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EPS – PROJECT

TITLE: **HP Multicolour digital pen**

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TITLE: HP Multicolour digital pen

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ABSTRACT

There are many digital pens on the market; however, none of them have more than one colour integrated into their body. The “HP Multicolour Digital Pen” project consists of designing and creating a working prototype of a multicolour digital pen, for the company Hewlett Packard. The pen is aimed at architects and constructors, who are still using traditional methods for working on paper plans, and will help them make the transition from the analogic to the digital world.

The final product will work with *Anoto* technology, therefore, research regarding *Anoto* technology and pens using this technology are included in the report. This research comprises of: a general description of *Anoto* digital pens; transmission methods used; processing units; pressure sensors; erasing methods and, to conclude the research, a brief summary of other technologies available. Furthermore, a study of the market has been conducted to analyse the features of different digital pens in the market. For the Mid-Term Report, three design proposals were presented and one was chosen by the company supervisor, in order to create the prototype for the final report.

Once the chosen concept was defined, the project incorporated design, mechanism, electronic and interface systems to create a Mark 1 prototype. This is a 2:1 scale prototype, which is used to study how well the systems work. This first prototype will greatly help in the development and refinement of future prototypes, so that the multicolour digital pen becomes a cutting edge, market leading product that is technologically advanced and economically viable.

Key words: digital pens, Anoto technology, dot patern, erasing Anoto, prototype

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1 Introduction

1.1 Background

Over the last few years, our daily lives have become more interconnected as the internet capable smartphones are becoming more common. The advances in technology offer the chance to redesign a Smartpen with newer, different purposes, than had been done in the past. Now it is possible to connect and interact with several smart devices, and be take advantage of different uses and functionalities that were not possible before. In today's market there are a number of different digital pens with varying functions and uses. Something that does not exist yet is a combination of these pens, with the ability to change colours. For some professions, this is necessity and it also creates new opportunities for other areas of work, such as in design professions.

This project is part of the European Project Semester (EPS) and International Design Project Semester (IDPS). The project results in a proposed solution, a design proposal, a prototype and potential development opportunities.

1.2 Hewlett-Packard

Hewlett Packard (HP) is a multinational information technology (IT) company based in Palo Alto, California, United States. The company is primarily focused on hardware and software services to small, medium and large-sized business. Bill Hewlett and Dave Packard founded the company on January 1st, 1939. The current CEO is Meg Whitman.

HP is well known for their imaging and printing group (IPG). According to the annual report (Shareholder.com, 2014, p. 6), “IPG is the leading image and printing systems provider in the world for printer hardware, printing supplies and scanning devices, providing solutions across customer segments from individual consumers to small and medium businesses to large enterprises". This means that HP always needs to be in the forefront of research and development (R&D) to maintain their top position.

HP is well known for their efforts towards reducing greenhouse gas emissions, policies for sustainable development, energy and climate-and environment-friendly products.

1.3 Problem definition

Many people feel frustration with the change in the modern work model. The transition from the analog to digital world should be a good experience for new generations, but is a struggle for the older generations that had already learned and worked for many years in the analogic way. A digital pen could solve this problem in many cases, but the existing pens on the market cannot change the pens on-paper colour at the same time as the on-screen colour. This gives us an opportunity to design a new product that can solve this desire of maintaining the traditional ways of interacting with work, while translating it to a digital output.

1.4 Solution Methods

To achieve the goals, the project team have disassembled an existing digital pen to closely analyse the structure and function of the product, by reverse engineering. The project team chose the Livescribe 3 as a good basis for further development and implementation of additional features. Gathering of information was also be made via manuals, product descriptions and on the Internet.

Creo Parametric was used to model the pen. Hand sketches, Adobe Photoshop, Paint.net and Illustrator were used for the design work.

Microsoft Project was used for administrative tasks such as the Gantt chart.

The microcontroller used was the Arduino Pro mini with a HC-05 Bluetooth module.

2 Project definition

2.1 Scope

The objective of this project was to design a multicolour digital pen for HP that holds up to four colours and can connect the physical colour to the one that is shown in the User Interface (UI) application. This means that each time that the user changes colour, the overall system has to have the intelligence to reflect exactly the same in the physical and in the digital document. This was a five-month project and the project team was composed of five people:

Anton, Mechanical Engineering

Julià, Computer Science

Joaquín, Electronics Engineering

Edward and Margaux, Industrial Design

In addition, two university supervisors and one company supervisor were also involved in the project. The project consisted of designing a pen which has at least four colours. The colour change must be analogical and digital, so that the change is on both paper and screen. The pen should also be able to work on tablets and will have an integrated a pressure sensor. The pen can share the information about what is written with the computer.

This project does not consider the cost of the design, manufacture or retail price. However, a small budget from the UPC has allowed the project team to buy a digital Smartpen that already exists in the market and to purchase the electronic components required for the final prototype. The internal electronics of the Smartpen are to be examined for both size and function. The programs for the internal sensors and for sending the data via Bluetooth can be written but the original proprietary programming is not to be changed.

The deliverable of this project is a prototype including four colours, the mechanism to change colours and the system that permit the pen to work on tablet. Diagrams of the mechanism for erasing should also be delivered. To fulfil the requirements of the university the project includes the following deliverables: written report, poster, video and a scientific paper.

2.2 The EPS project

The project timeline is divided in two phases, the first one includes the research and situation studies (the State-of-the-Art and the Market Study and the study of an actual digital pen), the project proposal and the skeleton outline of the possible design models (as sketches), with its description. The midterm report deadline was the 22nd of April. Then the objective was to manage to deliver three or four concepts of a multicolour digital pen to HP after the midterm deadline. These concepts were deeply reviewed and included the mechanism for changing colours. After that, a concept was chosen in agreement with the supervisors and the company. A prototype was designed and described in the final presentation.

From personal point of view, our objective was to get a better knowledge of teamwork inside an intercultural team. In addition, the project team looked forward to achieving the project goals and working for a large company such as HP.

2.3 Goals

Develop a Smart pen project and make a working prototype within the given requirements:

- Digital pen has at least four different colours integrated in the same case.
- When user changes the colour physically, there is a signal that also triggers the change in the UI application.
- The pen has to work on paper and on tablets. It has to connect the analogical to the digital world and vice versa.
- Pen has to connect with the computer (analyse what is the best system: Bluetooth vs. Wi-Fi)
- Pen must have a pressure sensor
- Ergonomic pen that can be used by both right and left handed people.
- Industrial design of the pen that holds 4 colours
- Mechanism for changing colour in the pen (working prototype)
- Mechanism for writing on paper and on tablet (diagrams)
- Mechanism for erasing (diagrams)

2.4 User Research

Our target is architects and constructors. Their main activities consist in drawing, making and modifying paper plans. They take notes during meetings and work at a desk or on-site. There are three phases in the process of architectural creation. First, the architect makes a diagnosis of the situation and during this phase the architect may do some rapid sketches. Then the architect does the 3D simulation, done with CAD software. Finally the architect draws the plans which are precise construction models for constructors. During this phase every detail of the construction is discussed between the two parties and modifications can appear.

The multicolour digital pen will be helpful for the architect during the last phase of the project. This is the reason why the pen should have four colours at least, and an eraser. In terms of its design, the pen should be easy to carry around outside, and also have an ergonomic shape. In addition, a recording function would be useful during meetings with the constructors, for instance.

3 State of the Art

This chapter includes all the research regarding digital pens that use Anoto technology. Firstly, a brief introduction to digital pens and its component is given. Secondly, Anoto technology (dot pattern) is explained, focusing on how the pattern is generated. Next, transmission methods are discussed and a comparison between Bluetooth and Wi-Fi is included. To continue, the microprocessor used in the latest Anoto pens is discussed; following that, a brief discussion about Force Resistive Pressure sensor and how they are integrated in the whole system. Furthermore, having a digital pen with erasing capability was one of the project requirements, therefore, erasing methods used for Anoto pens are analysed. To conclude, pens using infrared technology and non-optical sensor technology are briefly analysed.

3.1 Digital pens

The digital pen feels and looks like a regular ballpoint pen and it is used in the same way as one, with the addition that everything written on paper is also stored in a digital form. To accomplish this, the pen has an integrated digital camera, which in combination with a special printed paper, can follow the trace of the pen and reproduce the user handwriting in a computer, or mobile, application.

All Anoto technology based digital pens include mainly the same components, these components are:

- **Digital camera**: high speed infrared camera that takes up to 75-100 images per second with a resolution of about 850 dots per inch (dpi). For the camera to capture the images an LED has to be activated to provide enough light for the lens; the light of the LED goes through an infrared filter.
- **Microcontroller**: the imaging processing and the control of all the features of the pen are done by a microcontroller. The microcontroller of choice for most Anoto pens, discussed later on the chapter, is the ARM9.
- **Bluetooth or Wi-Fi antenna**: sends the data to the UI application. Depending on the model of the pen, the transmission can be done via Bluetooth or Wi-Fi.
- **Force Resistive Sensor**: when the user is writing, the Force Resistive Sensor (FSR) is pressed and it triggers a signal to the microcontroller allowing the pen to know when the camera should start recording.
- **Ink cartridge**: a tungsten carbide ink cartridge leaves a trail on the paper so what was written can be seen.
- **Rechargeable battery**: the pen holds a non-removable rechargeable lithium-ion or NiMH battery that can be recharge via USB or, in older models, with a docking connector. The battery last an average of nine to ten hours depending on the model of the pen and the usage given by the user.
- **LED indicators**: simple LED that indicates the status of the pen

3.1.1 Anoto technology

The Anoto technology consists of a non-repetitive dot pattern printed on paper that enables the pen, thanks to the integrated digital camera, to locate its absolute position on the paper. The tiny dots are placed above an orthogonal grid; each dot can have four different positions in the grid: up, down, left and right (figure 1).

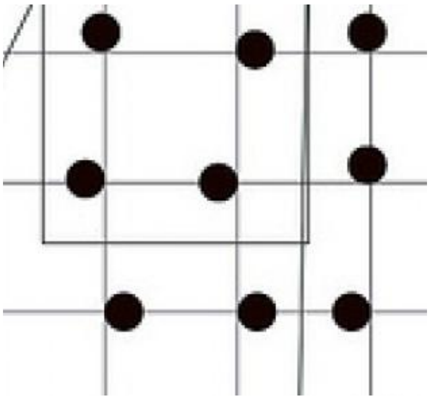

Figure 1: Anoto dot pattern

The dots in a particular axis are generated with what is called a single-track Gray code (STGC). The STGC generates a 52 bit long sequence (for the x and y axis, thus every single dot contains two bits of data), where no 6 bit pattern is repeated in the whole sequence, this means that an area of 6x6 dots encodes a unique position in the paper; the camera is used to capture this 6x6 area and, with the microcontroller, decode the position in the paper.

The pattern can be printed on regular paper with different printing techniques, such as laser, offset and inkjet printing. For an optimal performance of the pen, the printing should be done on a blank sheet of paper; if the dot pattern is printed over another printed content, then the camera might have problems seeing the dot pattern where the two contents have been overlaid.

3.1.2 Data transfer

Data transfer can be done in several ways depending on the model of the pen; these ways are: Bluetooth, WIFI, USB connection, and with a docking station (which serves also as a charging station for the battery). Since the pen being developed for this project is going to be used with a wireless form of communication, only the Wi-Fi and Bluetooth protocols are going to be evaluated.

3.1.2.1 Wi-Fi

Wi-Fi technology uses radio signals to transmit information, enabling wireless connectivity between computers, electronic devices and local area networks. In digital pens, Wi-Fi is used to send the data from the pen to the computer, through a local area network. Range wise, Wi-Fi devices can support a range of up to 92 metres on the outside and 46 metres indoors. In order to make the connection, the digital pen should have an integrated Wi-Fi antenna, and there should be router nearby to redirect the data from the pen to the network and subsequently to the computer. Furthermore, the pen requires access to a 2.4 GHz Wi-Fi network (802.11 b/g/n) according to the manufacturer.

3.1.2.2 Bluetooth

Used for short range connection between computers and several electronic devices, Bluetooth is a technology that transmits data via low power radio waves. The frequency used for making the connection range is from 2.402 GHz to 2.480 GHz. Up to eight devices can be connected via Bluetooth, without interfering with each other, using a technique called spread spectrum frequency hopping. This technique allows the Bluetooth transmitter to use, within a designated range, up to 79 different frequencies changing from one to another 1.600 times per second. In terms of range and power consumption, digital pens used what is called a Class 2 radio implementation allowing them to have a 10 to 15 metre range and a power consumption of 2.5 mW. The newer pens in the market use Bluetooth 4.0, allowing them to connect directly to the computer, or mobile phone, without any intermediary as the Wi-Fi pens.

3.1.2.3 Bluetooth vs. Wi-Fi

	Bluetooth	802.11b	802.11g	802.11n
Throughput (Mbps)	1 - 3	11	54	200
Max range (metres)	10 - 15	70	70	45
Power (mW)	100	750	1000	2000
Bandwidth (MHz)	1	22	20	40
Power efficiency 1 (mW/Mbps)	100	68	19	10
Power efficiency 2 (mAh/GB)	67	46	12	7
Price (€)	2.17	3.61	6.50	14.44

Table 1: Comparison between Bluetooth and Wi-Fi (802.11 b/g/n)

Table 1 compares some selected features about Bluetooth and Wi-Fi. These features were selected considering their implementation on a digital pen. The main important aspect to consider, in this particular case, is power consumption and power efficiency (power consumption should be as low as possible and power efficiency as high as possible), to give the digital pen as much autonomy as possible; it can be appreciated in the table, that in this regard, Bluetooth has the advantage over Wi-Fi. Followed by the power element, price is a relevant factor as well; depending on the Wi-Fi used, price can be in the same range, for example standard Bluetooth has a price of 2.17 € and Wi-Fi 802.11b a price of 3.61; however, Wi-Fi 802.11 g/n double in price. Taking into account the end user of this project and the applications that would be given to the pen, communication speed, bandwidth and range are not that relevant; in this regard, Wi-Fi has the advantage but Bluetooth is suitable enough for the uses the pen is going to have.

