Soother 2.0

WILDOR DI NOVO
MATTIAS DUROVIC

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Stockholm, Sweden
Soother 2.0

Authored By

Wildor Di Novo
wildor@kth.se

Mattias Durovic
durovic@kth.se
Abstract

A soother (also known as pacifier, dummy, or binky) is a device used by small children for non-nutritive sucking needs as well as to fall asleep at night. However, children often drop their soother without being able to retrieve it in the dark causing them to cry and alert their parents. This often means that parents are forced to go out of their way in order to assist the crying child. This can occur several times a night and is inconvenient for parents especially when trying to sleep.

This project explores different solutions to this problem and focuses on the development of a prototype of the best solution found. The solution is meant to allow children to assist themselves in retrieving their soother. The development is based on the integration of built-in electronics into the soother that are used to detect when the child is crying. Upon detection of the crying sound the device responds by lighting up for a given period of time allowing the child to see and retrieve the soother. This innovation is primarily intended to benefit parents with small children, improving the quality of their leisure time and sleep.
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1. Introduction

1.1 Overview

This project examines the possibility of developing a system that will aid small children in recovering their soother in a dark environment. It is the belief of the authors that such a system will help children go back to sleep without the assistance of the parents thus allowing the parents to stay undisturbed or sleep without interruption.

The project concerns itself with discovering if such a system can be built in a way that follows the strict safety requirements that surround devices meant for use by unsupervised infants in Sweden. The goal is to briefly study various possible mechanisms by which such a device could function, as well as the various methods by which the device could be manufactured, and then attempt to build a prototype of the most likely candidate. Ideally this prototype will be constructed using the same methods and materials as a commercially available soother however if this is not possible a scale model will instead be built to see if the chosen solution is small enough to be used as a replacement for a classical soother.

While this report primarily concerns itself with the feasibility of solving the problem it also pays some attention to the cost and lifetime of the final device. This because a successful solution must be not only technically feasible but also cheap enough to be affordable by those parents it is designed to help.

This report is divided into four main parts. Chapter 2 is a background overview of the problem and of those subjects considered important to understanding the final design. This is followed in chapter 3 by a review of the various designs and manufacturing methods considered. Chapter 4 contains a specification describing the candidate design in detail. Chapter 5 is a description of the prototyping process itself. Finally, chapter 6 describes our conclusions.
1.2 Goals

The aim of this project is to develop a system capable of detecting when a child drops their soother and is trying to recover it. The system should respond by providing some cue that allows the child to recover the soother.

In order to achieve this the following goals must be met.

• The system must have some way of determining that the child wants their soother.
• The system must provide some form of effect that allows the child to recover the soother in a dark environment.
• The system must be either small enough to fit inside a soother or capable of working from a distance.
• The system must comply with the general safety requirements to allow use by an unsupervised child in Sweden.
• The system should not wake the child if they are sleeping.
2. Background

2.1 Parental Problem and Benefits

During a social gathering in late 2011, a mother of two was repeatedly inconvenienced having to make several trips to her children's bedroom while her son was in the process of falling asleep. The mother reported that the 2 year old kept crying for attention because he repeatedly dropped his soother. From numerous conversations the authors have had with parents this appears to be a situation that a lot of parents with young children find themselves in.

That same evening a conversation among the present adults got started about the subject matter. The mother argued that if only her son could see the soother he would undoubtedly be able to assist himself [1]. She had been noticing how he was capable of assisting himself during the day time when the surroundings where bright enough for him to see and localize the soother. However, it is difficult for a young child who hasn’t yet developed the ability to swipe for objects without visual aid to find a soother in the dark. This prompted the search for a solution and led to the idea presented in this project.

We have aimed at creating a soother that will primarily benefit parents. One of the most beneficial aspects of such a soother is that it might reduce the interrupted sleep cycles that parents suffer from due to having to attend to their children at night. On the assumption that parents in our present day fast societies live under tight schedules and consequently suffer from stress, this project aims at reducing this burden. The value of this project lies in the implementation of modern technology to increase the well being among members of our society. Assuming that the soother 2.0 proves to be beneficial to parents with small children it is also worth noting that there could be a market potential for the soother 2.0 given that these parents constitute a large group of society.

2.2 Soothers

A soother is a device given to infants and small children to pacify and satisfy non-nutritive sucking needs. It is usually made out of rubber, plastic or silicone [2] and consists of a teat, shield, a knob and/or a ring, and a cover. The soft bulb on the front of the soother on which the child suckles is known as the teat or nipple. The teat attaches to a protruding shield meant to prevent the child from swallowing or choking on the soother. On the opposite side of the shield from the teat extends a hollow knob and/or ring complemented by a cover. The soother model shown in figure 1 shows a knob type soother standing on its cover.
2.3 General safety requirements

Soothers are designed to be used by young children for long periods of the day or night [3]. Specific safety requirements should therefore be met primarily to ensure the safety of the child and reduce the risk of accidents occurring. There is a specific set of general safety requirements that soother manufacturers need to comply with. General safety requirements relating to materials, construction, and use of soothers are provided by the European standard: EN 1400 which “has the status of a Swedish Standard” (SS-EN 1400) [4].

The first safety requirement relevant to this project concerns the physical dimensions of the soother knob: “A rigid knob, plug or cover, whichever projects furthest beyond the rear face of the shield shall not be less than 10 mm and not more than 16 mm.” [5]. This dimension can be increased to 35 mm if the part is made of a flexible material [6]. There are no specified restrictions concerning the width and length of the knob. The relevance of this requirement to the project concerns the space available inside the knob (see 4.1 Overview).

The second requirement relevant to this project concerns the construction of the soother: “The soother shall be free from any sharp projecting points or edges...The soother shall have no removable parts.” [7]. The relevance of this requirement to the project concerns the need to ensure that any additional parts added to the soother not be removable (see 4.1 Overview).

The development of the soother 2.0 prototype has primarily aimed at meeting these two safety requirements for the purpose of demonstrating a proof of concept. The realization of such a prototype within the boundaries of the discussed requirements ensures that in the event of the development of a marketable product all safety requirements specified in the EN 1400 standard can be met without hindrance from the development of this project.
Concerning the legal liability of companies that would sell the soother 2.0, the EN 1400 standard provides regulations to follow regarding consumer packaging, general product information, purchase information and instructions for use. Necessary warning signs would also need to be provided in a specific form [8].

A lot of children's toys that use electronics specify a minimum age. There is however no age restriction for soothers in the current EN 1400 standard, although a new version of the standard is scheduled to be released in 2013. The authors have not been able to acquire any information as to the changes made to the standard and what potential consequences they may have for this project.

### 2.4 Behavioral and psychological aspects

There are two main considerations relating to child behavior and child psychology that are central to this project. The first is about the age at which motor skills have developed enough in children in order to successfully handle a soother. The other concerns the psychological impact of the color and brightness of the soother on children.

#### 2.4.1 Motor skills

Motor skills are categorized in two groups: gross motor skills and fine motor skills. Gross motor skills are the movements of the feet, legs, arms or the entire body. These control actions such as crawling, walking, running and other activities. Fine motor skills involve the movement in the hands, fingers, toes, lips and so on. They control more detailed actions such as picking up objects between the thumb and finger, using a pencil to write, holding a fork and using it to eat, and other small muscle tasks [9]. We shall focus on the last mentioned group.

At 5 to 6 months, small children tend to use two hands to reach for objects; by 8 or 9 months, they know how to use two hands for big toys, one hand for small ones [10]. The data in table 1, taken from Kurtz, Lisa A. (2007) [11] shows an approximate time-line for milestones one can expect a normally developing young child to go through during the first year. Based on table 1 we can deduce that a young child will normally gain the necessary motor skills for handling a night time soother at the approximate age of 6 months.

