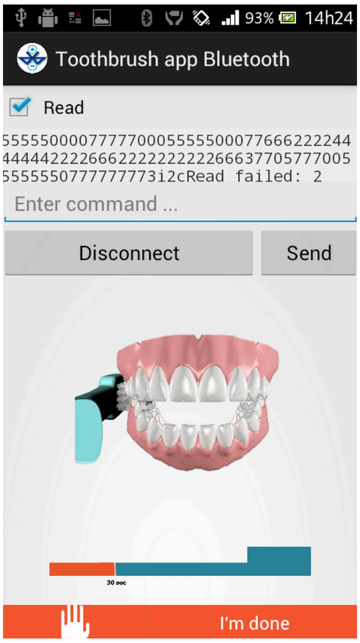


Figure 102 - First design of the application



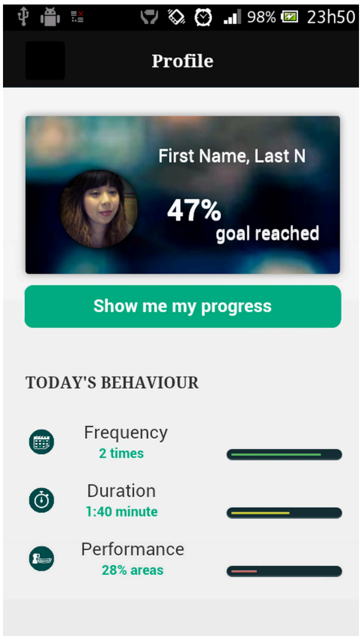
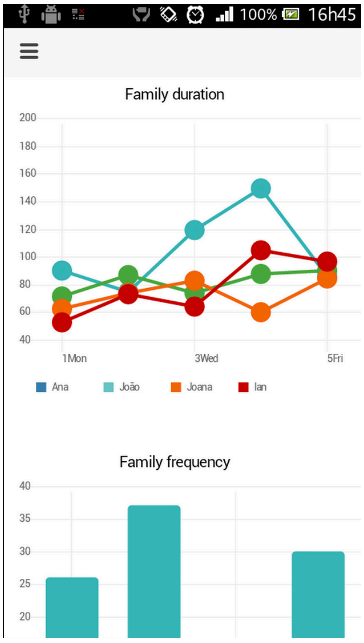


Figure 103 – Interface for Bluetooth communication testing plus 3D image representation