3.1.3 Microcontroller

As commented previously in subsection 1.1, the control of all features available in the pen is done by the microcontroller. Such features include:

- Turning on the camera LED to allow the camera to start recording.
- Capturing the data from the camera.
- Timing the data transmission.
- Turning on/off and changing the colour of the status LED depending of the status of the pen.
- Imaging processing to trace the pen movement.

The microcontroller used in the latest Anoto pens is the ARM9. This microcontroller has a 32-bit Harvard architecture but also supports 16 bit or 8 bit data types. The design pattern follows a RISC (Reduced Instruction Set Computing) core architecture with instructions sets providing efficient support for DSP (Digital Signal Processing) applications such as: imaging processing; 2D and 3D transformation; font generation and digital filters.

ARM introduced a new family of microcontrollers with the V5TE architecture, the ARM9E, which added new sets of DSP instructions to the ARM9 instruction set, creating a DSP-enhanced 32-bit RISC processor especially suited for applications requiring a mix of DSP and microcontroller performance as a digital pen would. Even though the ARM9E performance compared to a DPS dedicated chip is inferior, it has an advantage over a DSP based implementation system, in that the ARM9E chip alone can perform key DPS algorithmic processing while performing all the required system control functions. This reduces power consumption, minimizes chip area and simplifies the software and hardware development; whereas, in a DSP based implementation, another chip would be required to perform all the tasks related to the system control functions.

3.1.4 Force Resistive Sensor

To detect that the user is writing, an FRS (Force Resistive Sensor) is placed at the top of the cartridge; therefore, when a force is applied to the nib, thus indicating that the user is writing, a signal is sent to the microcontroller allowing the system to start tracing the pen movement. .

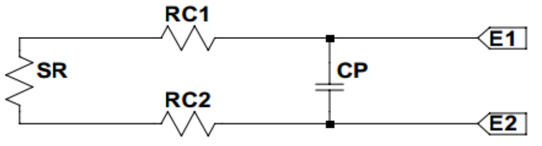

Figure 2: Simplified sensor equivalent circuit

An FRS consists of a resistor that changes its resistive value depending on the force applied to it (figure 2). When there is no force applied, the sensor acts like an infinite resistance, however, when a force is applied, the resistive value decreases as shown in figure 3.

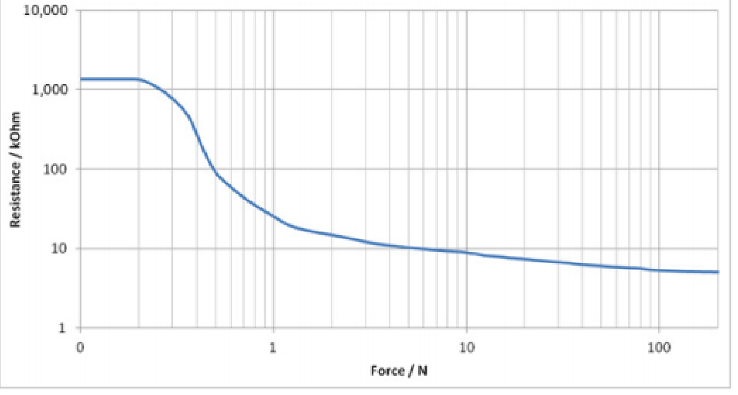

Figure 3: Example of FRS resistance/force curve

3.1.5 Erasing

One of the disadvantages of using regular ballpoint pens is the inability to erase the written content, and Anoto pens are no exception. Furthermore, in Anoto pens, a correction fluid cannot be used because the dot pattern will be deleted as well.

This topic has not been thoroughly researched; nevertheless, some solutions have been proposed in order to solve this matter.

3.1.5.1 Pencil and rubber

Pencil leaves small particles of carbon inside the paper's fibres. The rubber moves the fibres which free the carbon particles (figure 4).

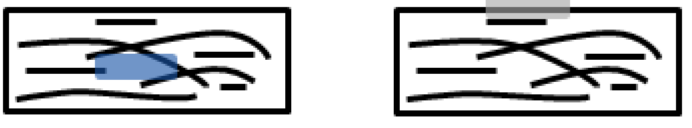

Figure 4: Difference of location between Ink (left)and pencil, carbon particles (right)

A graphite refill can be inserted into the pen, as shown in figure 5, allowing the pen to use pencil to write. As for the eraser, a piece of rubber can be plugged into a standard Anoto ballpoint reservoir (figure 6).

Figure 5: Graphite refill

Figure 6: Rubber plugged into an *Anoto* standard reservoir

3.1.5.2 Fountain pen

Aniline Blue is used for the ink and Sodium Bisulfide for the eraser. The sodium bisulfide initiates the reduction of the blue aniline: electrons relocation. The reduced form of the blue aniline has an ultraviolet colour (figure 7). This type of ink and eraser has the advantages of being low cost and to have grand autonomy. On the other hand, the eraser is only able to erase one colour, and might also erase the dot pattern on the Anoto paper.

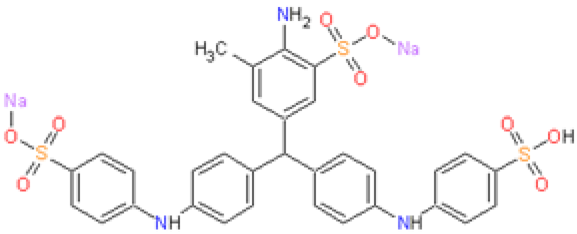

Figure 7: Reduction sites of blue aniline

3.1.5.3 Erasable ballpoint pen

The ink inside the pen is a special kind of ink with heat-sensitive properties. When the ink on the paper is rubbed with the eraser, the friction on the paper produces heat up to 65°C making the ink colourless. In order to make the colour reappear, the paper has to be exposed to cold below -12°C. A test was done by researchers in the Technical University of Darmstadt with this type of system. To create the eraser, a tip was constructed using a part of the Frixion pen's rubber ball and then plugged into the tip of a standard Anoto refill (figure 8 and 9).

Figure 8: Frixion rubber ball being cut

Figure 9: *Anoto* refill with Frixion rubber ball plugged in

In all previously analysed cases, data indicating that the pen is erasing needs to be sent to the computer, or mobile, application to be able to delete the written content also in the digital form. It has been proven, by the previously mentioned Technical University of Darmstadt researchers that this system works when a modification in the software is made in order to detect erasing traces. The results of the eraser tip can be appreciated in figure 10.

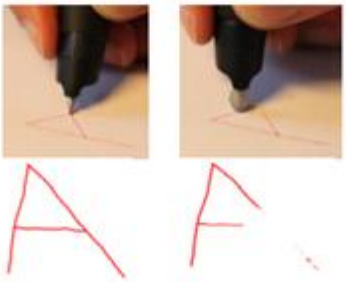

Figure 10: Users write with the heat-sensitive ink (above left) and then erase (above right) with the erasing tip. The software application recognizes the erasing of the letter (below)

3.1.6 Other technologies available

3.1.6.1 Infrared pens

The digital pens that rely on infrared technology use a positional receiver, placed at the top of the page, to enable the tracing of the handwriting. To send the position of the pen to the receiver, the pen has an integrated infrared transmitter. The receiver uses a silicon photodiode to convert the infrared radiation into electrical current.

There are some advantages and disadvantages regarding infrared technology. On one hand, the circuitry is really simple where no special or proprietary hardware is required. Furthermore, it has low power requirements, making it ideal for a digital pen, and the circuitry is low cost. On the other hand, infrared digital pens do not allow live feedback when writing and a receiver has to be carried in order to use the pen. Moreover, the weather can adversely affect the transmission, for example if there is direct sunlight, fog or dust. Additionally, there cannot be any interference between the transmitter and the receiver, for example supporting the paper across the top with a hand would block the signals.

3.1.6.2 Non optical motion sensor pens

Depending on the model of the pen, a triaxial accelerometer can be used as the non-optical motion sensor. A gesture trajectory algorithm recognizes the acceleration from the users gestures when writing and is able reproduce the user’s handwriting. These state of the art non-optical sensor pens use a combination of three sensors (accelerometer, gyroscope and a magnetometer) to calculate the pens 3D movements and generate 2D vectors to reproduce the pens movement in a computer application.

The main advantage of this type of digital pen is that no special paper, or device, is needed to trace the pen movement. Paper is not even necessary to recognize what the pen is doing. The user can write in the air and, thanks to the sensors, the computer application can trace the movements of the pen. However, taking into account the end users of this project and the software application being developed for this pen, one important feature that the pen should possess is precision; Anoto pens are more precise, when working on architectural plans, than non-optical motion sensor pens.

4 Market Study

4.1 Comparison tables:

4.1.1 Wi-Fi/Bluetooth

Connectivity Type	Wifi	Bluetooth				
Digital Pen	**Livescribe Sky Wifi Smartpen**	**Mobile Notes Pro**	**Staedtler Pen 990 02**	**IRISNotes 1 for smartphones**	**Capturx for OneNote**	**Livescribe 3 Smartpen**
Specifications						
Battery Life (hours)	10	8	8	8	10	10
Diameter of grip (mm)	11.5	16.8	12.9	12.9	15.2	14.9
Length (mm)	158	153	135	135	153	162
Weight (grams)	34	21	34	15.9	29.8	34
Type of paper used	Anoto	Any paper	Any paper	Any paper	Anoto	Anoto
Receiver Device	PC	Cabled Receiver to PC	Yes, cabled to PC, Bluetooth to	Yes	PC	Tablet/phone
Features						
Desktop software	Evernote	Note Manager	Note Managing	IRISNotes 1	Capturx Pen Manager	N/A
Mobile App	Evernote	N/A	Note Managing	N/A	N/A	Livescribe+ App
Handwriting Conversion Software (OCR)	Evernote	MyScript	MyScript	N/A	Yes	N/A
Storage Capacity	800h	100 pages	100 pages	100 pages /50MB	50 pages	20.000 pages / 2GB
Pressure levels	Single	Single	Single	Single	Single	Single
Layers per page	Single	Single	Single	Single	Single	Single
Audio Recording and Playback	✓	✗	✗	✗	✗	✓
Audio Sync with Notes	✓	✗	✗	✗	✗	✓
Language Recognition	✓	✓	✓	✓	✗	✗
Write On Any Paper	✗	✓	✓	✓	✗	✗
Compatible with Mobile Devices	✓	✓	✓	✓	✓	✗
Operating Systems Supported						
Windows XP	✓	✓	✓	✓	✓	✗
Windows Vista	✓	✓	✓	✓	✓	✗
Windows 7	✓	✓	✓	✓	✓	✗
Windows 8	✓	✓	✗	✗	✓	✗
iOS	✓	✓	✓	✗	✓	✓
Lowest Price (Euros)	**107.16**	**91.70**	**113.99**	**80.29**	**218.26**	**142**

Table 2: Comparison Wi-fi vs Bluetooth conectivity

4.1.2 Infrared-Ultrasound/Cable

Connectivity Type	Infrared/Ultrasound			Cable	
Digital Pen	**Wacom Inkling**	**IRISNotes 2 Executive**	**LogiPen Notes**	**Livescribe Echo Smartpen**	**DigiMemo L2**
Specifications					
Battery Life (hours)	15	8	15	10	80
Diameter of grip (mm)	16.8	12.9	12.9	11.5	11.5
Length (mm)	153	135	135	158	134
Weight (grams)	21	15.9	15.9	34	13.6
Type of paper used	Any paper	Any paper	Any paper	Anoto	Any paper
Receiver Device	Cabled Receiver to PC	Cabled Receiver to PC	Cabled receiver to PC	Cabled to PC	Clipboard by cabled to PC
Features					
Desktop software	Inkling Sketch Manager	IRISNotes 2	LogiPen File Manager	Livescribe Desktop	DigiMemo Manager
Mobile App	N/A	IRISNotes 2App	N/A	N/A	N/A
Handwriting Conversion Software (OCR)		MyScript	MyScript	MyScript	Yes
Storage Capacity	200 pages / 2GB	100 pages	50 pages	800h	80 pages
Pressure levels	Multiple	Single	Single	Single	Single
Layers per page	Multiple	Single	Single	Single	Single
Audio Recording and Playback	✗	✗	✗	✓	✗
Audio Sync with Notes	✗	✗	✗	✓	✗
Language Recognition	✗	✓	✓	✓	✗
Write On Any Paper	✓	✓	✓	✗	✗
Compatible with Mobile Devices	✗	✓		✓	✗
Operating Systems Supported					
Windows XP	✓	✓	✓	✓	✗
Windows Vista	✓	✓	✓	✓	✗
Windows 7	✓	✓	✓	✓	✗
Windows 8	✓	✓	✗	✓	✗
iOS	✓	✓	✓	✓	✗
Lowest Price (Euros)	**72.26**	**87.49**	**50.36**	**80.40**	**116.05**

Table 3: Comparison between infrared-ultrasound and cable conectivity

4.2 Digital pen types:

4.2.1 Anoto (dotted paper – with no receiver)

The following pens use the Anoto system to digitalize writing.

4.2.1.1 Livescribe Sky Wi-Fi Smartpen

This is a very versatile Smartpen uses Wi-Fi to send data to your device. However, your notes and recordings are not sent to your computer or tablet in real-time. Instead they are sent all at once whenever you sync the devices. Among its many functions it can record voice and has a speaker, calculator, dictionary, piano and can work as a mouse. These options are thanks to the many downloadable applications, which are available. It comes in different versions with different storage capacities, 2GB, 4GB and 8GB. Its external design is sleek, simple and elegant. It incorporates a digital screen, which displays information such as the time, the signal quality and the state of the battery. Beside the screen there are some long, angled slots behind which are the microphone and speaker. There is also an on/off button beside the Livescribe logo, and an 3.5mm audio jack so that you can plug in your headphones to listen back to your recordings privately.