The quality of a child's motor skills depend upon the combined influences of several factors, including the child's motivation to practice and improve these skills [12]. Every time a young child reaches for a toy he or she is refining these skills. Catching a young child’s interest with a variety of toys is an effective way to achieve this. Therefore, introducing a night-time soother to the child starting from a young age can help in the process of refining these motor coordinates. The soother can be used to refine the very skill necessary for its handling. So, parents needn’t wait until a child has gained the necessary motor skills to make proper use of the soother before introducing it to the child.

In addition, a key developmental stage for infants is exploration by oral touch. By mouthing different objects infants discover texture and taste [13]. The use of a night time soother can therefore be expected to work in a most natural way during this developmental stage.
### Table 1: Typical developmental milestones.

<table>
<thead>
<tr>
<th>Age</th>
<th>Fine motor skills</th>
<th>Cognitive/perceptual</th>
<th>Personal/social</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3 months</strong></td>
<td>• Hands remain open during rest.</td>
<td>• When lying on back, promptly looks at toy and follows with eyes</td>
<td>• Shows anticipation of bottle/food through facial response</td>
</tr>
<tr>
<td><strong>6 months</strong></td>
<td>• Passes toy from hand to hand when lying on back</td>
<td>• Shakes rattle on purpose</td>
<td>• Holds own bottle</td>
</tr>
<tr>
<td></td>
<td>• Rakes at tiny objects using all fingers</td>
<td></td>
<td>• Drinks from cup that is held by adult</td>
</tr>
<tr>
<td><strong>9 months</strong></td>
<td>• Grasps block with fingers, not palm of hand</td>
<td>• Holds one block of toy in each hand and bangs together at midline</td>
<td>• Mouth/gums hard cookie or cracker</td>
</tr>
<tr>
<td></td>
<td>• Wrist is extended (bent back) during grasp of block</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>12 months</strong></td>
<td>• Builds tower of two blocks</td>
<td>• Imitates scribbling with crayon</td>
<td>• Brings pre-filled spoon to mouth but spills</td>
</tr>
<tr>
<td></td>
<td>• Uses mature pinch grasp (thumb and tip of forefinger)</td>
<td></td>
<td>• Hold handle of cup while drinking</td>
</tr>
<tr>
<td></td>
<td>• Holds crayon using fisted grasp</td>
<td></td>
<td>• Holds out arms and legs for dressing</td>
</tr>
<tr>
<td></td>
<td>• Helps to turn pages in a book</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4.2 Brightness and color

A soother is meant to facilitate the child’s sleep so it is important that the characteristics of the light be determined in such a way as to not disturb the child in the process of falling asleep. The brightness of the light is one factor.

To avoid disturbing the child the light should not be too bright but it is crucial that it remain bright enough to be visible from hidden angles such as when the soother is hiding under a blanket, behind a toy or when the knob is angled in an unfavorable position in relation to the child's view. A level of brightness that avoids both of these extremes in an ideal way is difficult to establish but based on the tests conducted in a dark environment we have concluded that an adequate brightness is achieved using one LED. We have also avoided using blinking LED's and instead chosen a continuous illumination.

Regarding the color of the light, color psychology claims found in popular culture suggest that color gives rise to a range of different human responses, both psychological and behavioral. There seems to be general consensus within popular psychology on this matter [14]. However, many of these claims lack concrete empirical support, and may include factoids presented as facts. In addition,
such claims often refer to outdated research without keeping up with current research findings. It is therefore advisable to apply the principle of *caveat emptor* when evaluating magazine articles and internet websites on color psychology [15].

Speculative as these claims may be, they are not necessarily disproved. The fact that the evidence for them is inconclusive does not logically imply that they are necessarily incorrect. Therefore, we have decided to make use of the available information on color psychology because at worst it will have no effects on the child and at best have a positive outcome. We therefore see no reason to ignore the information.

According to color psychology the best suiting color for a light in a crib environment is the color green. An excerpt from a 2009 study by O'Connor [15] exemplifies the general claims made in popular culture about the effects of the color green: “Green is restful, soothing, cheerful...Green is thought to relieve stress” [16].

### 2.5 Prototyping and 3D printing

There are different methods when it comes to manufacturing products. Using 3D printers has become ever more popular. Companies have in the last decades increasingly been using them to create prototypes before mass production [17].

3D printing (aka additive manufacturing) concerns the manufacturing of the casing of the soother prototype. It is a process in which a three-dimensional solid object is produced from a digital model in which the additive process usually consists of constructing an object layer by layer using a given material, be it metal, ceramic or, as in the case of this project, plastic. The technology and it's various processing methods makes use of a wide range of materials that are used in the manufacturing of products spanning from industrial design to medical industries [18].

#### 2.5.1 MakerBot industries Thing-O-Matic 3D printer

The 3D printer used for this thesis project is called the MakerBot Thing-O-Matic [19] and is ideal for domestic use given it's low cost and size, although it is being developed for commercial use as well [20]. The 3D printer functions by using a stepper motor located inside the tool head to feed a plastic rod through the heated tool head (standard temperature: 225 °C). The melted plastic is then extruded out of the nozzle (0.4 mm in diameter) producing the filament that is used for the printing [21]. This filament is then pressed down on the heated automated build platform (ABP) (standard temperature: 125 °C) to build the object layer by layer. Within seconds the plastic cools and hardens to a solid form.
In order for the filament to be laid down on the ABP in a specific geometric shape the ABP is driven by stepper motor controllers to move the ABP from side to side and back and forward along the x- and y-axes while the tool head is controlled to move along the z-axis. Two rubber belts, one for each axis and each attached to a stepper motor are used to guide the movement of the ABP. This mechanism allows the tool head to move simultaneously in three dimensions relative to the build platform. Once the first filament layer has been laid out on the ABP the head is moved up a given step and another layer is then extruded. This layering process enables the construction of a geometrically detailed solid object.

Finally, the ABP is equipped with a conveyor belt. Once the printing is complete the conveyor belt is moved forward to the edge of the ABP from which the printed object can easily be detached and a new printing process can start. The maximum building volume for the Thing-O-Matic is 10x10x10 cm [22].
2.5.2 ReplicatorG

This is the software that drives the Thing-O-Matic. It is used to calibrate the machine. It activates and deactivates the stepper motors and controls the movement, speed and temperature of the extruder head and ABP as well as the flow rate of the filament (mm/sec). When the printing is complete it runs the conveyor belt to eject the printed object.

In relation to the digital 3D model, ReplicatorG processes the STL file of the model and enables the viewing, positioning, rotation, and scaling of the model before printing. A tool-path of the 3D model is then generated. This is called the Gcode. It is a list of commands that tell the computerized machine tools how to build the object.

2.5.3 Gcode

Gcode or the G programming language is the most widely used programming language for CNC machines [23]. The Gcode specifies the building process of the object. It gives instructions to the machine on how to move to various points of the build platform at a desired speed [24] among other things. It specifies the flow rate which is the amount of extruded filament (mm/s), feed rate which is the speed at which the tool head moves relative to the ABP, layer thickness, which is the step the tool head takes along the z-axis for each layer of filament, temperature, and many other parameters. These settings are specified by a chain tool called Skeinforge [25].

2.5.4 Skeinforge

Skeinforge is written in python and it is the most important plug-in for the 3D printer. It is what generates the Gcode. A large range of tool settings can be tweaked through this plug-in to fit ones requirements in the process of perfecting the result of the printed model through the commands of the output Gcode [25].
3. Evolution of the Soother

3.1 Soother functionality

The functional challenge has been to engineer a soother that responds dynamically to a child’s demand for the soother. This can be achieved in a number of ways. The different approaches that were considered are listed in chronological order below.

The initial concern surrounding this project has been about the use of electronic components inside a soother. It was assumed from the start that this approach would encounter too many legal challenges. On this assumption, the original plan was to create a soother with a phosphorescent coating. A UV-lamp suspended from the crib would then be used to illuminate the soother. Finally, a microphone built into a baby monitor would be used to register the child’s cry and trigger the UV-lamp.