Figure 104 - First design of the application



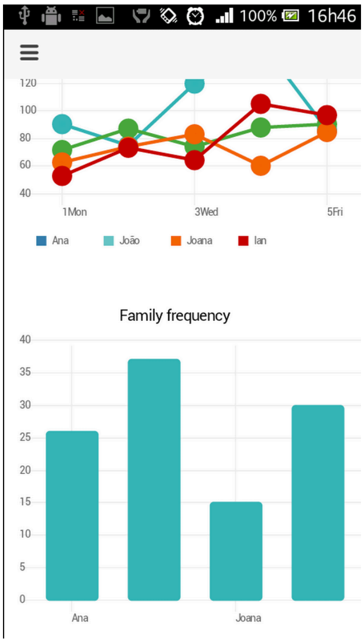


Figure 105 - First design of the application

Figure 106 - First design of the application

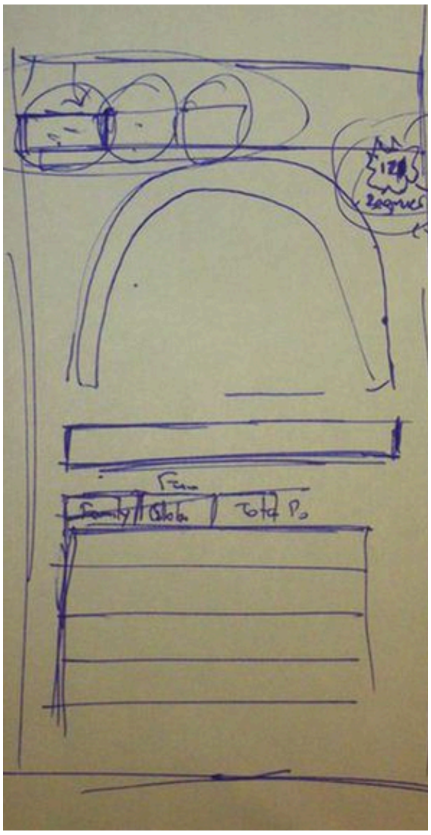


Figure 107 - Sketches for the second iteration

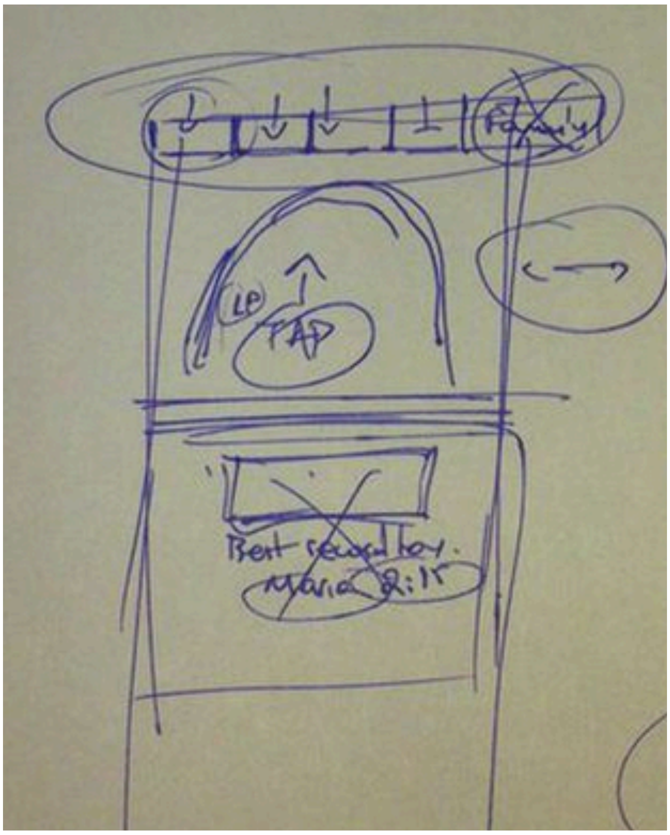


Figure 108 - Sketches for the second iteration

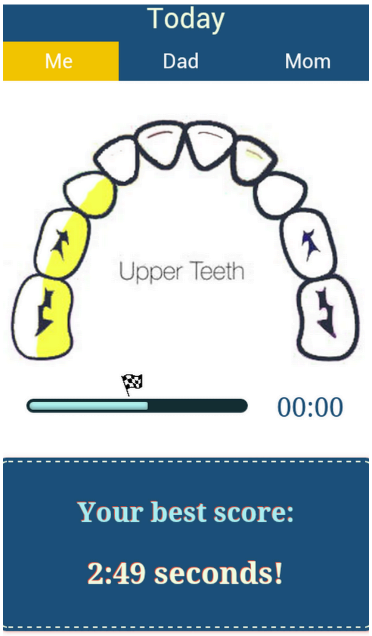


Figure 109 - Second design of the application

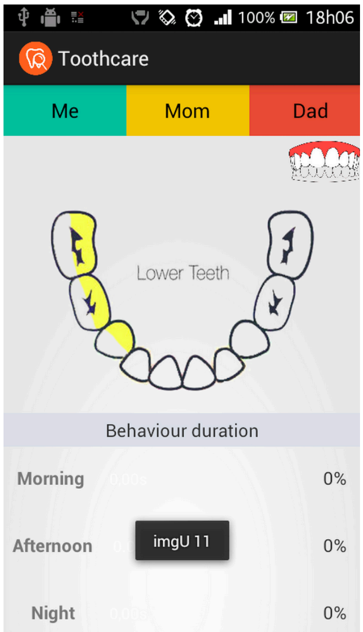


Figure 110 - Second design of the application