Figure 11: Livescribe Sky Wi-Fi Smartpen

Pros

- Wi-Fi syncing
- Audio recording
- Headphones jack
- Downloadable apps
- Versatility
- Large memory 2GB, 4GB or 8GB
- Soft touch grip
- Can be used as a mouse

Cons

- This pen only works digitally with special paper
- All of the apps functions work with the special paper.
- Syncing is not in real-time
- It cannot convert handwriting to text

4.2.1.2 Livescribe 3 Smartpen

This pen is a simplified version of the Sky Wi-Fi Smartpen, and uses Bluetooth to wirelessly transfer its data from the pen to another device such as a tablet or a phone in real-time. Currently the only devices that are compatible are the newer iOS tablets and phones. The many functions of its predecessors are gone; however its voice recording is still there (albeit the coupled device does the recording instead of the pen). The pen is visually elegant, with an all-black shiny finish, glossy metal ends and a small LED indicator. The writing end houses the infrared camera and retractable ballpoint, which can be operated by twisting the central grip of the pen. This rotation also turns the pen on and off. At the other end of the pen there is a soft rubber stylus for basic swiping and taping on touch sensitive screens. Underneath of this, there is microUSB port for charging the pen and a small hole for resetting the device if necessary.

Figure 12: Livescrive 3 Smartpen

Pros

- Syncs with devices in real-time
- Easy to use
- Incorporates the latest technologies

Cons

- Only works with latest iOS devices
- This pen only works digitally with special paper
- Only 2GB of memory
- Rubber end cap can be lost easily when charging

4.2.1.3 Livescribe Echo Smartpen

Visually this pen is almost identical to the Sky Wi-Fi, however the main difference is that it transfers the notes to your computer via a USB cable, and so the synchronization is not done in real-time. When the cable is connected the pen does sync in real time, but it is not very practical to write with a cable connected to a PC. With the cable connected the pen can be used as a mouse. It records audio at the same as the writing. These are called Pencasts, and can be used for making presentations that can be shared online easily.

Figure 13: Livescribe Echo Smartpen

Pros

- The pen records audio and can replay it
- Syncs audio as well as notes
- Can convert handwriting to text using MyScript
- Can be used as a mouse
- Headphones jack
- Downloadable apps
- Versatility
- Large memory 2GB, 4GB or 8GB
- Soft touch grip

Cons

- This pen only works digitally with special Livescribe Dot Paper
- Sync is not in real-time
- Cannot replay shared pencasats on iOS or Android devices

4.2.1.4 Capturx for OneNote

This is an industry specific pen, made by Adapx. It is an industry focused pen, only available for certain businesses through a customer service agent. This means that whenever you have a problem, there is a telephone operator waiting to help you. It uses dedicated programs depending on the businesses requirements. For these reasons, the Capturx does not compete with the other digital pens at a consumer level.

Pros

- Pen is water and temperature resistant
- Paper can be printed on your home laser printer
- Sync with PC and mobile devices in real-time

Cons

- Not available to the general public, only to specialized businesses through a customer service agent.
- Only saves 50 pages
- Bluetooth drains the battery very quickly
- Programs need to be purchased separately
- This pen only works digitally with special paper

Figure 14: Capturx for OneNote

4.2.2 Pens with receiver device – write on any paper

4.2.2.1 Mobile Notes Pro

This pen uses a positional receiver, which is place at the top of each page. The receiver can be connected to a PC via a cable for syncing. If the signal between the pen and the receiver is blocked by your fingertips or the receiver is accidently moved after you have begun writing, the digital copy will become distorted and inaccurate.

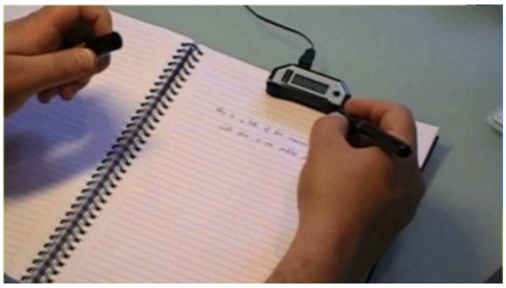

Figure 15: Positional receiver

The pen incorporates Bluetooth which allows you to sync notes to mobile devices and use the pen with programs like Evernote and OneNote. The Bluetooth also allows the pen to be used as a mouse.

Pros

- Pen is slim and light-weight for comfort
- Can connect to mobile devices
- Can write on any surface

Cons

- The receiver must not be moved once you start writing
- Only the basic Note Manager and Photo Sketcher software is included

Figure 16: Mobiles Notes Pro

4.2.2.2 Staedtler Pen 990 02

The Staedtler Pen 990 02 uses a receiver device, which is placed at the top of your notepad or sheet of paper. The receiver uses infrared and ultrasound to communicate with the pen, and the then sends the data by Bluetooth or by cable to a Mobile device or PC. This means that the pen does not require special dot paper, and so can be used with whatever paper you may have. It can store 100 pages and is comfortable to use due to its narrow grip. The pen is sold with three different programs included to ensure that you can take full advantage of the pens capabilities, whether it is the MyScript for converting handwriting into editable text or Notes Manager to help you archive your notes. The Bluetooth can be used to connect with mobile devices and write in real-time, and the cartridge can be swapped for a stylus tip for use in mouse mode. When writing the receiver is placed at the top of the page, its button is pressed to start writing and to also save the written page.

Figure 17: Receiver device

Pros

- The pen creates quality sketches and notes
- Three software programs included
- Bluetooth connectivity for mobile devices

Figure 18: Staedler Pen 990 02

Cons

- The positional receiver is easy to bump or move
- The tapered end of the pen means that your fingers may block the signals and results in notes being lost.

4.2.2.3 IRISNotes 1 for smartphones

The IRISNotes 1 is similar to the Staedtler Pen in that it uses a receiver device, which is placed at the top of your notepad or sheet of paper. The receiver uses infrared and ultrasound to communicate with the pen, and the then sends the data by Bluetooth or by cable to a Mobile device or PC. This means that the pen does not require special dot paper, and so can be used with whatever paper you may have, and because it connects with your mobile device it means you can take notes wherever you are. However it is not compatible with Apples iOS. It can store 100 pages and is comfortable to use due to its narrow grip.

Figure 19: Receiver device

Pros

- The Bluetooth connects to Android and Blackberry devices
- Comfortable to use due to low weight and thickness
- Grip is shaped to prevent fingers from blocking the signal to the receiver
- Has a rechargeable Lithium Ion battery
- Writes on any surface

Cons

- The pen is not compatible with iOS
- It does not include Optical Character Recognition (OCR) software
- Difficult to write while moving as the digital copy may distort if the receiver gets bumped

Figure 20: IRISNotes 1

4.2.2.4 IRISNotes 2 Executive

Unlike the IRISNotes 1, the IRISNotes 2 Executive does not have Bluetooth, so notes made must be sent from your PC to your mobile device. It works in the same way as the IRISNotes 1 but does have OCR software and its receiver needs to be connected by cable to a PC for syncing.

Figure 21: Mobile device sending

Pros

- The pen is compatible with iOS, Win8 and 7
- Comfortable to use due to low weight and thickness
- Grip is shaped to prevent fingers from blocking the signal to the receiver
- Has a rechargeable Lithium Ion battery
- Has OCR software
- Writes on any surface

Cons

- Difficult to write while moving as the digital copy may distort if the receiver gets bumped
- Sync only by cable
- No sync in real-time

Figure 22: IRISNotes 2 Executive

4.2.2.5 Wacom Inkling

The Wacom Inkling is aimed at consumers who want to do sketches and have them automatically digitalized. To ensure that the sketches are good quality, there are 1024 levels of pressure sensitivity and multiple layers can be created on each page. These layers create depth and greater control when editing the images in photo editing software. This pen has no OCR software, but this can be purchased separately. It has a very comfortable ergonomic rubberized grip, and comes with a special carrying case that can also carry the receiver device, the USB cable and an extra 4 ink cartridges. The carrying case also doubles as a recharging station.

Figure 23: Carrying case

Pros

- Multiple layers per page
- 1024 levels of pressure sensitivity
- Ergonomic grip

Cons

- No OCR software
- No note managing software
- Uses NiMH battery
- Not meant for note taking

Figure 24: Wacom Inkling

4.2.2.6 LogiPen Notes

This is a slender easy to use pen, with a flared area near the end that stops your fingers from sliding down and blocking the infrared and ultrasound signals. Like the IRISNotes and Wacom, it uses a receiver device to send the data to a PC. However it does so with a USB cable and syncing in real-time can be frustrating due to lag and when the software often doesn't recognize the pen or starts using the pen as a mouse, which can be difficult to switch off. The pen can be slotted into a small hole on the receiver device when not in use, but often falls out as only the tip fits into the hole.

Figure 25: Receiver Device

Pros

- Writes on any surface
- Economical
- Comes with MyScript ORC software

Cons

- The software has bugs
- The pens materials look and feel cheap

Figure 26: LogiPen Notes

4.2.3 Pens without camera

4.2.3.1 DigiMemo L2

This pen uses a special clipboard that any paper can be inserted into. The clipboard uses batteries and has a button to start the recording of the new page. It has software that can be adapted to any survey or form in order to quickly input the analog results of the survey into the computer and make Excel or other statistical tables.

Figure 27: Clipboard

Pros

- Software for filling out forms saves time
- Is compatible with Microsoft OneNote
- Files can be saved as PDF, TIF, BMP, JPG, GIF or PNG

Cons

- Pen doesn’t work very consistently or sometimes not at all
- Can only write on pages that fit into the clipboard
- MyScript OCR software is available but must be purchased separately

Figure 28: DigiMemo L2

5 Design of the multicolour digital pen

5.1 Concepts design

5.1.1 Concept 1

5.1.1.1 Description

This pen concept has a really simple design with soft curves reminiscent of HP's designs and a clip that follows the curves of the body. There is a rubberised grip at the writing end of the pen and it curves outwards to prevent fingers from sliding down to the nib or covering the camera.

To change one of the colours that the pen is using, simply twist the tip and pull it away from the main body of the pen. The pen has 4 colours and an eraser. The different tip would be stored in a case. The ink should be a heat sensitive ink, erasable with a plastic eraser. The tablet stylus is a special nib with a really smooth tip. The camera is not integrated in the colour tips, but is part of the body of the pen. The design of the tip should be different for every colour in order to be recognised by the electronic system.