Given that the risks of suffering damage from UV radiation, especially to the eyes, are higher in children than adults [26], a target seeker would have to be implemented in order to detect the location and exact boundaries of the soother so that the UV-lamp could direct its beam within the boundaries of the target. This approach is, however, incapable of dealing with cases where the beam between the UV-lamp and the soother is obstructed by other objects such as blankets, toys, or even worse the child itself. So this idea was deemed unpractical and also unsafe.

As was later revealed by the EN 1400 standard, a soother with electronic components could be built without violating the safety requirements. This requires the components to be sealed inside the soother so that no parts are removable. In light of this new information our next approach consisted in integrating a thermometer into the soother itself. Soother thermometers are already widely available on the market [27] [28] [29], however the reason for using one would be novel.

The idea consisted in installing a thermometer inside the teat of the soother. The thermometer, when inside the child's mouth, would reach body temperature and stabilize. Once the child drops the soother a temperature drop would be registered. This would trigger the LEDs and reveal the location of the soother. An additional benefit of using a thermometer is that it could help parents keep an eye on their child’s body temperature. In this way the soother would serve a double function.

The approach ended up being problematic for legal reasons. According to the EN 1400 standard, soother thermometers are only allowed to be used as medical devices [30], meaning that for safety reasons they can only be used in the presence of a parent. This requirement would not satisfy the goals of the project and the idea was therefore discarded.
Also considered was the possibility of adapting the previous concept to make it legal by relocating the heat sensor into the hollow knob of the soother placing it as close as possible to the teat. Another related approach that was considered was to instead place a pressure sensor in the knob that would react to the air flow created by the child's sucking on the teat. This could be used to detect when the child is sucking on the teat and the LED's could be programed to light up when the child stops sucking on the teat.

These last two mentioned approaches, although not being restricted by legal requirements, both proved to have practical limitations. In the first case, placing the heat sensor inside the knob would make it difficult to measure the temperature difference in a reliable way because the sensor and the heat generated from the child's mouth would be separated by the shield. In the second case a pressure sensor could be used to work around this problem. However this too is a limited approach. Children do not always suck on the teat and so when the teat sucking ceases the soother programming would tell it to light up. If this happens in cases when the child drops the soother it's fine. But it could just as well happen in cases when the child just falls asleep. The soother lighting up in this case would only disrupt the child’s sleep and so be counterproductive.

Something that has been mentioned earlier takes us to what is the biggest practical issue using most of these approaches. There is a dynamical aspect that is missing in these approaches. More specifically, there is no way for the soother to detect when the child is actually crying. Most of the above approaches can only help detect when the child has dropped it. So as soon as the soother exits the mouth it would light up whether the child wants it or not. Considering how often children drop their soothers this would quickly consume the battery, not to mention the risk of waking the sleeping child.

So, a night time soother needs to respond dynamically to the child. It is becoming more and more popular for parents to use a baby monitor nowadays. So one way to approach this would be to go back to using a baby monitor with a built-in microphone, only this time it would send a signal directly to the soother when the child is crying thereby illuminating it.

Using a microphone would resolve all the above mentioned practical issues as well as establish a direct and dynamic interaction with the child. The soother is made to light up only when the child is crying. When a certain sound level is registered the LED’s of the soother light up and the child is then able to visually locate and recover the soother.

Attempts to design this baby monitor controlled version revealed that the baby monitor was in fact unnecessary and that the microphone and control logic was small enough to fit inside the soother itself. Needless to say this was preferable from both use and design standpoints since it meant the end user would not need to own a compatible baby monitor nor would it require extensive tests to ensure compatibility with the various baby monitor brands on the market. We could find no reason to reject this design and so decided to settle on this model and construct a prototype.
3.2 Manufacturing

The initial aspiration of this project was to manufacture a prototype that would fulfill the complete list of requirements specified in the EN 1400 standard. These relate to the materials and chemicals used as well as the mechanical tests that the soother needs to undergo before it can be put on the market. Getting through this process requires CAD constructors and expensive machines as well as other services whose cost far exceeded the budget available for this project and it was therefore decided to exclude this particular aim from the project.

Some time later the authors were introduced to the Thing-O-Matic printer at KTH. Although the printer can build detailed solid objects it is not an advanced printer able to handle the materials needed for a marketable soother, such as the silicon for the teat for example. It is however possible to build a scale model with it that can be used to approximate what a final product can look like and be used to ensure that the internal electronics will fit inside the casing of the soother.
4. Design

4.1 Overview

The soother 2.0 is a knob type soother with the electronic components mounted inside the hollow knob. The knob is made out of a semitransparent material and can be lit up using an internal LED which draws the attention of the child and allows the soother to be located in the dark.

The soother functions by using a microphone to detect the sounds made by the child and a microcontroller to decide when to activate the LED based on the sound pressure level (SPL) of the noise. Once activated the LED remains lit long enough to allow the child time to recover the soother. In the prototype this time period is 5 seconds as an initial estimate, however this will need to be refined once tests with actual children are carried out.

The trigger level of the soother needs to be set low enough to detect the child crying even when the sound is dampened by an obstacle such as a blanket while still being insensitive to environmental noise such as a conversation or noise from a nearby road. The lower limit is simple enough to determine using data from tables such as [31] and should be at least 70, preferably 80 dB SPL. Reliable data regarding the sound pressure of a crying child has proven much more difficult to locate, however the study [32] found average sound pressure levels above 95 dB SPL. Seeing that the SPL of the crying child is considerably higher than the 80 dB SPL level to filter environmental noise 80dB SPL was initially selected as the trigger level. However breadboard tests (see 5.1 Simulation & Breadboard Tests) revealed that this was too sensitive to speech and the trigger level was adjusted to 83.5dB SPL. Finally it should be noted that these values have not been tested in a crib environment and that such tests should be carried out to fine tune the trigger level.

The general safety requirements set by the EN 1400 standard state that the knob be 10 mm to 16 mm high. Using a flexible material to increase this limit is permitted but this would be difficult given that it would require the electronic components to also be flexible. The EN 1400 also states that there be no removable parts. The first requirement can be met by ensuring that the electronic parts are small enough to fit into a knob less than 16 mm high. The second requires that there be no removable cover through which the internal components can be accessed, that is to say the knob must be permanently sealed before the soother is put into the hands of a child.

This places special requirements on the power supply which cannot be accessed and replaced and will therefore need to last long enough to allow the soother 2.0 a lifetime that is considered acceptable to parents when compared to it's cost. Preferably the soother 2.0 should have a lifetime similar to that of a standard soother, which manufacturers commonly state as one month[33][34]. Subsequent tests run on the prototype (see 5.5 Prototype Tests) showed a battery lifetime of 45 days and the soother 2.0 should therefore have the same lifetime as a normal soother assuming the casing is made from the same materials.

The cost of a production model of the soother 2.0 can be estimated from the cost of a normal soother by adding the adding cost of the electronics. The cost of a classical knob type soother in Sweden ranges between 39 and 79 SEK depending on design and manufacturer [35]. Although the
particular design for a market model of the soother 2.0 casing will need to take into account the fitting of the electronics, the cost of such a design should not differ much from the design of classical soother given that it only concerns the dimensions of the knob and possibly some internal shape to hold the electronics in place. The electronic component cost for our prototypes meanwhile was 70SEK however cost reductions from the order of larger quantities of components would at least halve component costs. The cost for manufacture and assembly of the PCB and mounting of the PCB in the soother would need to be added and a rough guess would put this, for such a low component count, slightly below the cost of the BOM. This would put the cost of the electronics at roughly 70SEK which when compared to the 39-79SEK cost estimated for the casing would suggest a retail cost for the soother 2.0 of two to three times that of a classical soother.