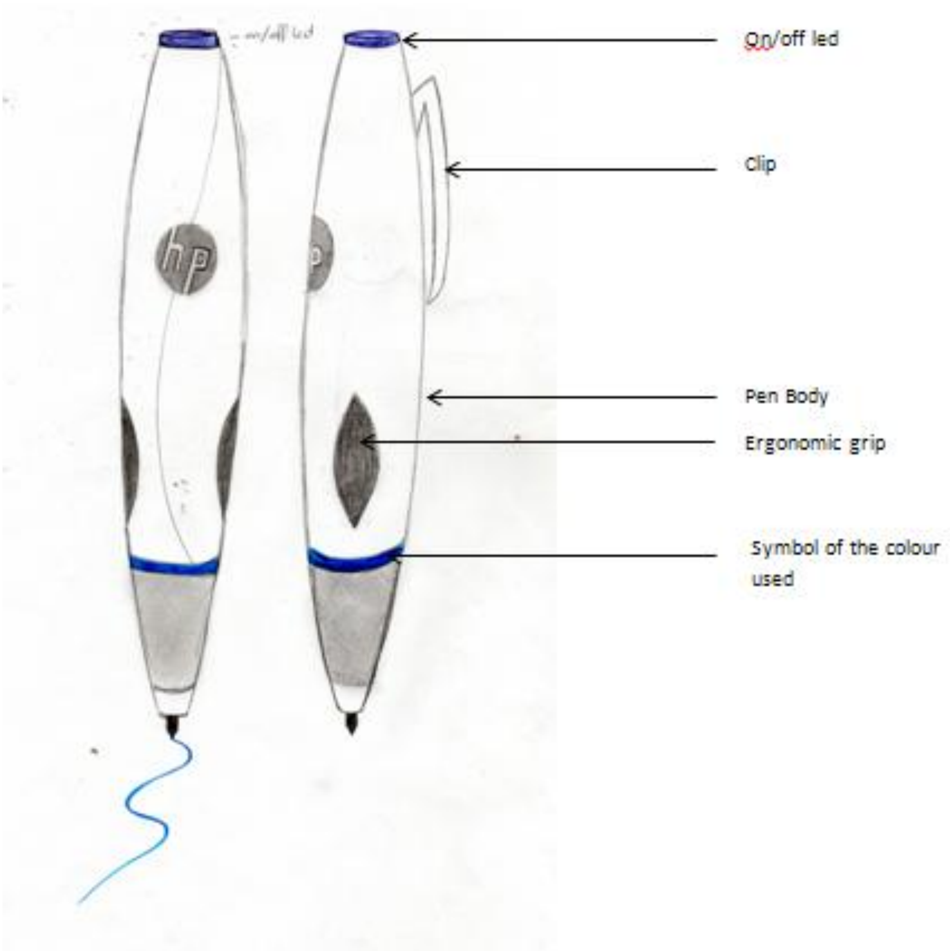

Figure 29: General description of the system

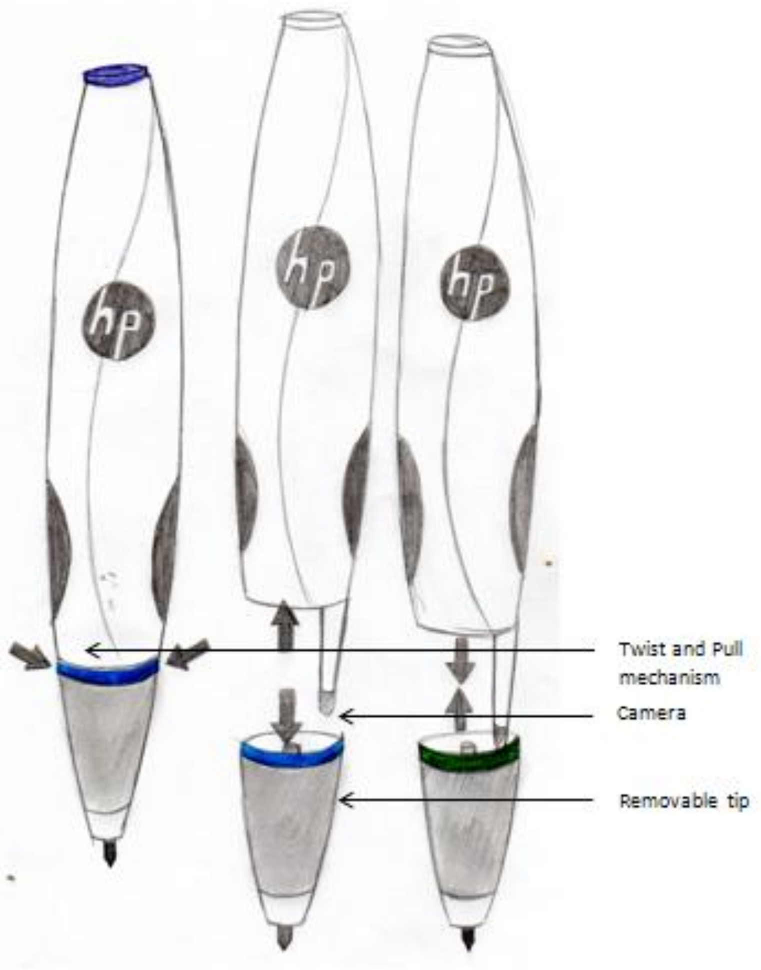

Figure 30: Mechanism for changing colours

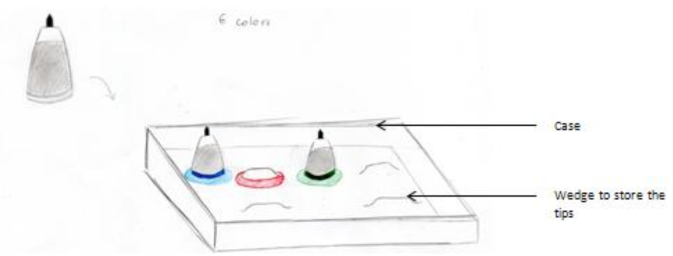

Figure 31: Case to store the tips

5.1.1.2 Pros

- Easy to refill
- Space saving in the pen
- The ink cartridge has a bigger capacity
- Pen is more ergonomic
- Many different tip possibilities (thickness, highlighter)

5.1.1.3 Cons

- Case needed to store the tips
- More time is needed to change the colours
- Tips can be lost
- Not easy to use outdoors

5.1.2 Concept 2

5.1.2.1 Description

The design is simplistic with gradual soft curves and an oval shaped clip that follows the curves of the body. There is a rubberised grip at the writing end of the pen and it curves outwards to prevent fingers from sliding down to the nib or covering the camera.

The pen is easy to use with 5 different cartridges that are chosen by moving down the tabs. Each of the four individual cartridges has a different colour (blue, green, black and red) and the fifth is an eraser and a tablet stylus. The camera surrounds the nib to ensure a good view of what is written at all times even when the ruler is being used. The HP logo is illuminated. The end of the pen can be unscrewed so that the ink cartridges can be changed easily.

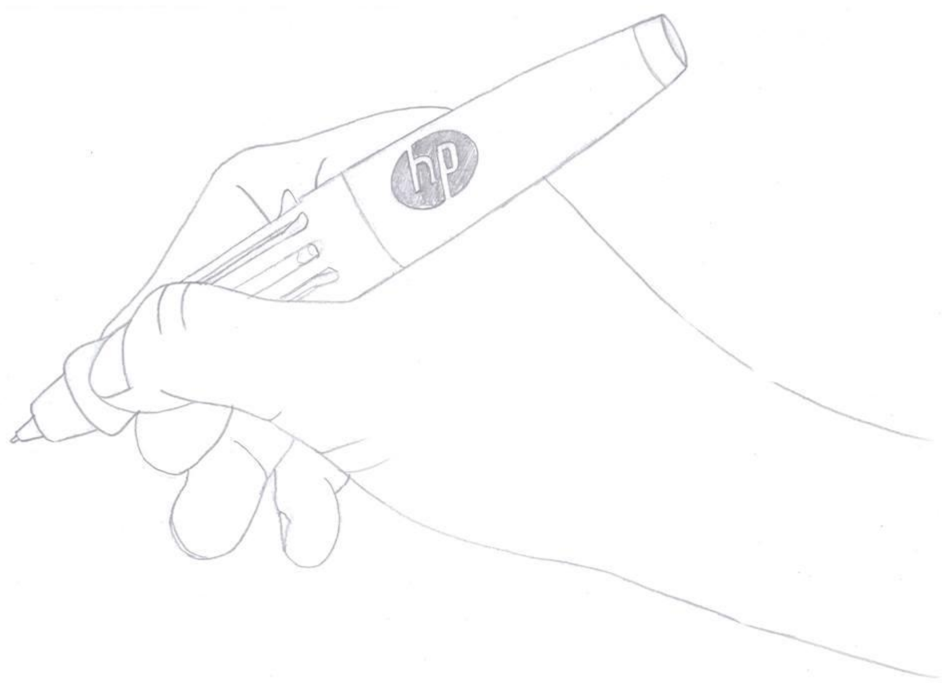

Figure 32: General aspect of the design

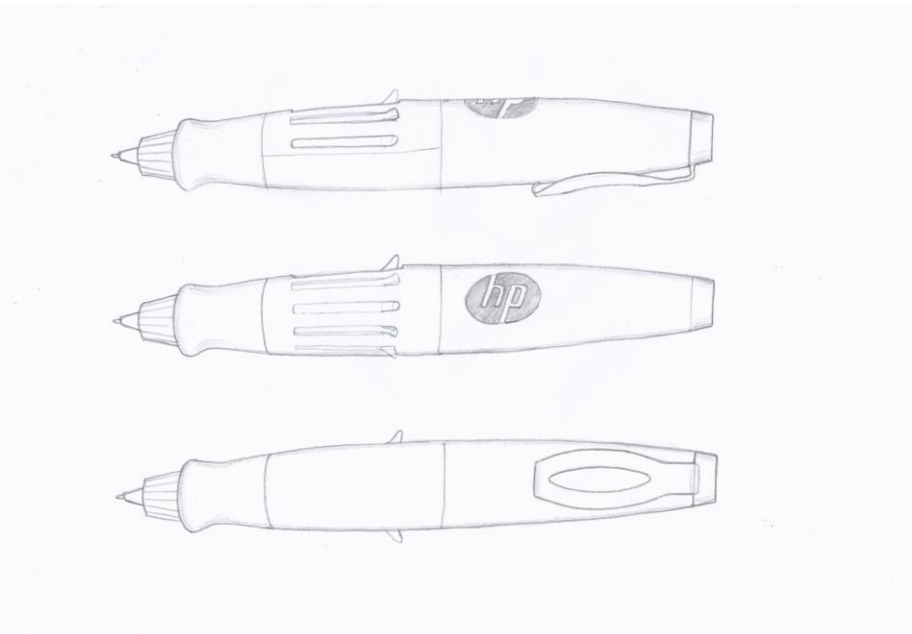

Figure 33: Mechanism for changing colours

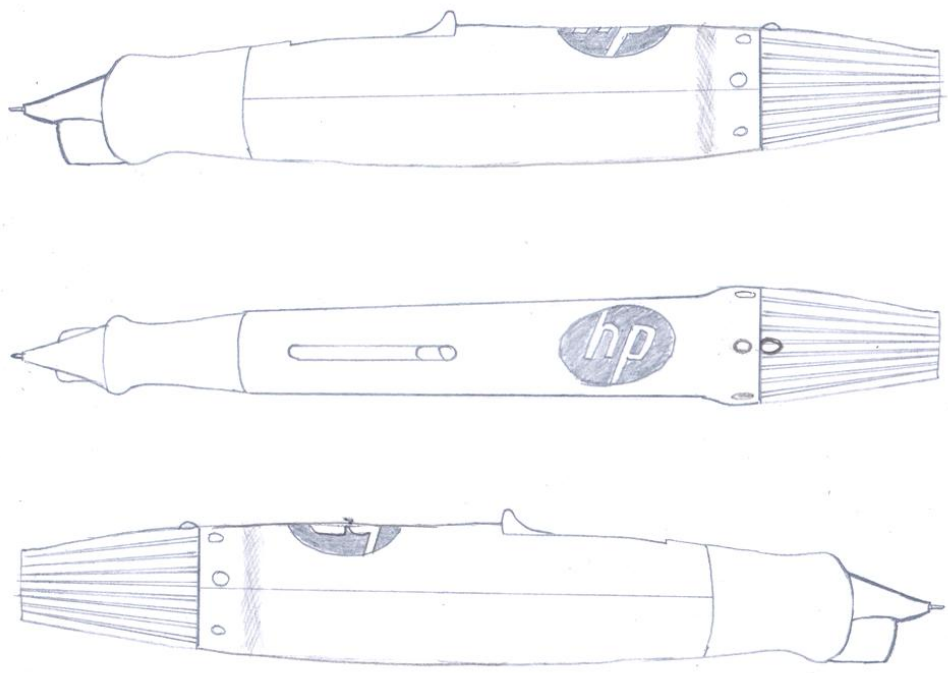

Figure 34: First revision of Concept 2

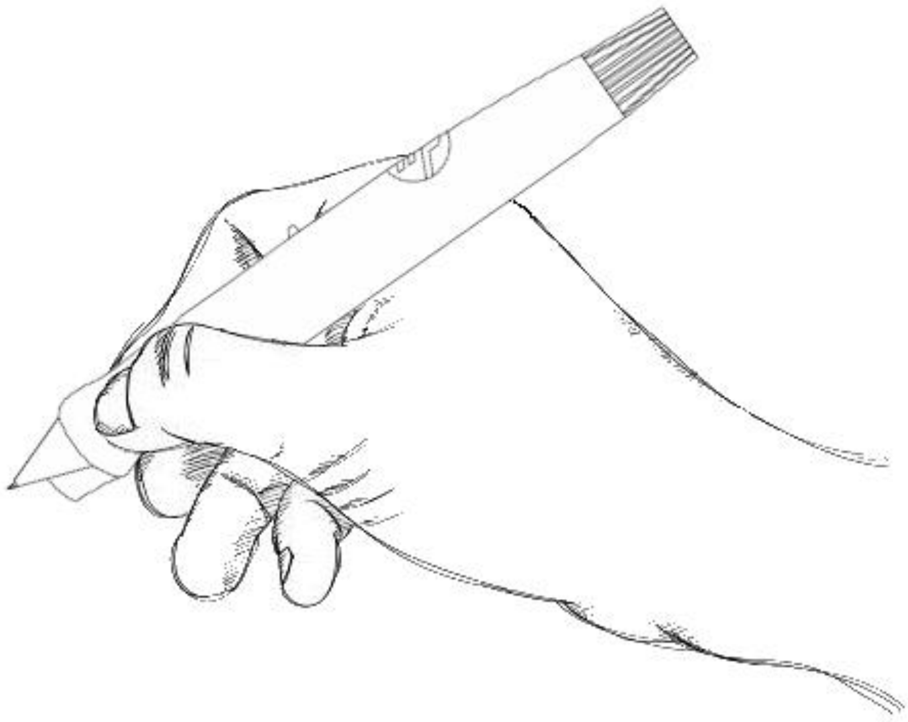

Figure 35: Second revision of Concept 2

5.1.2.2 Pros

- Speed of changing colours
- Easy to use
- Ergonomic shape
- No case needed, easy to use outdoors
- Easy to carry

5.1.2.3 Cons

- Overly thick pen
- Difficult to change ink cartridges
- The tabs might protrude and be in the way when you write

5.1.3 Concept 3

5.1.3.1 Description

This the most avant-garde design of the pens. The design is inspired by a Swiss army knife. The pen rotates in the middle and the ink cartridges are stored in a rotating arm that folds downwards into the end of the pen. Only one arm can fold downwards completely at a time. To choose the next colour, the arm that is currently in use must be folded away. Then the pen is twisted until the next arm is lined up and can be folded downwards into the slot. To facilitate folding the arm there is a tab that you can grip with your thumb. The grip of the pen is rubberised and curved in an ergonomic way to prevent the fingers from slipping. There is a slot on the underside where the folding arm slots into. This design enables much of the electronics to be contained within the writing end of the pen. Thus creates a more balanced weighted pen.

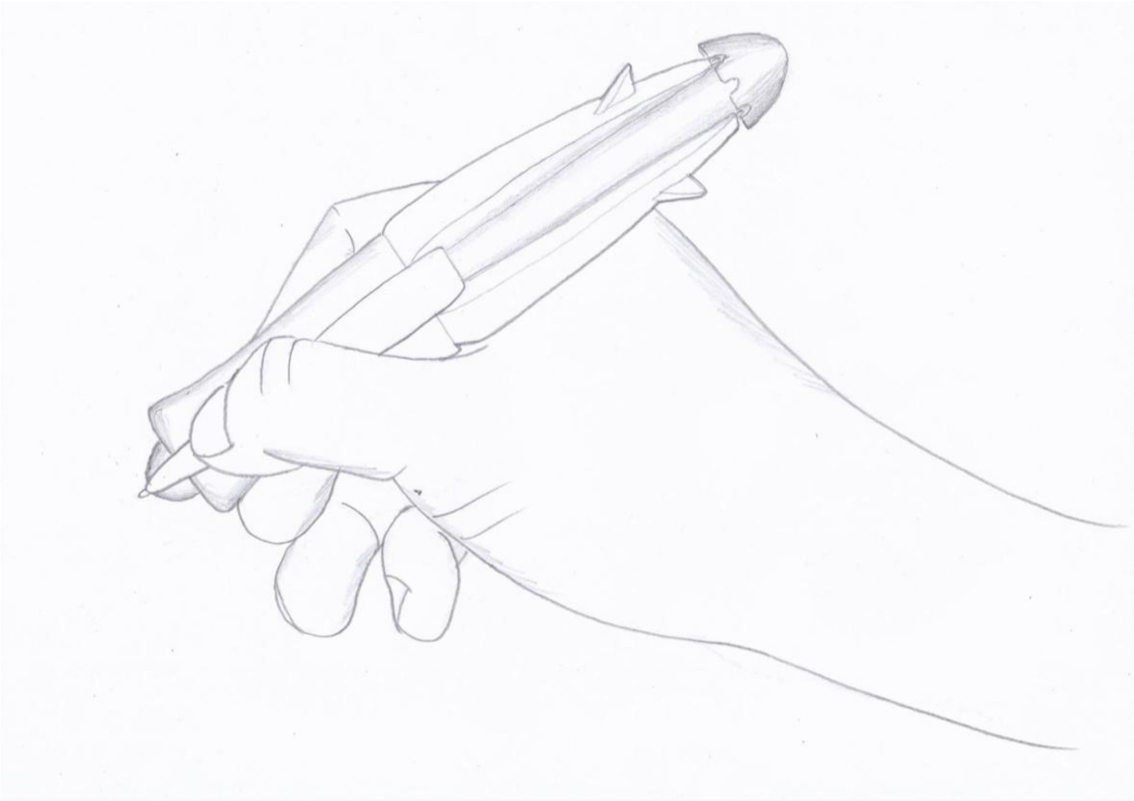

Figure 36: General aspect of the design

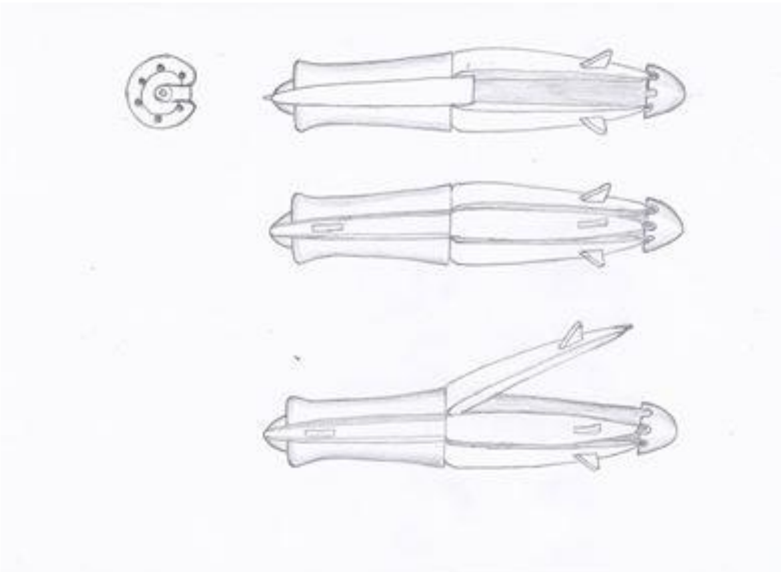

Figure 37: Mechanism for changing colours

5.1.3.2 Pros

- Visually interesting
- Easy to change the ink cartridges
- Good weight distribution
- Space for the electronic part
- Easy to see which colour is chosen (coloured arms)

5.1.3.3 Cons

- Folding arm can be easily broken
- Risk of cartridge leaking
- May be difficult to fold away the colour you're using
- Confusing to someone who is not familiar with the design
- The slot must always be on the underside of the pen or the arm may pop out of the slot

6 Reverse engineering

This project is about designing and producing a digital pen. Digital pens are already in the market, but it is a high tech area for the team, and several issues were unknown (managing space, special components, etc.). In order to be able to design a proper digital pen, we took the decision to choose an existing pen on the market, and disassemble it, i.e. by doing a reverse engineering study on it. The pen selected to purchase, after the market research had been done, was the Livescribe 3. This is one of the newest digital pens on the market, and matched many of our requirements. The study of this pen has been conducted in two parts. The first one describes the use of the pen and all the external features the pen has. The second part deals with the internal design of the pen at an electronic and a mechanical level.

6.1 External study of the Livescribe 3

This part of the reverse engineering was focused on external features of the Livescribe 3 such as the packaging, the technical properties and the design.

6.1.1 Packaging description

The packaging is a luxurious wraparound made of cardboard. The external part of the packaging wraps a cardboard box where the pen is stored in a plastic wedge. A user's guide, a notebook and a USB cable to charge the pen are stored below this wedge.

Figure 38: External view of the packaging

Figure 39: Internal views of the packaging

6.1.2 Technical description

The Livescribe 3 is a digital pen that allows the user to record digitally in a User Interface (UI) everything that you write in its notebook. The first step to use the pen is to download an application to your device, and then you can use the Livescribe. The writing data is sent to your device via Bluetooth. The Livescribe 3 is also able to record audio using the smartphone recorder.

Taking into consideration the fact that the target of the project is architects and constructors, the digital pen to design must work with a ruler. According to our study it seems that the user needs to be careful with the camera orientation of the Livescribe 3. In some particular cases the camera does not see what has been written. Only transparent rulers orientated in a particular way work for the pen. This is something that must be taken into account for the final design. The pen is able to work in dark conditions, which is also an important feature for architects that may have to work outside in a dark location.

On average, there is a delay of three seconds between the moment when you lift the pen from the page and the moment when the words appear on the screen. In addition, the pen has a memory of fourteen seconds. When the user keeps writing on the paper and does not lift the pen from the page, the writing appears on the screen anyway after a fourteen second delay.

The Bluetooth range is about twelve to thirteen meters and works both outdoors and indoors. However, the walls are an obstacle big enough to block the Bluetooth signal.

6.1.3 Design description

The pen has a weight of 34 grams. The design is simple and classic. The materials used convey an impression of luxury. To turn the pen on/off the user has to twist a band and a LED shows if the pen is connected, disconnected or discharged. The tungsten carbide ballpoint ink cartridge is easy to remove so that the user can refill the pen as many times as is desired.

Figure 40: Dimensions of the pen (left) and the cartridges (right)

6.2 Internal study of the Livescribe 3

6.2.1 Analysis of the components

6.2.1.1 Twisting mechanism

The pen turned on/off by a twisting mechanism located in the middle section (figure 42). It is made possible thanks to a ramp. When you twist this part of the pen, the cartridge goes down and meets the pressure sensor, which activates the board (light signal from the LED).

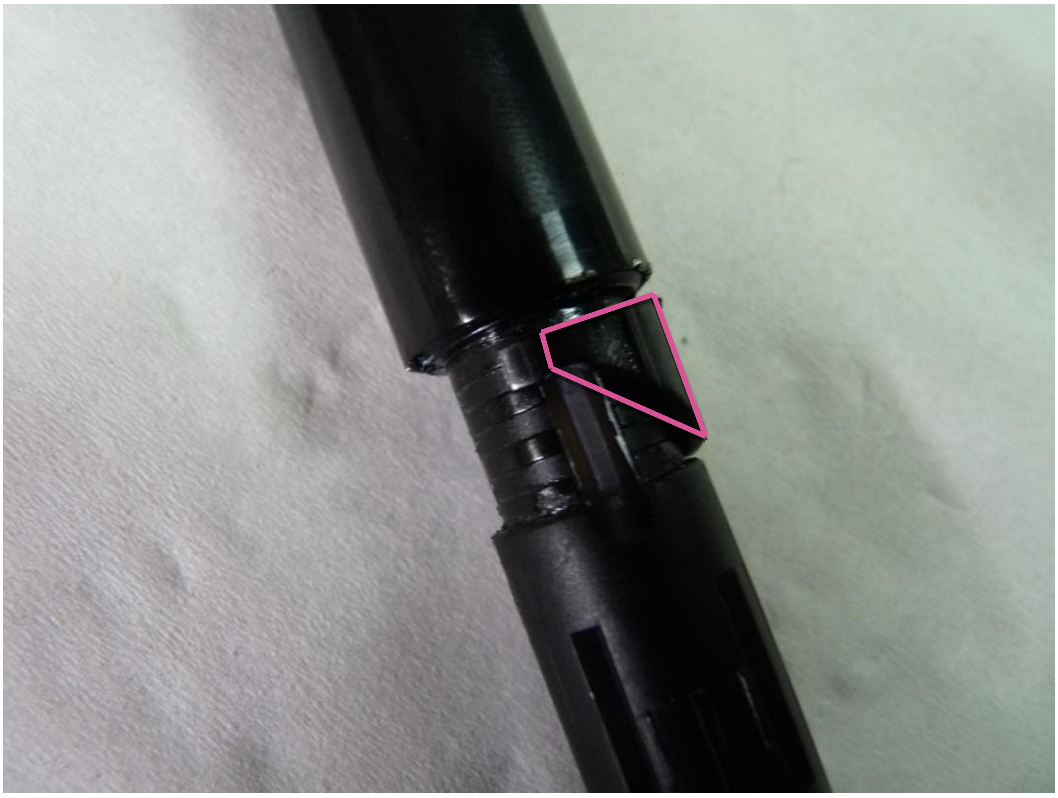

Figure 41: Ramp used for the twisting mechanism

6.2.1.2 Electronic boards

The electronic boards are protected in an inner case made of plastic. This case is made of two parts and allows the main board and the battery to remain attached together.

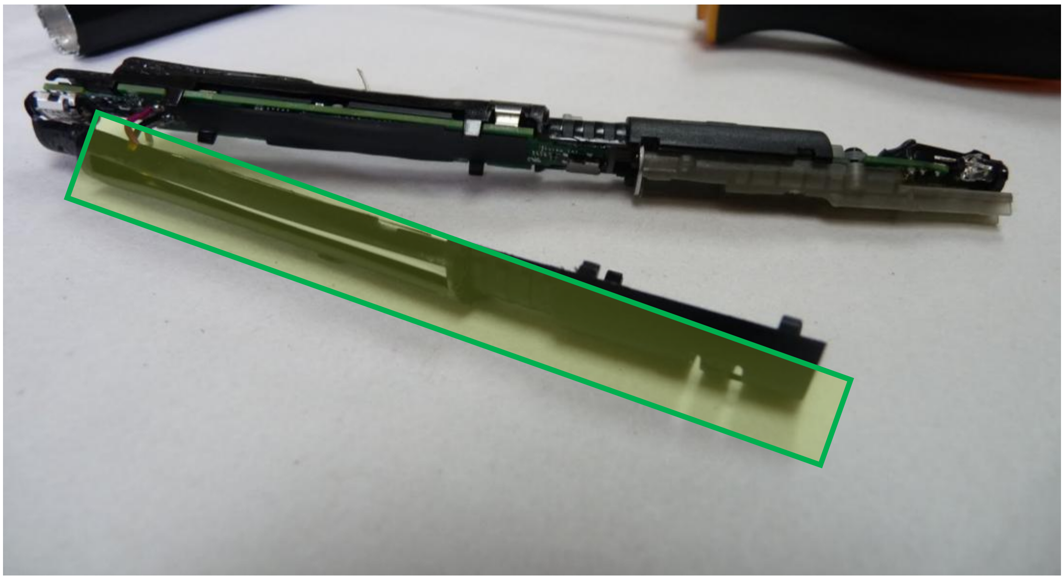

Figure 42: Two part plastic case

There are two boards, one for the camera and the other one which has all of the other components and the microcontroller. The reverse engineering helped the team during the process of designing the multicolour digital pen, by allowing us to picture the space needed for the different boards.

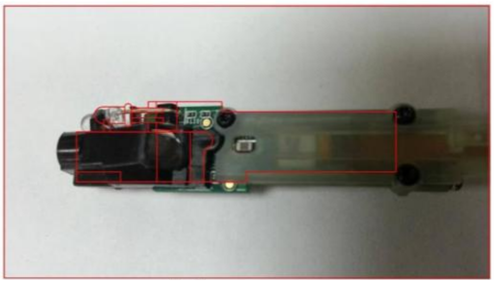

Figure 43: Camera electronic board

6.2.1.3 Space Management

One of the most important things learned from the Livescribe 3 was how to fit all components into the body of the pen, and how it was done to connect electronics and the mechanisms.

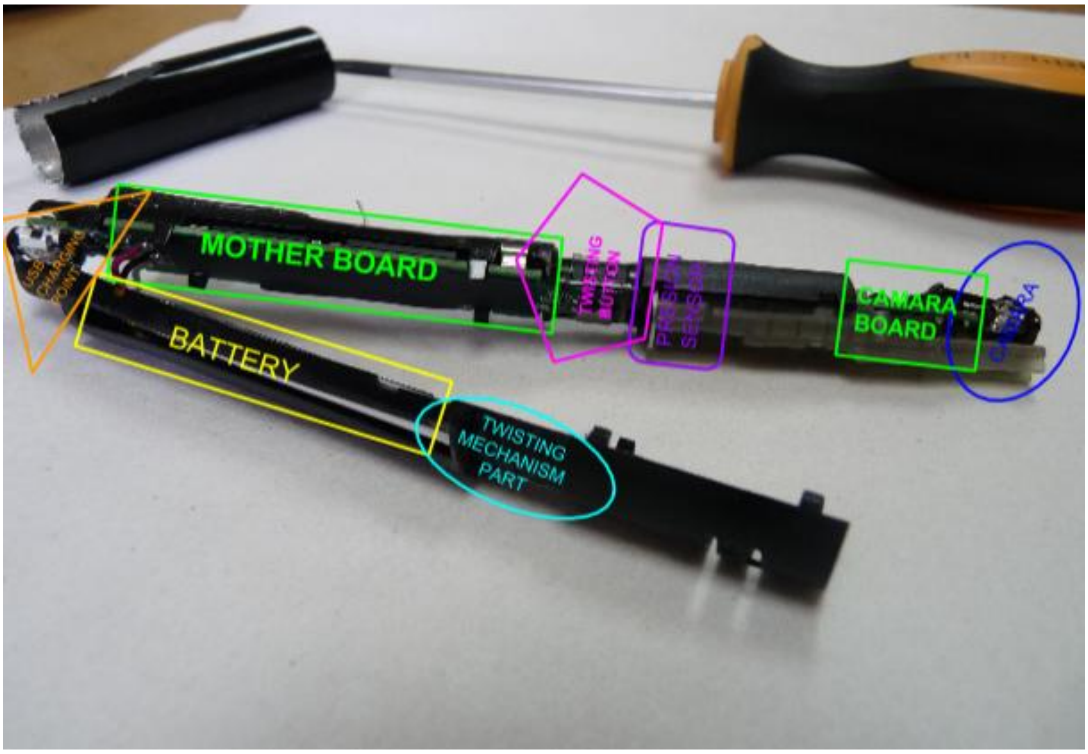

Figure 44: Space management

7 Description of the final concept

7.1 Concept chosen

After the midterm report, the team presented the concepts to HP. The chosen concept was concept 2 (see 5.2.1 Concept 2) which is the most user-friendly. However, this design required more work in terms of mechanism and electronics.