<table>
<thead>
<tr>
<th>Size, Knob &amp; Cover (LxWxH)</th>
<th>41x26x16 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size, Total (LxWxH)</td>
<td>73x47x43 mm</td>
</tr>
<tr>
<td>Weight, Casing</td>
<td>10.5 g</td>
</tr>
<tr>
<td>Weight, Electronics</td>
<td>7.7 g</td>
</tr>
<tr>
<td>Trigger Level</td>
<td>83.5 dB SPL</td>
</tr>
<tr>
<td>LED On-Time</td>
<td>Signal Duration + 5s</td>
</tr>
<tr>
<td>Battery Lifetime</td>
<td>45 days</td>
</tr>
<tr>
<td>Cost, Prototype Electronics</td>
<td>70 SEK</td>
</tr>
<tr>
<td>Estimated Production Cost, Total</td>
<td>109-159 SEK</td>
</tr>
</tbody>
</table>

*Table 2: Soother Specification Overview*

### 4.2 Electronics

The soother electronics, pictured in figure 4, are built around a PIC12F615 model microcontroller chosen for it's small size, low power consumption and cheap price. The trigger signal is sensed using the microcontrollers built-in comparator, which compares the amplified microphone signal against the built-in 0.6V passive reference. Once a peak higher than the reference is registered the PIC illuminates the soother by powering a LED.

![Block diagram showing signal (dashed) and power (solid) connections.](image)

*Figure 3: Block diagram showing signal (dashed) and power (solid) connections.*
The desired trigger level is 83.5 dB SPL or 0.3 Pa overpressure. The PVM-6052 microphone used has an output signal of 12 mV per Pascal of overpressure which means that a 0.3 Pa sound wave input creates a 3.6 mV AC-signal. As the voltage reference on the microcontroller is 0.6 V an amplification of 167 times, that is 44.6 dB, should be ideal.

<table>
<thead>
<tr>
<th>Ref</th>
<th>Maker</th>
<th>Part Number</th>
<th>Description</th>
<th>Qty</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>Microchip</td>
<td>MCP6002-I</td>
<td>Dual, low-power op-amp</td>
<td>1</td>
<td>2.70 SEK</td>
</tr>
<tr>
<td>U2</td>
<td>Microchip</td>
<td>PIC12F615-I</td>
<td>Low-power, 8 pin microcontroller</td>
<td>1</td>
<td>10.20 SEK</td>
</tr>
<tr>
<td>D1-2</td>
<td>NXP</td>
<td>BAT54</td>
<td>Schottky Diode</td>
<td>2</td>
<td>2.06 SEK</td>
</tr>
<tr>
<td>Q1-2</td>
<td>Diotec</td>
<td>MMFTN3018W</td>
<td>N-channel MOSFET</td>
<td>2</td>
<td>1.58 SEK</td>
</tr>
<tr>
<td>C1</td>
<td>Murata</td>
<td>GRM188R60J106ME47D</td>
<td>X5R ceramic capacitor +/- 20%</td>
<td>1</td>
<td>2.36 SEK</td>
</tr>
<tr>
<td>C3-5</td>
<td>Murata</td>
<td>GRM188R71H104KA93D</td>
<td>X7R ceramic capacitor +/- 10%</td>
<td>3</td>
<td>0.81 SEK</td>
</tr>
<tr>
<td>C2,6,7</td>
<td>Murata</td>
<td>GRM188R71E224KA88D</td>
<td>X7R ceramic capacitor +/- 10%</td>
<td>3</td>
<td>3.03 SEK</td>
</tr>
<tr>
<td>R1-9</td>
<td>Vifay</td>
<td>D10/CRCW0402</td>
<td>Resistances 0.063 W +/- 1%</td>
<td>9</td>
<td>2.16 SEK</td>
</tr>
<tr>
<td>LED</td>
<td>Everlight</td>
<td>1254-10SYGD/S530-E2/T2</td>
<td>2V green LED, diffused, 63 mcd</td>
<td>1</td>
<td>2.98 SEK</td>
</tr>
<tr>
<td>MIC</td>
<td>Vansonic</td>
<td>PVM-6052</td>
<td>Electret microphone, 12 mV/Pa</td>
<td>1</td>
<td>18.20 SEK</td>
</tr>
<tr>
<td>PWR</td>
<td>VARTA</td>
<td>CR 2032 SLF</td>
<td>3V, 230 mAh lithium battery</td>
<td>1</td>
<td>16.80 SEK</td>
</tr>
<tr>
<td>PGM</td>
<td>Molex</td>
<td>53398-0671</td>
<td>1.25 mm pitch, 6-pin header</td>
<td>1</td>
<td>6.77 SEK</td>
</tr>
</tbody>
</table>

Table 3: Soother 2.0 bill of materials. Cost refers to total cost for all parts of that type.

Amplification is provided by a two stage active high-pass filter. This design prevents any amplifier offset voltages and currents from getting amplified. The two amplification stages are identical and each uses one of the U1 capsule amplifiers in a non-inverting configuration with a simple low-pass feedback circuit that provide unity gain for DC voltages and 13 times amplification for the signal. This gives a total amplification of 169 times and a trigger level of slightly less than 83.5 dB SPL. Since the design is insensitive to large offsets, and has low demands for amplification and slew rate, it allows the choice of op-amp to be governed by price and power consumption, and the selected op-amp is therefore the MCP6002.

The amplified input signal is routed to the microcontroller input through a passive high-pass filter to remove the bias voltage needed by the microphone and a Schottky diode to protect the input from the negative part of the AC signal. Once the microcontroller detects a trigger signal it controls the illuminating LED by means of an output pin tied into a transistor switch Q2 acting as an on/off switch for the connection between the LED and GND. Space for a second LED is provided by the design, however only one LED is used in the prototype to reduce power consumption.

3V power is provided by using a single lithium button cell battery mounted against the interior bottom wall of the soother knob and wired to the main PCB. The requirements of the EN 1400 standard prevents replacement of the battery and extending battery lifetime by keeping power consumption low is therefore a high priority. The dominant current consumer is the LED. However this is expected to be on for only a negligible fraction of the total soother lifetime and power saving measures are therefore focused on the microcontroller and the input stage.
The simpler of these is the microcontroller. Like most modern low power microcontrollers the PIC12F615 chosen has the ability to enter a sleep mode in which it draws less than 70μA even with the built-in comparator enabled. The processing time needed to control the circuit is low allowing the PIC to spend more than 99.9% of its time in sleep mode.

To decrease the current consumed by the input stage a duty cycle scheme is implemented by having a transistor switch Q1 control the microphone and amplifier GND connection. The period and on-time of this cycle is dictated by two factors. First the minimum on-time is determined by the settling time needed for the turn-on noise of the active filters to fall below the activation threshold. Prototype tests show the safe limit here to be 30 ms (see 5.1 Simulation & Breadboard Tests). Beyond this minimum requirement the on and off times are a trade off between battery lifetime and responsiveness. Tests carried out using the prototype suggest that a 684 ms period with a 16% duty cycle is the least power consuming setting that does not result in a degradation of the signal response in a way that is noticeable to a human.

Further the microphone requires a voltage bias of 1-10V which the resistor R1 provides as a bias of 1.5V. Current limiting resistors R8, R9 provided for each LED connection limit the current to less than 20mA. Bulk capacitance is provided by C1 while C2 and C7 act as bypass capacitors. The connector header PROGRAM as well as the resistor R7, capacitor C6, and Schottky diode D2 are added into the circuit in accordance with the PIC12F615 datasheet and provide low voltage detection for the microcontroller as well as allowing in-circuit programming of the PIC through the header using a compatible programmer.
Figure 4: Schematic of the soother 2.0 control circuit
4.3 Software

The PIC12F615 code is written using mikroC PRO for PIC [36] and the full source can be seen in Appendix B: PIC12F615 Code. The flow schematic seen in figure 5 gives an overview of the main soother 2.0 control loop flow. The starting point on power up is an initialization stage in which I/O pins, interrupt controls, and the on-board comparator are setup. Once this setup is complete the PIC enters it's main control loop starting in the longer wait (sleep) step to give the circuit time to settle.

The main control loop consists of two branches. The microcontroller is expected to spend the majority of it's time inside the left branch in which the input stage and comparator are toggled on and off at regular intervals in a duty cycle scheme meant to conserve power and extend battery life. This cycle consists of two wait (sleep) blocks separated by code to enable or disable the input stage and comparator. A third shorter wait (sleep) block is also included between the input stage enable and comparator enable to prevent noise generated during power up of the input stage from creating false trigger events. The necessary time delay between the two was determined trough tests (see 5.1 Simulation & Breadboard Tests) to be at least 30 ms. For the same reason it is also crucial that the comparator be disabled before the input stage.

![Flow Chart schematic of the soother 2.0 control code. Note that sleep times are approximate and depend upon microcontroller power supply voltage and temperature.](Image)
The right branch is entered only when the PIC receives a trigger event from the on-board comparator. While inside this branch of the loop the LED is illuminated and the input stage and comparator are kept permanently enabled to better catch the end of the trigger signal. When the trigger event is ended by the signal falling below the trigger level a loop iteration counter starts decreasing to create the turn-off delay between the end of the signal and deactivation of the LED. Once this counter reaches zero the microcontroller returns to the left branch in the flow diagram.

To conserve power the PIC12F615 can enter a sleep mode in which processing is suspended until a wake-up signal is received. This wake-up signal can be generated either by the microcontroller watchdog timer (WDT) or by a peripheral interrupt. Both of these methods are utilized in the soother 2.0 control code.

Typically the PIC will be woken by the WDT which is set before entering sleep mode and which has it's own separate clock source and so does not suspend with the main system clock. This allows the WDT to count down during sleep, and upon reaching zero generates an interrupt signal that wakes the microcontroller. The WDT has a nominal 18 ms countdown time, though a prescaler can be used to multiply the time by up to 128 times. It should also be noted that the WDT countdown time can vary considerably depending on the power supply voltage and the microcontroller temperature but this is not a problem for this project as the system controlled has no need for precise timings.

The second type of wake-up used is provided by a peripheral interrupt coming from the on-board comparator which continues to operate during sleep mode if enabled. This allows the microcontroller to wake up if a trigger event is detected allowing an immediate response to the triggering signal. It should be noted however that the way the sleep mode is implemented on chip means that the PIC will only enter interrupt mode to deal with the incoming signal on it's second instruction after waking this way. To avoid any difficulties the first instruction after wake-up is therefore always a no operation call in the code.

### 4.4 Casing

The design of the knob is the main focus concerning the casing because it is where the electronic components are fitted. The design of the knob needs to be spacious enough for the electronics to fit within the mentioned height limit of 16 mm. The electronic components will in turn need to be organized in a spatially economic way. Given that the EN 1400 standard only places restrictions on the height of the knob there is the possibility of making adjustments to the width and length while still preserving the functional design of a soother so that the child can handle it with ease.

The height of the knob is 14 mm. The cover sealing the knob contributes an additional 2 mm giving a total height of 16 mm, which is the limit specified by the general safety requirements. This means that the battery, LED and microphone, as well as other smaller components such as resistors, transistors and capacitors need to be organized on the PCB in a way that will minimize the total height of the assembled electronics allowing them to fit within the mentioned limit. This is done by making full use of the length and width of the knob. The PCB is therefore shaped after the oval design of the knob giving the electronic components the necessary space for their organization. The interior dimensions of the knob that fulfill the height requirements are $35 \times 21 \times 14$ mm (LxWxH).
The physical dimensions of the main electronic components are:

**Battery**: Diameter: 20 mm, Height: 5 mm.

**Microphone**: Diameter: 6 mm, Height: 5.2 mm

**LED**: Diameter: 3.2 mm, Height: 5.1 mm

**Circuit board**: Length: 34 mm, Width: 20 mm, Height: 1.6 mm

As can be seen in figure 6 the hollow knob of the soother is complemented by an attachable cover allowing for the electronic components to be sealed in and isolated from any direct and potentially harmful contact with the child. This also fulfills the requirement that the soother shall have no removable parts. The knob needs to also be waterproof to prevent electric shocks to the child as well as the preservation of the electronic components. In a production line model the process of sealing and waterproofing can be done by for example gluing the cover to the knob using a silicone waterproof sealant. A waterproof soother also facilitates the sterilization of the soother, which is recommended be done on a regular basis.

*Figure 6: View of the hollow knob into which the electronics are mounted. The electronics are sealed in by the cover.*
5. Implementation

5.1 Simulation & Breadboard Tests

To ensure that the electric circuit would work as intended tests were run using simulation software and a breadboard build before constructing the prototype.

The first concern was to check that the input stage concept was sound by means of simulation. The first input stage design involved a passive high-pass filter to remove the DC voltage followed by an active high-pass filter intended to provide amplification. Simulations were carried out using Cadence OrCAD v9.2 [37] using a model of the MCP6002 [38]. These simulations revealed that the microphone would not be capable of driving the capacitance of the passive filter. To fix this the filter order was switched so as to have the microphone connect directly to an opamp in the active filter. This version functioned better and showed a simulated amplification of 44.55dB very close to the expected 44.6dB. An attempt was also made to simulate the turn-on noise of the filters but no useful results were obtained. Our continued uncertainty as to whatever the active filter solution would function as desired lead to the construction of a breadboard version of the circuit.

![Figure 7: Schematic of the simulated network containing the two stage amplifier and the passive filter.](image)

Testing was complicated by having access to neither a sound meter or an AC signal source capable of outputs in the low digit millivolt range. Lacking these tools the test signal had to be generated by connecting a PVM-6052 microphone to the amplifier-filter circuit set up on the breadboard and having a human speak or shout into it at varying levels of loudness. While this was sufficient for testing and tuning the trigger level well enough for a functional prototype it left the authors incapable of collecting accurate measurements of the exact trigger SPL. As such the numerical trigger level had to be estimated by assuming that all components were functioning according to their specifications and calculating the theoretical trigger level from the amplification and output voltage. The trigger level was tuned by varying the resistances R3 and R5, speaking at the microphone in a normal conversational tone from 1 meter, and checking the peak output voltage using an oscilloscope. Using this procedure the trigger level was tuned until the amplifier-filter output voltage peak fell just below 0.6V at which point the trigger level was calculated to 83.5dB SPL.
Including the microcontroller and LED into the breadboard test circuit proved considerably more time consuming due to difficulties in creating and debugging the PIC12F615 code. Once correctly programmed however the circuit functioned as intended with the LED lighting up when triggered and remaining lit for the programmed duration.

Finally the duty cycle scheme was tested by rerouting the microphone and amplifier VSS connections through a transistor switch controlled by the microcontroller. As expected noise caused by the input stage powering up triggered the LED causing it to blink. To counteract this a wait period was added between enabling the input stage and the comparator in the microcontroller code. The duration of this wait period was then varied in the code until finding the minimum time needed to prevent the input stage noise from triggering the LED which was determined to be 30 ms. Once a stable minimum had been determined the time period and on-time was tuned by attempting to maximize the off-time without introducing any lag or irresponsiveness noticeable to a human. The best settings found had a 684 ms period with 16% on-time.

5.2 Prototype Casing Manufacture

The manufacturing of the prototype casing was done using a Thing-O-Matic consisting of a motherboard with microcontroller (v2.4) (firmware motherboard v2.81), an extruder controller (v3.6) (firmware 2.92), a MK6 tool head and an automated build platform (ABP). An Intel Q35 PC, running Linux OS, is first connected to the printer via USB. The machine type and serial port connection is then selected in the ReplicatorG software as shown in figure 8 and 9. These three steps link the software to the printer, after which one can connect to the machine.

![Figure 8: Selecting the machine type that corresponds to the Thing-O-Matic](image)
5.2.1 From STL file to Print

There are five main steps in this process. The first is opening the STL file into the ReplicatorG software. The second is adjusting the position, rotation, and scale of the model. The third is calibrating the machine. The final step before printing is generating the Gcode.