The main issue faced was the pressure sensor, the purpose of which is to detect if the pen is writing or not. As there are five cartridges, we decided to avoid the need for five pressure sensors, by having only one that gets used by all of the individual cartridges at different moments. This is the reason why the final concept only has one tab instead of five different tabs. We came up with the idea of a revolving barrel mechanism. This would only need one pressure sensor, and would allow the cartridges to rotate to a precise upper point, from which they could be extended until they protrude from the end of the pen, for writing. Finally, concept 2 evolved through different stages until reaching the best solution in terms of mechanism and electronics.

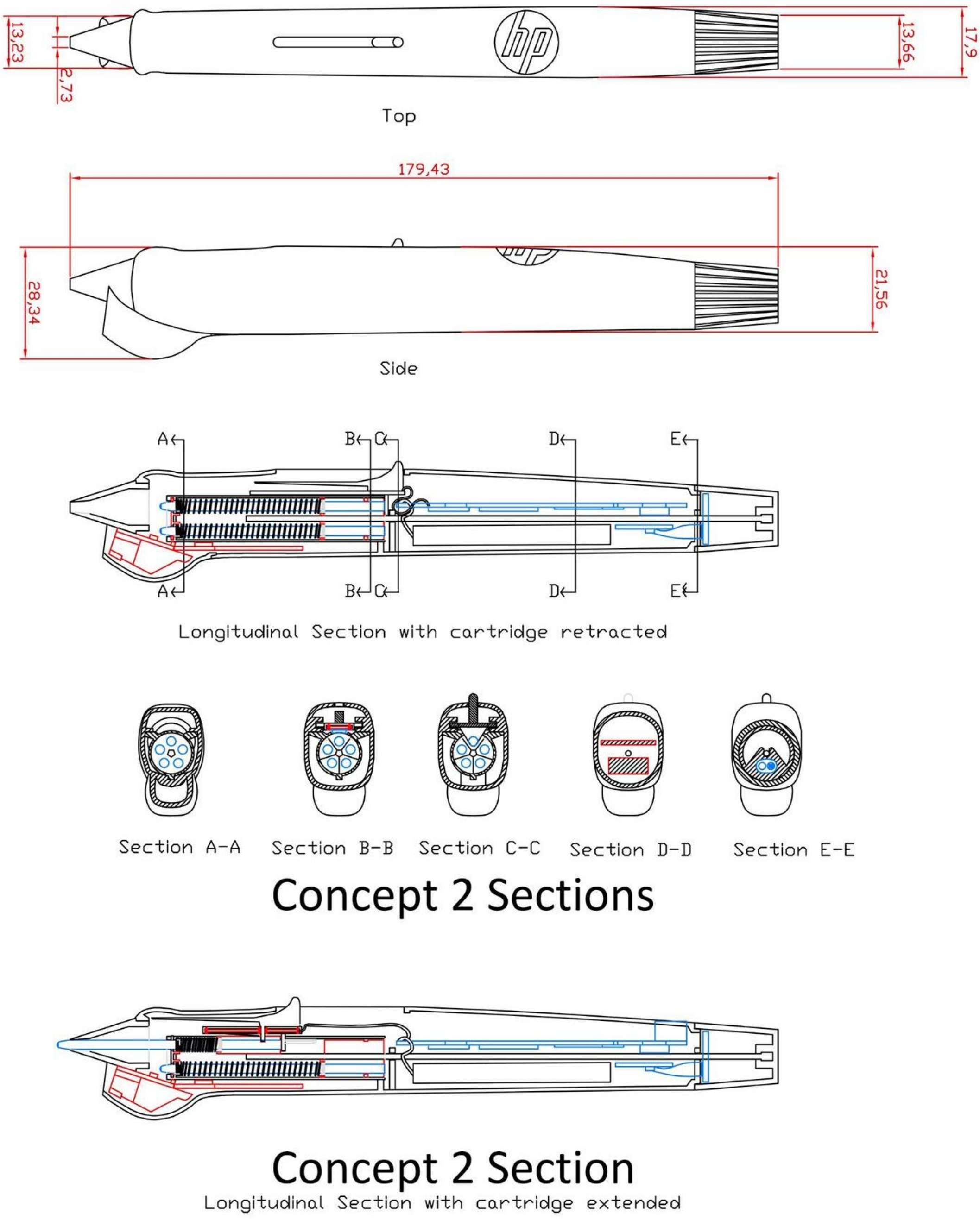

Figure 45: Latest evolution of the Concept 2

7.2 Design

The pen designed is a **digital pen** that means it is an **interface**. As such, the design has to be ergonomic and attractive to be easy to use by the consumer and has to contain special features.

7.2.1 Features of the pen

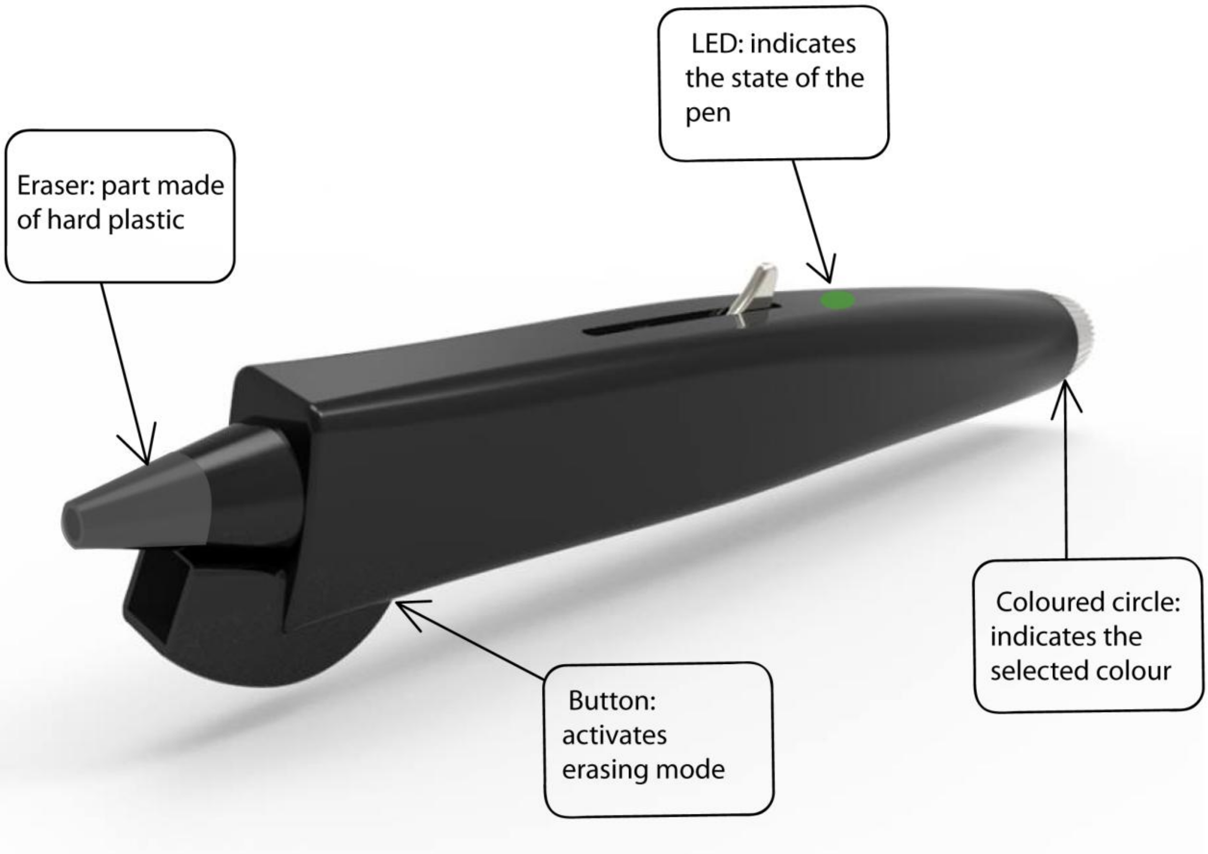

Figure 46: Features of the pen

7.2.1.1 LED indicator

The pen is designed to be a user interface. Therefore, the user needs feedback on the state of the pen in order to use it correctly. This is the reason why the design includes a status LED that illuminates in different colours and intermittent flashing patterns. The different status are related to the battery, the connectivity and system failure:

- Battery lower than 30%: flashing
- Battery higher than 30%: continuously on
- Connectivity with the receiver device: light colour = green
- No connectivity with the receiver device: light colour = yellow
- System failure/error (eg: memory full): light colour = red

7.2.1.2 Erasing function

One of the requirements of HP was to design a pen which had an erasing function. Our concept makes it possible by using Frixion heat-sensitive ink cartridges of different colours. To erase this heat-sensitive ink the user has to rub the paper to produce heat up to 65°C. This is possible by rubbing a hard plastic part (eraser) that is situated at the writing end of the pen where the tip of the cartridge usually pokes through. The user has to release the tab so that it slides to its upper position, an action which retracts the cartridge, and then the user must push the erasing button while rubbing the written ink with the hard plastic eraser.

7.2.1.3 Cartridge design

The pen is designed to be refillable because these heat-sensitive ink cartridges have a smaller autonomy than normal ink cartridges. The user has to press the tab down to its maximum, and then pull the cartridge out of the end of the pen. The tab should not be retracted during this step lest a different colour becomes selected, and the cartridge may be replaced into the wrong slot. To help the user during this step, the pen will contain coloured cartridges or cartridges with a small colour indicator.

7.2.1.4 Colour selection

To help the user during the colour selection phase, the pen will have a coloured band under the twistable colour selector, in order to indicate to the user which colour is selected at any time. Furthermore, the colour selector should twist and have five defined positions so that the user knows which colour has been selected.

7.2.2 Materials

7.2.2.1 Description of the materials

In this section we are going to have a look at some possible materials that can be used in our design. For the body and mechanicals we can use either Polypropylene plastic or an aluminium alloy such as 6061 or a combination of the two depending on the parts requirements and the economy of producing the parts. The parts will be made by injection moulding so the characteristics of the materials used will be very important. The polypropylene is an ideal choice due to its ease of injection moulding, its strength and durability, and it smooth shiny surface texture. The alloy 6061 is a strong alloy relative to the polypropylene, and is light weight and can have a very smooth shiny reflective surface, giving the pen an expensive feel.

7.2.2.2 Eco Audit of the design

In this part we made a comparison between a metallic and a plastic body using the CESedupack software. CESedupack is software developed by the University of Cambridge. It is a database with detailed information about the technical, economic and environmental properties of materials and processes.
CESedupack allowed us to compare metallic and plastic materials and to forecast which design will have the lowest ecological impact. The only part of the two designs which is different is the body of the pen: in the first product the body is made of polypropylene and in the second product the body is made of an aluminium alloy. There is a difference of weight in the two design description because of the materials.

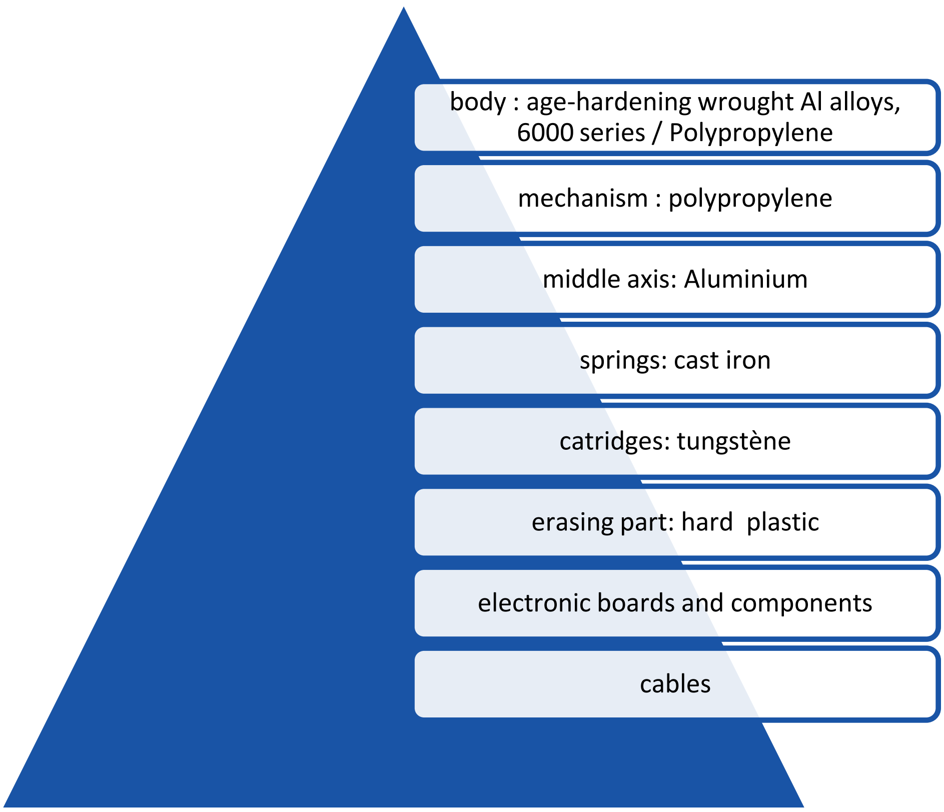

Figure 47: Materials of the different parts of the pen

The following tables show how was described the two designs in the software:

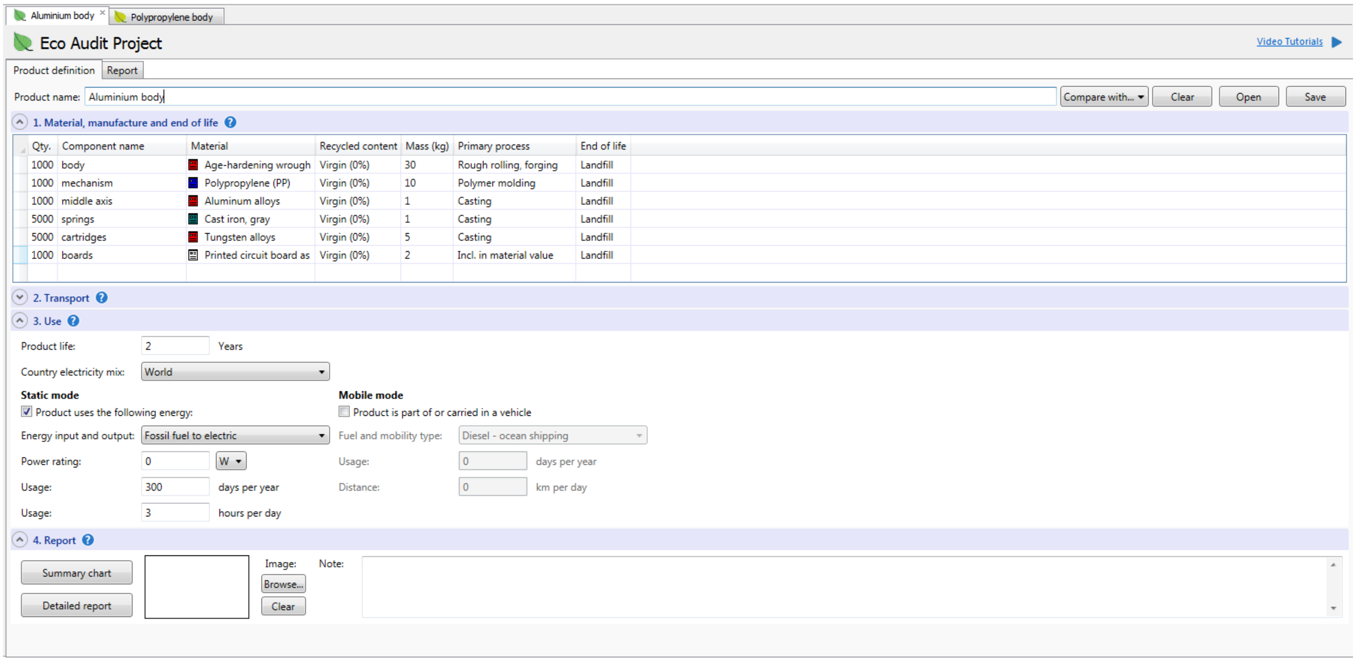

Figure 48: Description of the concept with an aluminium body in the CESedupack software

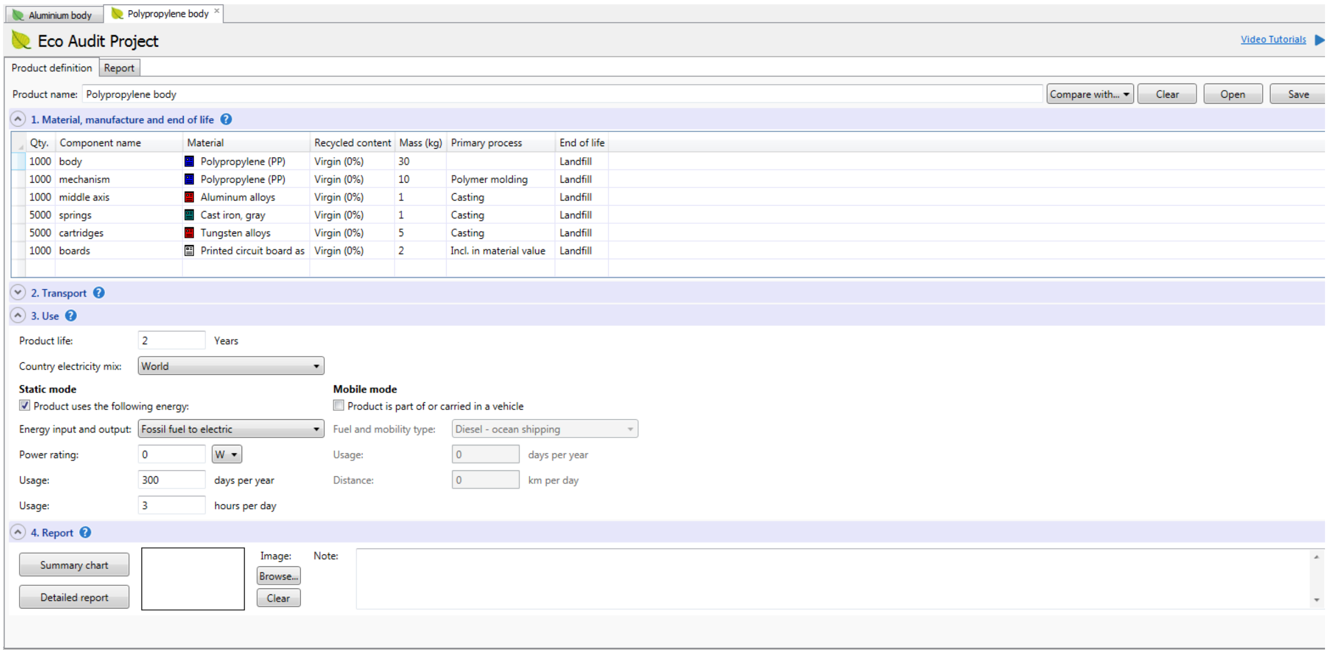

Figure 49: Description of the concept with a polypropylene body in the CESedupack software

The Eco Audit gave the following results:

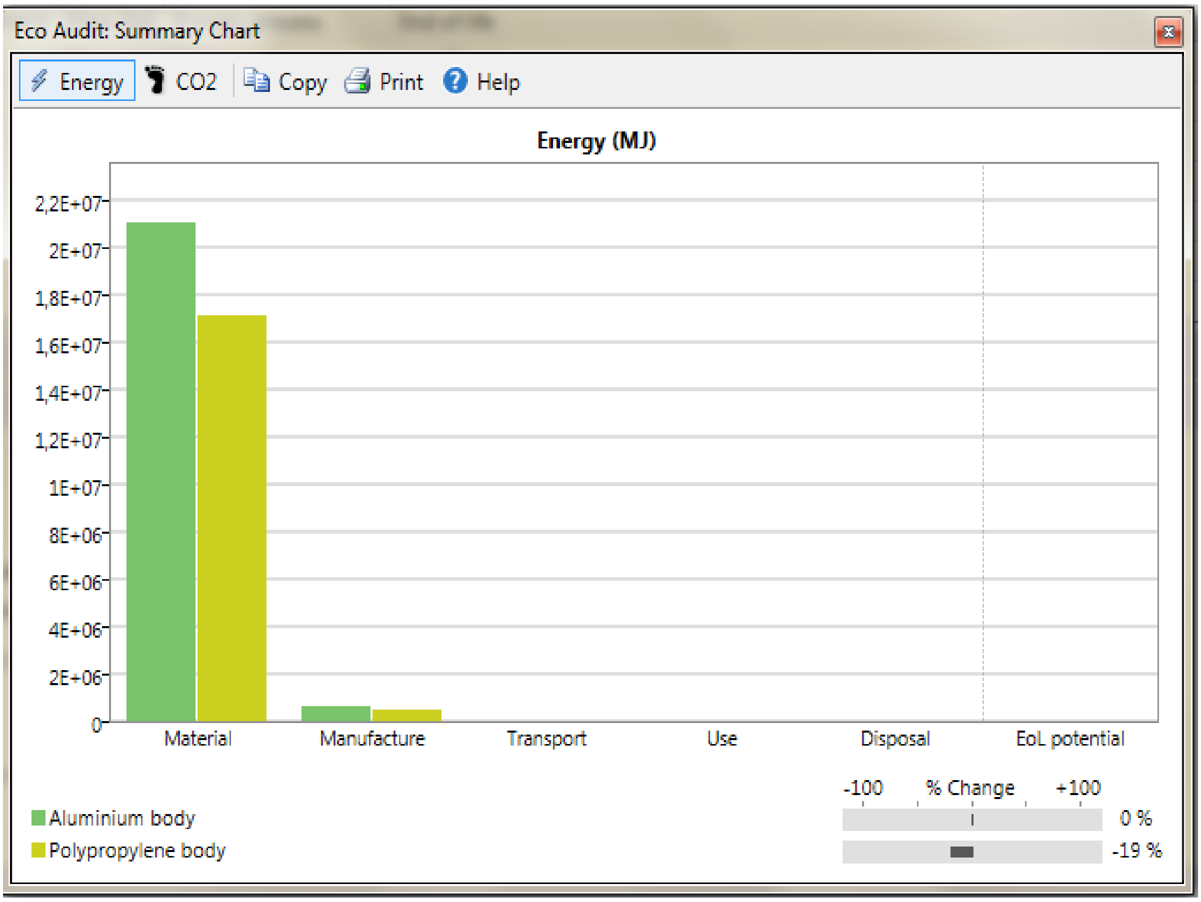

Figure 50: Comparison of the Eco-Audit of the differents bodies

According to this chart, the product with a metallic body has a stronger impact on the environment in terms of materials and manufacture. Still, prototypes should be produced to test the mechanical resistance of both materials and their capacity to protect the inner part of the pen.

The other information is out of the scope of the project so it was not possible to complete the Eco Audit for transport, use and disposal. In addition, as we had no budget requirement or marketing brief for this project, we did not define the materials and the processes in a detailed way.

7.2.3 Ergonomics

7.2.3.1 General description

In order to study the ergonomics of the pen we constructed a 1:1 scale prototype based on the 2D drawings that we had made. This pen was crafted for an ergonomics study and to test out colour schemes.

We knew that the pen must be comfortable for both left and right-handed people. With this in mind we made the pen symmetrical, and invited left and right-handed people to test the ergonomics prototype.

Another factor of importance is the way the user selects a colour and puts it into operation. Simplicity is the key with this colour changing operation. Taking this into account, we chose a variation of our second concept.

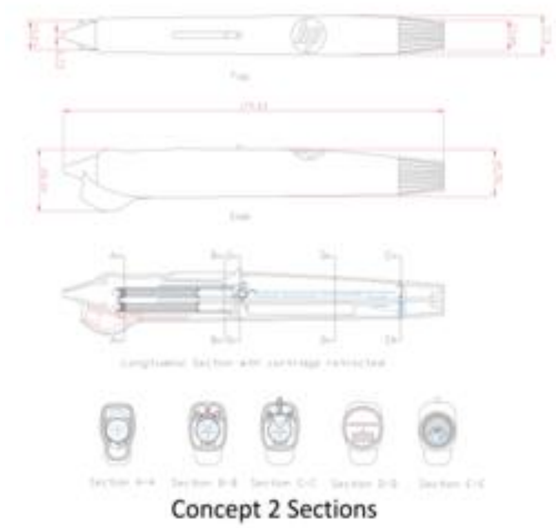

Figure 51: Concept drawings

This concept was adapted to have a rotating barrel containing the 5 different cartridges, and the user simply has to twist the end of the pen in order to choose a colour, and then slide the tab downwards to activate this colour. This simplistic operation allows us to have a very clean smooth exterior to the pen, as the body is not cluttered with buttons and tabs protruding in all directions.

Figure 52: Wooden prototype in a hand

Figure 53: Wooden prototype

Finally, the pen must be comfortable to use. The end that the user grips must not be too thick, and the pen must sit into the hand, gently resting on the edge of the hand between the first knuckle and the base of the thumb. The balance is also important here as the weight distribution should be biased to the writing end in order to avoid having a top-heavy, difficult to control pen.

7.2.3.2 Using erasing function

When the user needs to erase something that has been written, the simplest way to do this is by rotating the pen until it is upside down. At this point the erasing button which is on the camera housing is easily accessible by the index finger, which naturally presses down on it while the pen is rubbing and erasing on the paper. The position of the button is ideal, as the shape of the camera housing prevents the index finger from sliding down, no matter how vigorously the eraser is used. The grip on the end of the pen is secure and comfortable.

Figure 54: Pressing the erasing button

7.2.3.3 Defining shapes

The pen is limited in terms of shape by the internal mechanics. These mechanisms dictate what can and cannot be done with the external design. The largest part is a cylindrical barrel, which contains all of the different coloured cartridges. This is the part that most affects the ergonomics of the pen as it is contained within the tapered end of the pen that the user's fingers grip when writing. This cylinder makes the end of the pen thicker which can make the pen difficult to write with, especially for user's with small hands. The cylinder is below the central axis and has a small space above and below, in order to accommodate the sliding tab mechanism above and an IR camera below. This gives the pen a more rectangular section, which can impede the user's fingers.

The bulbous protrusion which houses the camera further impedes the fingers, making gripping the pen with small fingers very difficult (figure 55).