Scaling the STL file in ReplicatorG

The digital model of the soother was acquired from GrabCAD [39]. The STL file of the model is dragged over to the ReplicatorG window upon which an automatic rendering process of the file begins allowing for the viewing and manipulation of the model. One can make the necessary rotational, scaling and positioning adjustments that will be reflected in the print. Because the ReplicatorG does not provide the option for measuring dimensions before hand, establishing the exact dimensions of the print where problematic. Several printouts at different scale values where therefore necessary to achieve the required dimensions. The smallest print that enables the insertion of the 20 mm battery has a knob height of 14 mm and is equivalent to the scale value of 0.89 of the original model.
Calibration

The next step is to calibrate the machine. This ensures that at the start of the printing the tool head will move down and center its nozzle on the surface of the ABP in such a way that the first layer of the extruded filament sticks to the ABP while moving along the surface of the platform. This first layer is crucial for the outcome of the following layers and so the filament should neither be too heavily pressed, nor too loose on the ABP. The outcome also depend on the flow rate and feed rate specified in the Gcode and can vary depending on the model. Also the condition of the conveyor belt is a determining factor here. Therefore, the best way to ensure a successful result is to check the calibration and if necessary adjust it to fit the outcome of the model.

There is a standardized calibration that works well for most 3D printer models. The calibration process consists in moving the ABP to a centered position and bringing the nozzle down to the platform leaving just enough space for a sheet of paper between the ABP and the nozzle. This is done through the control panel in ReplicatorG. However the MK6 Thing-O-Matic used in this project yielded much better results with a slightly modified calibration. The calibration yielding the best print results in this project were achieved by finalizing the procedure manually and applying a light amount of pressure on the ABP surface with the nozzle without leaving any space in between. This is done by manually rotating the Z-rod and moving the tool head down to a position where the nozzle gently presses on the platform. This manual method provides a good feeling for the applied pressure, something that is more difficult using the control panel alone. Once the position of the nozzle is set, the "build" button completes the calibration. These steps are illustrated in figure 11
and 12.

Figure 11: Selecting the machine for calibration script.

```
(* *  Thing-O-Matic calibration gcode  * *)
(* *  *** This script will guide you through *** *)
(* *  *** the start position *** *)
(* *  *** *** *)
H108 (This disables the stepper motors.)
H01 (Move the build platform until the nozzle lies in the center, then turn the threaded rod until the nozzle...)
G92 X0 Y0 Z0 A0 B0 (Declare the current position to be (0,0,0,0,0))
G162 Z7500 (Move z-axis maximum; go until reaching the end stop.)
G161 X Y Z 5000 (Move X and Y-axis minimum; go until reaching the end stop.)
M131 X Y Z A B (record the current coordinates to the motherboard)

H00 (Congratulations, your coordinates are now saved! To tweak them, use the 'Motherboard Onboard Preferences'.)
```

Figure 12: Calibration script.
Generating Gcode

Before generating the Gcode the 3D model must be positioned on the ReplicatorG platform otherwise the Gcode will tell the tool head to either start extruding above the surface of the ABP or drive through the ABP causing damage to the machine. Generating the Gcode can take anywhere between one and five minutes, depending on the size and complexity of the object. The commands of the Gcode will then appear on the screen. They will include a start code, which prepares the machine for printing, the Gcode for the actual model, and finally an end code, which prepares the machine for shut down. See Appendix A: Gcode for the start- and end-Gcode. To generate the Gcode one simply presses the “generate Gcode” button in the ReplicatorG window.

Printing

Originally the soother was going to be printed in one piece (separate from the cover). However, there was a problem with this method. The printer builds from bottom to top and the shield stretches horizontally beyond the edge of the knob (see figure 1). So, unless a support raft is provided, the soft filament for building the shield will fall off when being laid out horizontally.

Instead of building a support raft, this issue was resolved by modifying the model itself using a full-featured freeware edition of netfabb® Studio [40]. The modification of the soother model consisted in cutting [41] the model into separate parts. The shield was cut loose from the rest of the soother and the knob was cut loose from the teat. This allows for the rescaling and single manipulation of the knob alone in order to preserve the realistic appearance of the soother once reassembled. Printing each part separately especially allows for a printing process that is more compatible with the printing method of the Thing-O-Matic.

To print one simply hits the “build” button, the same button used in the calibration stage, and the machine takes over from there and does the rest. Shown in figure 13 is a picture of the printer in its initial stage of printing the cover.
5.2.2 Encountered problems and solutions

Abnormal shape of model:

One problem that was encountered toward the end stage of the project concerned an abnormality in the geometrical shape of the printed model. This usually happens if the ABP does not move as it should in the x and y directions. There may be objects in the way of the platform not allowing it to move freely or, as in our case, the rubber belt may be too loose on at least one of the axes. To tighten the belt we needed to loosen the bolts to the wooden plate protecting the stepper motor that the belt was attached to and then loosen yet another set of bolts that kept the stepper motor in place. This allowed us to slide the stepper motor and tighten the belt.

A lot of maintenance work done on the printer requires the removal of bolts. Worth mentioning is the fragile nit-picking required to detach and reattach bolts without dropping the nuts inside the printer. It can be extremely difficult to recover them if this happens. A practical and reliable way to avoid this from happening is to tape the exits of the nuts before removing the bolts so that they stay in place during the maintenance work after which the reassembly process becomes quick and easy.
Figure 14: A tightened rubber belt and position of the bolts.
Worn out conveyor belt:

A conveyor belt usually lasts a fairly long time. However, when it is time to replace it, the operation can be a little tricky. In our case the wear and tear of the old conveyor belt was starting to affect the results of the prints so a replacement was necessary.

The replacement procedure is done as follows: Taping all six exits of the nuts belonging to the ABP surface bolts. These can be seen on the edge of the ABP in figure 15; Removing all 6 bolts from the ABP surface; Lifting out the rods on both ends of the platform from their locked position; Sliding the conveyor belt out; Cleaning the ABP surface; Applying the new conveyor belt; Repositioning the rods and re tightening the bolts.

Extrusion problems:

A frequently encountered problem using the printer has been concerning the extrusion of the filament. If the filament doesn't flow properly the quality of the print can be drastically affected. See figure 16.
Several approaches are useful in solving this problem. The first is to check if the plastic rod being fed into the tool head may be stuck somewhere along the path from the filament bundle under the printer to the tool head. If the rod is stuck it will prevent the stepper motor from pulling plastic through the tool head. This is easily remedied by locating where the rod is blocked and then manually freeing it.

Another cause of extrusion problems may be the lack of grip between the stepper motor and the plastic rod, in which case one will observe the motor spinning in an attempt to feed plastic without any movement from the rod. This is fixed by checking the tightness of the bolt which keeps the rod and the stepper motor pressed tightly against each other. One may also need to check the speed of the stepper motor in ReplicatorG. The default value should be 1.98 RPM.

Optimizing print quality:

The main challenge during most of the time spent working with the Thing-O-Matic has been to improve the quality of the prints. Low quality prints have often been the result of too thinly extruded layers of filament. In such cases the quality of the prints deteriorated during the course of the printing process as can be observed in figure 16 where the quality of the shield deteriorates from left to right. This is indicative of a problem with the flow rate (mm/s).

Figure 16: Soother shield built with insufficient flow rate.
To optimize the print quality there are a number of parameters that can be tweaked. Tweaking the Gcode itself proves to be unpractical because most parameters, such as the layer thickness, feed rate and the various flow rates require altering large parts of the Gcode. This is where Skeinforge comes in to facilitate the adjustments (see 2.5.4 Skeinforge). In Skeinforge one can easily adjust countless parameters as well as redefine the building path for the printer.

One of the most important parameters is the layer thickness. This controls the resolution of the print given that it defines the thickness of each layer. We lowered this value and made changes to the feed rate as well as the flow rate. However, the new Gcode resulting from the altered parameters proved to be incompatible with ReplicatorG on our given PC setup for reasons that were never established. We had to find a different way to work around this problem.

Our new approach consisted in measuring the flow rate for different extruder head temperatures. Although the recommended temperature is 225 °C, slightly raising the temperature proved to be very helpful. It was however important to be careful not to damage the conveyor belt with an overheated extruder head.

We collected data to show the relation between flow rate and temperature (see figure 17. This was done by extruding filament at different temperatures using a fixed duration for the extrusion, a standard motor speed of 1.98 RPM and then weighing the filament for each trial using a precision scale.

![Figure 17: Flow rate variation through temperature.](image)

Figure 17: Flow rate variation through temperature.
From the plot it can be seen that at higher temperatures there is a significant increase in flow rate. Raising the temperature too high would increase the flow rate to the point where the filament would start to be pressed beyond the borders of the outline of the model resulting in uneven surfaces. Based on the various trials the best prints were observed at an extruder head temperature of 235 °C. This adjustment resulted in a well defined prints as shown if figure 18 & 19.

Figure 18: Good quality print of the soother teat.
5.3 Prototype PCB

Knowing the required circuit topology as well as the physical dimensions of the casing our next step was to design and manufacture a circuit board to mount into the soother. Layout of the PCB was done using the open source software suite KiCad [42] and proved fairly straightforward despite the lack of prior experience.

The layout is two sided with the back side used only for signal traces. All traces are 10 mils wide using a 55 mil via with a 22 mil hole where needed. All components used are surface mount so as to save space. External components such as the battery and microphone are connected using a simple 2 pad solder terminal with each pad being 67 mils across with a 37 mil hole trough which the connecting wire is threaded. Vias were placed so they could double as test points and an additional four 55 mil diameter circular test points were added to ease debugging and testing the circuit board.

A second revision of our PCB ended up being necessary due to the first version not fitting into the casing. Thankfully this was discovered before manufacture of the PCB and could therefore be corrected by adopting a partially oval layout and adjusting traces and footprints to fit within the new outline. The final layout can be seen in figure 20.
Manufacture of the PCB was done using a LPKF ProtoMat S42 [43] milling machine with no issues worthy of note occurring.

5.4 Prototype Assembly

The electronic components were manually soldered onto the PCB following a three part guide [44] and a PCB layout map as shown in figure 20.

The cables to the battery run on the bottom side of the PCB where the isolated battery lay flat on the bottom surface of the PCB. The LED terminal pins have been shortened to minimize the space between the LED-head and the top surface of the PCB. The cables to the microphone are laid down on the PCB with the same minimized distance between the microphone head (also isolated) and the PCB. These main components are positioned on spaces of the PCB that are free from other components in order to save space. The highest point from the surface of the top side of the PCB is reached by the LED and Microphone at approximately 6 mm. The 5 mm thick battery reaches approximately 6 mm below the PCB. Together with the 1.6 mm thick PCB the thickness of the
The electronic system is a total of nearly 14 mm, which is equivalent to the total height of the knob. Finally, the oval edge of the PCB is mounted to the inside walls of the knob by applying a layer of hot glue in between the two.

5.5 Prototype Tests

To ensure that the prototype was working properly, it was exposed to noise in the form of an audio recording of a small child crying. The tests showed that the soother responded consistently to sound with no noticeable delay visible to the human eye. In addition, the test was conducted at different sound levels. The prototype responded at a level just above a normal conversational tone.

With the prototype working as intended, tests were run to determine the current draw and ability of the soother to operate at lower than intended voltages in order to approximate battery lifetime. First, the soothers behavior at voltages lower than the intended 3V was tested. The test was carried out by connecting the circuit board power connectors to a lab power supply instead of a battery. By varying the voltage it was found that the soother operated as intended down to 2.4V, after which the prototypes responsiveness to sound gradually worsened down to 2.1V, at which point it stopped responding entirely.
Next the current consumed by the circuit during the on and off stages of its duty cycle was measured. This was done by connecting the circuit board power connectors to a lab power supply in series with a multimeter and then reprogramming the microcontroller so the input stage was constantly on or off. The multimeter measurements showed that at 3V there was a 0.47mA current draw with the input stage enabled and a 0.08mA draw with the input stage disabled. This means that with a 16% duty cycle the soother will draw approximately 0.15mA when the LED is not active. Finally the current draw with the LED active was measured by reprogramming the microcontroller to keep the LED constantly active. The measured current draw with the LED active was 13.7mA.

An approximate cell capacity for the Varta CR2032 button cell battery used can be found from Varta provided technical data [45]. Judging from this data it seems reasonable to assume a cell capacity close to 230mAh. Assuming then that the LED is active for less than 0.5% of the total soother lifetime, 230mAh should provide a soother lifetime of at least 40 days. Considering that the soother 2.0 will spend most of it's time in stand-by while the child sleeps, the actual time the LED is active should be considerably less than 0.5%, giving the soother 2.0 a battery lifetime well above the single month desired.

After this, the minimum time needed for the input stage to stabilize after being turned on was measured by decreasing the duration of the wait period between the input stage enable and the comparator enable until the noise created by the input stage powering up activated the LED. The minimal period needed to avoid activations from this noise was found to be the same 30 ms as during the breadboard tests.

The final test concerned the actual lifetime of the battery. For this the soother was exposed to music at a volume just above the trigger level for 10 minutes daily, that is to say slightly more than 0.5% of the total time. This test was continued until the soother no longer responded to the music. The battery lasted for 45 days under this test scheme.

![Figure 22: Assembled and functioning soother prototype](image)
6. Conclusion and Further Development

6.1 Conclusion

We have managed to find a method by which to detect when a child craves their soother and a means by which to illuminate the soother to aid the child in recovering it. We have also shown that our circuitry can be made small enough to fit inside a soother and comply with the general safety requirements for soothers. As such we consider this project to have been completed successfully.

The soother has been designed to detect the cry of a small child, which we consider to be a suitable indication of the child craving their soother. This method of detection also acts as a reliable way of ensuring that the soother will not disturb the sleeping child because any noise capable of activating the soother would in itself be enough to wake the child.

When triggered the soother lights up by means of an internal LED, and while we have not had any opportunity to test this with an actual child the illumination is quite clear in a dark room and should allow the child to find the soother in the dark.

It is important to note that the prototype developed in this project does not itself comply with the full list of requirements specified in the EN 1400 standard. Nor was it our intention. Given the limited resources, regulations concerning materials and construction could not strictly be followed. We have however demonstrated that it is possible to develop a soother that complies with the EN 1400 standard given that we have worked within the boundaries stated in 2.3 General safety requirements. This means that is is possible to develop a marketable soother of the kind elaborated in this project.

There are also other standards that electronic equipment needs to comply with for sale in Sweden. However since these all relate to the electrical safety and reliability of a product and since we have not used any nonstandard parts or designs in our soother we are confident that it could pass these tests with at most minor modifications.

Considering that the retail cost of the soother 2.0 would be two to three times that of a classical soother, that is to say between 100 and 160 SEK, with a similar lifetime before needing replacement the authors see no reason why the device should not be economically viable as a product. The cost is higher than that of a classical soother but not so high as to be an unreasonable expense for parents that find the extra functionality useful.

6.2 Further Development

In the above proof of concept we have realized the soother 2.0 idea and demonstrated its feasibility. There are however several technical and conceptual aspects that need further consideration in order for the soother 2.0 to be introduced as a market product.

First of all a solution is needed to prevent depletion of the power supply while the product is still in
its packaging. An on/off switch may need to be incorporated into the design for that purpose. An even better alternative would be to use inductive charging to provide a way to recharge the battery without opening the soother. One issue here is the increased cost as well as the available space and weight of the soother.

The LED timer also needs further work to make the soother more child-friendly. How long should the soother stay lit after the child's cry has subsided? That is, how long should the LED remain active after being triggered? This needs to be tested in a crib environment for more conclusive results. A fade in/out function is worth considering as well.

This brings us to a related question. What should the exact threshold dB level be that activates the soother? As of now the soother is activated at a level slightly above normal speech. But depending on the position, distance and angle of the soother the optimal sound level for triggering the soother can vary. For instance, a child would need to cry louder to activate the soother if the microphone is covered by a blanket. The trigger-sound level needs to be tested on real subjects in order to determine a dB SPL level that can be implemented to make the soother more child-friendly. This should be done by monitoring how the soother functions in a crib environment.

For a market product of the soother 2.0, a better casing would need to be designed to allow for a proper sealing of the knob. The physical dimensions of the shield and teat need to be standardized and the manufacturing process needs to meet the requirements of the EN 1400 standard.

Relating to the future conceptual evolution of the soother, one beneficial feature would be to incorporate a speaker into the soother that plays soothing sounds when the child is crying. A recorded voice of the mother may be ideal for this purpose.

Another possibility is the inclusion of a wireless transceiver into the circuit which could be used to have the soother act as a baby monitor allowing the parents to monitor the child trough a smartphone or other internet connected device. Also worth considering in this case is the implementation of new available technology who's function is to detect, through the cry of the child, one of a number of states such as stress, hunger, discomfort, boredom, or sleep [46]. The registered state of the child could in turn be sent to one of the parents who will then be able to take the appropriate measures in assisting the child, possibly even by controlling the soother using the wireless link.

Finally, the project can be extended with respect to the parents along the lines of social networking allowing for feedback to the parents and activity logging. A Facebook group could be a starting point to introduce the concept.
References


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URL(http://www.mikroe.com/mikroc/pic/)

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# Appendix A: Gcode

This appendix contains the start and end code which applies to every part of the soother model. The complete Gcode for the soother will be provided upon request. Contact: [wildor@kth.se](mailto:wildor@kth.se)

<table>
<thead>
<tr>
<th>Gcode: start code</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&lt;alteration&gt;)</td>
</tr>
<tr>
<td>(**** beginning of start.Gcode ****)</td>
</tr>
<tr>
<td>(This file is for a MakerBot Thing-O-Matic)</td>
</tr>
<tr>
<td>(**** begin initialization commands ****)</td>
</tr>
<tr>
<td>G21 (set units to mm)</td>
</tr>
<tr>
<td>G90 (set positioning to absolute)</td>
</tr>
<tr>
<td>M108 R1.98 (set extruder speed)</td>
</tr>
<tr>
<td>M103 (Make sure extruder is off)</td>
</tr>
<tr>
<td>M104 S225 T0 (set extruder temperature)</td>
</tr>
<tr>
<td>M109 S125 T0 (set heated-build-platform temperature)</td>
</tr>
<tr>
<td>(**** end initialization commands ****)</td>
</tr>
<tr>
<td>(**** begin homing ****)</td>
</tr>
<tr>
<td>G162 Z F500 (home Z axis maximum)</td>
</tr>
<tr>
<td>G92 Z10 (set Z to 0)</td>
</tr>
<tr>
<td>G1 Z0.0 (move z down 10)</td>
</tr>
<tr>
<td>G162 Z F100 (home Z axis maximum)</td>
</tr>
<tr>
<td>G161 X Y F2500 (home XY axes minimum)</td>
</tr>
<tr>
<td>M132 X Y Z A B (Recall stored home offsets for XYZAB axis)</td>
</tr>
<tr>
<td>(**** end homing ****)</td>
</tr>
<tr>
<td>(**** begin pre-wipe commands ****)</td>
</tr>
<tr>
<td>G1 X52.0 Y-57.0 Z10.0 F3300.0 (move to waiting position)</td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td>M6 T0 (wait for toolhead parts, nozzle, HBP, etc., to reach temperature)</td>
</tr>
<tr>
<td>M101 (Extruder on, forward)</td>
</tr>
<tr>
<td>G04 P5000 (Wait t/1000 seconds)</td>
</tr>
<tr>
<td>M103 (Extruder off)</td>
</tr>
<tr>
<td>(**** end pre-wipe commands ****)</td>
</tr>
</tbody>
</table>
Gcode: end code

(**** Beginning of end.Gcode ****)
(This file is for a MakerBot Thing-O-Matic)
(*** begin settings ****)
M109 S95 T0 (set heated-build-platform temperature)
(**** end settings ****)
(**** begin move to cooling position ****)
G1 X0.0 F3300.0 (move to cooling position)
G1 X0.0 Y55.0 F3300.0 (move to cooling position)
(**** end move to cooling position ****)
(**** begin filament reversal ****)
M108 R1.98
M102 (Extruder on, reverse)
G04 P2000 (Wait t/1000 seconds)
M108 R1.98
M103 (Extruder off)
(**** end filament reversal ****)
M18 (Turn off steppers)
(**** begin eject ****)
M6 T0 (wait for toolhead parts (nozzle, HBP, etc) to reach temperature)
M106 (conveyor on)
G04 P14000 (wait t/1000 seconds)
M107 (conveyor off)
(**** end eject ****)
(**** begin cool for safety ****)
M104 S225 T0 (set extruder temperature)
M109 S100 T0 (set heated-build-platform temperature)
(**** end cool for safety ****)
(**** end of end.Gcode ****)
(</alteration>)
::M113 S0.0
Appendix B: PIC12F615 Code

The following code is written in mikroC for PIC. To function it requires the config register be set to 0x006C.

```c
unsigned short lightOn = 2;

void interrupt () {
    if (PIR1.B3) {
        PIR1.B3 = 0;       //Clear the interrupt bit
        lightOn = 4;
    }
}

void main() {
    INTCON = 0xC0;       //Enable the global and peripheral interrupt.
    GPIO = 0x00;         //Init GPIO
    TRISIO = 0x1B;       //Set mic enable = pin 2 (GP5), led enable = pin 5 (GP2)
    ANSEL = 0x78;        //(note that cin is 0.4V lower than amp out)
    VRCON = 0x10;        //Configure Vref to 0.6V.
    CMCON0 = 0x15;       //Set comparator to inverted polarity, c+ = vref, c- = pin 3
    CMCON1 = 0x0A;       //Enable comparator hysteresis
    while (1) {
        asm clrwdt           //Clear the watchdog timer
        OPTION_REG = 0xFD;   //Set WDT prescaler to 1:32
        asm clrwdt           //Clear the watchdog timer
        asm sleep            //Sleep for long period (320-960ms)
        asm nop              //Ensure first instruction after sleep is unimportant
        PIE1.B3 = 0;         //Disable comparator interrupt
        GPIO.B5 = 1;         //Enable microphone & amplifier
        CMCON0.B7 = 1;       //Enable comparator
        asm clrwdt           //Clear the watchdog timer
        OPTION_REG = 0xF9;   //Set WDT prescaler to 1:2
        asm clrwdt           //Clear the watchdog timer
        asm sleep            //Sleep while mic & amp & comp stabilize (20-60ms)
    }
}
asm nop            //Ensure first instruction after sleep is unimportant
PIR1.B3 = 0;        //Clear any pending interrupts
PIE1.B3 = 1;        //Enable comparator interrupt
asm clrwdt          //Clear the watchdog timer
OPTION_REG = 0xFA;  //Set WDT prescaler to 1:4
asm clrwdt          //Clear the watchdog timer
asm sleep           //Sleep for short period (40-120ms)
asm nop             //Ensure first instruction after sleep is unimportant
if (lightOn != 0) {
    //True if there's been activity recently
    GPIO.B2 = 1;        //Turn LED on and keep comparator running
    lightOn--;
}
else {
    //If no recent activity
    PIE1.B3 = 0;        //Disable comparator interrupt
    CMCON0.B7 = 0;      //Disable Comparator
    GPIO.B5 = 0;        //Disable microphone & amplifier
    GPIO.B2 = 0;        //Turn LED off
}
}