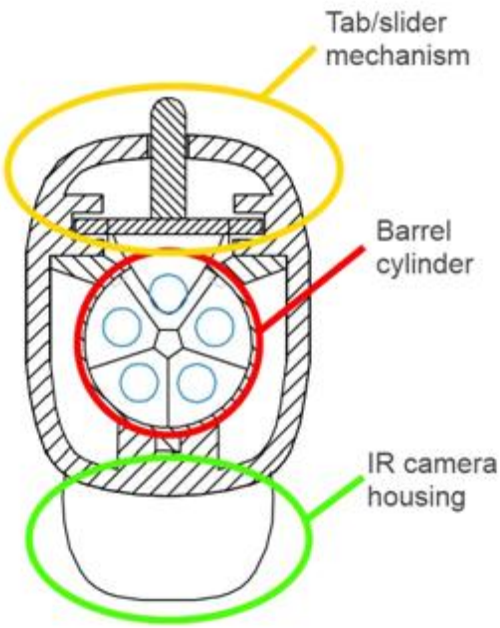

Figure 55: Use of the space in the pen

7.2.3.4 Conclusions

Reducing size of the camera housing would greatly improve the ergonomics in this area. The camera housing was deliberately made large enough to accommodate the same IR camera as the Livescribe 3 that we disassembled, however, ergonomically and visually speaking, the camera is far too large to be used in our pen as it protrudes in an area that affects grip and therefore control. If the user cannot control the pen with ease, then they will not enjoy the writing experience.

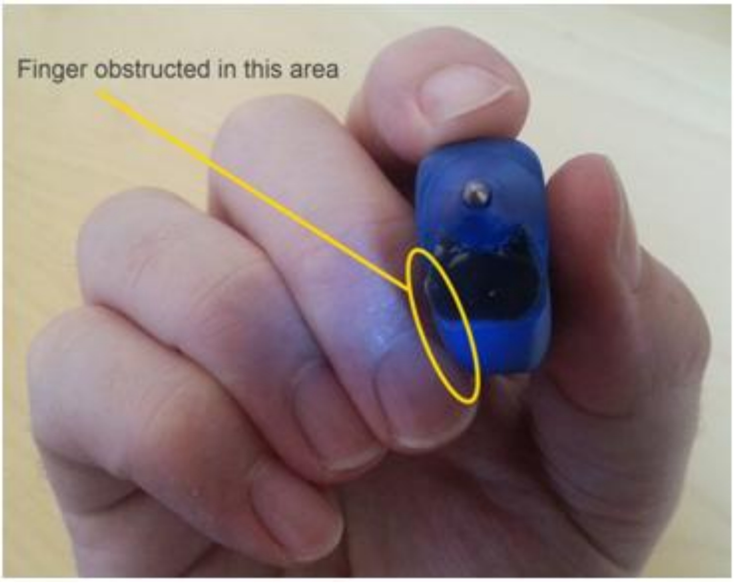

Figure 56: Digital pen in a hand

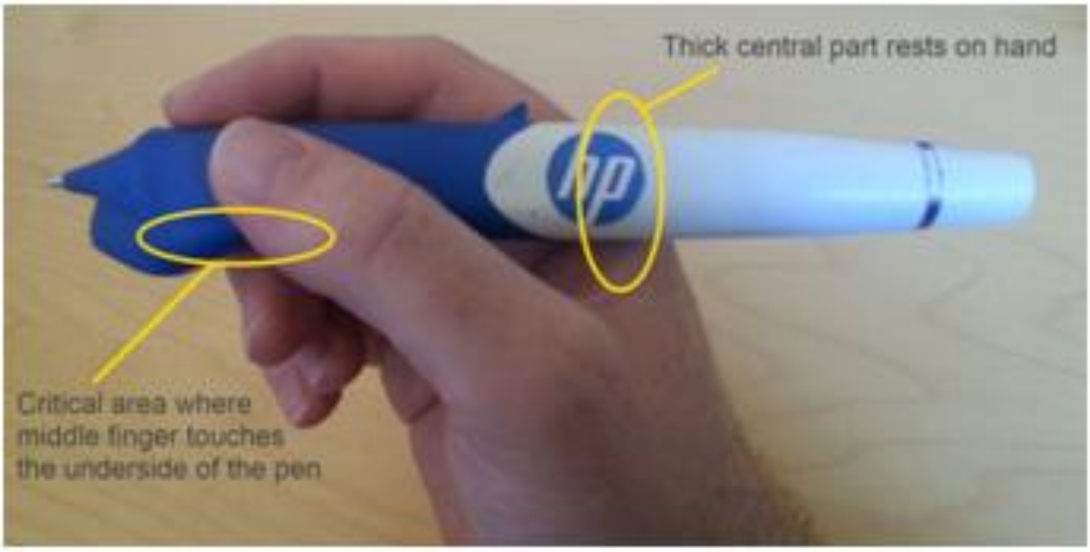

Figure 57: Critical areas

So, we can conclude that a new **smaller IR camera** must be found and integrated into the design (figure 58).

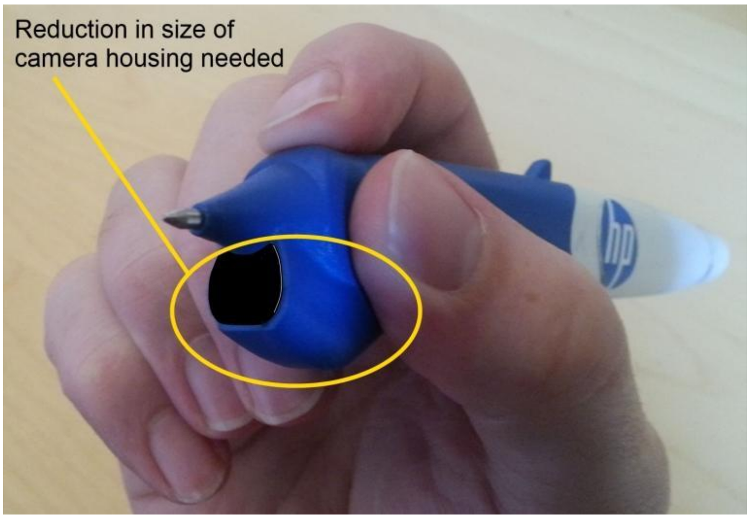

Figure 58: Camera Housing

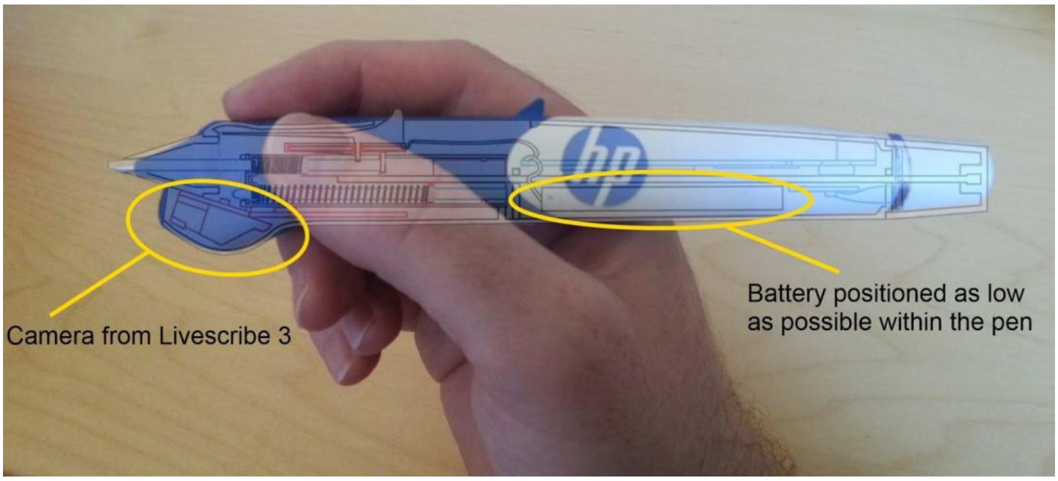

Figure 59: Side view of the drawing

The positioning of the battery will also add to the feel of the pen. Its weight should be as low as possible to ensure a **good weight balance**. A possible improvement would be to split the battery (as seen in figure 59) into **two smaller batteries**, one positioned in the current position and the other above it on the other side of the central axis.

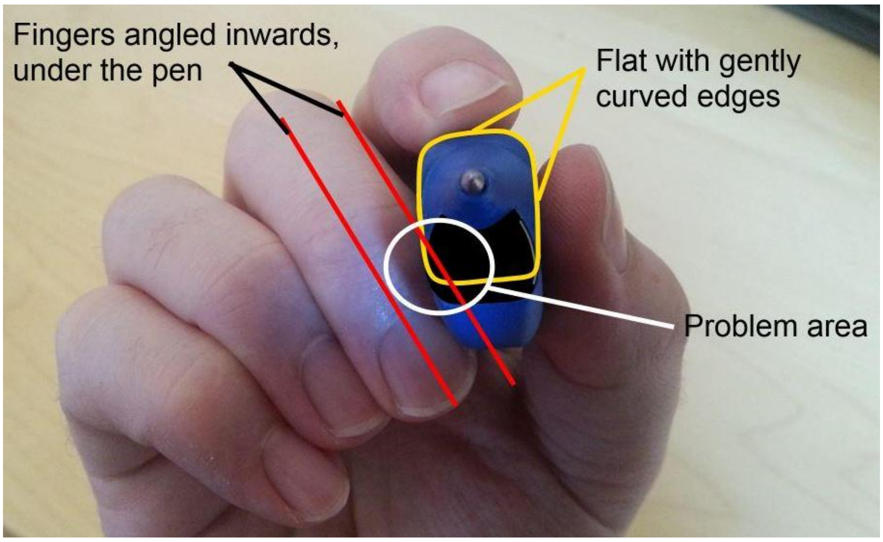

Figure 60: Problem Area

In figure 60 we can see how the thumb and index fingers are angled inwards under the lower edge of the pens body. This problem is even **worse when the hands are smaller** as the fingers cannot comfortably reach the underside of the pen, which results in a lack of grip and control.

Figure 60: The Stabilo Boss Highlighter Marker

Perhaps a good reference that everyone is familiar with is the Stabilo Boss highlighter marker shown in figure 61. This marker also has a **rectangular body and rounded edges**. It's body is 27mm high, which is a full 7mm higher than our design (which is 20mm not including the camera housing) and 17mm wide (compared to 17.5mm in our design)

There are many areas of the pen where a reduction in volume could greatly improve the ergonomics of the grip. In figure 62 we can see some of the main areas highlighted. These are areas of empty space within the body that only exist so that electronic wires can connect the various electronic parts to the motherboard. A more purposefully designed channel for these cables could allow the body to be redesigned to be less voluminous.

In brief, a reduction in volume, a smaller camera and housing, a better weight distribution and a more ergonomic shape will all improve the pens ergonomics and should all be thoroughly investigated before the pen can go into production.

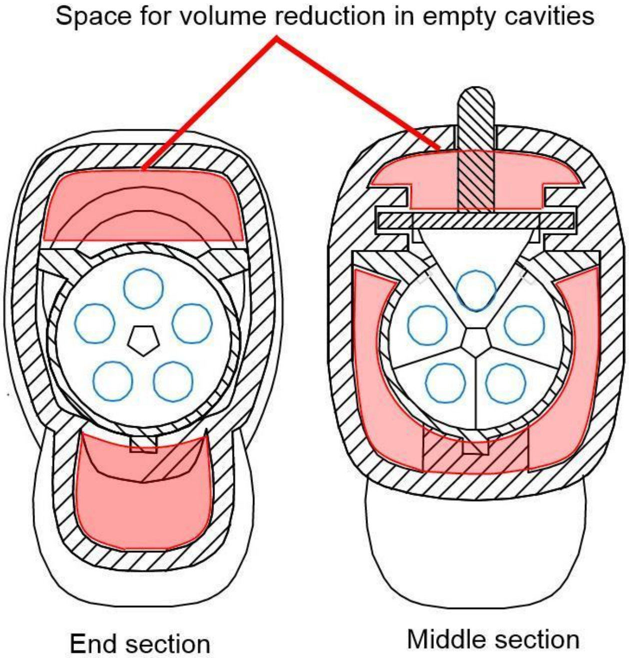

Figure 61: Areas of possible reduction in volume

7.3 Mechanism

7.3.1 About the mechanism

The mechanical design is an essential part of the multicolour digital pen. It is the mechanical parts that make it possible for the user to change the colour.

The main mechanical limitation in the project was the lack of space inside the pen. A camera, sensors and electronic boards are just some of the components that also require space inside the body of the pen. In order for all this to fit, the mechanical parts must be as space efficient and minimalistic as possible.

7.3.2 Choice of mechanism

A number of proposals were generated during the analysis phase of the project. However, soon it turned out that many of them could not be implemented in the multicolour digital pen. Mechanical inspiration was taken from Bic's traditional multicolour pen (See figure 63). But Bic’s solution is not suited for use in a multicolour digital pen since it needs a lot of space, four tabs that are dependent on each other, and flexible cartridges.

A number of ink pens were disassembled to study the mechanical designs. Simple hand sketches were made to illustrate how the pen should work.

Figure 62: Bic's traditional pen

7.3.2.1 The two-step operation

The mechanism that the group chose to proceed with was influenced by a revolver barrel (see picture). The process of extending the cartridge is based on a two-step operation. The first step is to rotate a wheel until the desired colour is in line with an indicator (see photo). The second step is to pull down a tab and thus extend the selected colour cartridge (see picture). The operation is now complete and the pen is ready to use.

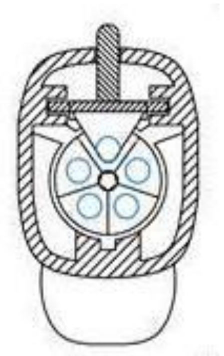

Figure 63: Revolver barrel

Figure 65: Rotating colour selector

Figure 64: The tab in its down position

To retract the cartridge back inside the pen, the user has to push the tab about 5mm downwards. This action causes the guide arm on the tab mechanism to jump out of a notch that it had been slotted into. Thus, the tab to returns to its original retracted position and this makes it possible to change the colour using the rotating wheel (7.3.4.2 The tab).

7.3.3 Modelling

7.3.3.1 2D drawings

When the mechanism of the pen was selected, 2D drawings were made. The main purpose of this was to create a common picture of how the pen would work and what it would look like, but also to prepare for the upcoming 3D modelling. The drawings mainly consisted of sections of the pen (see figure 67). The drawings were made with Auto CAD 2007.

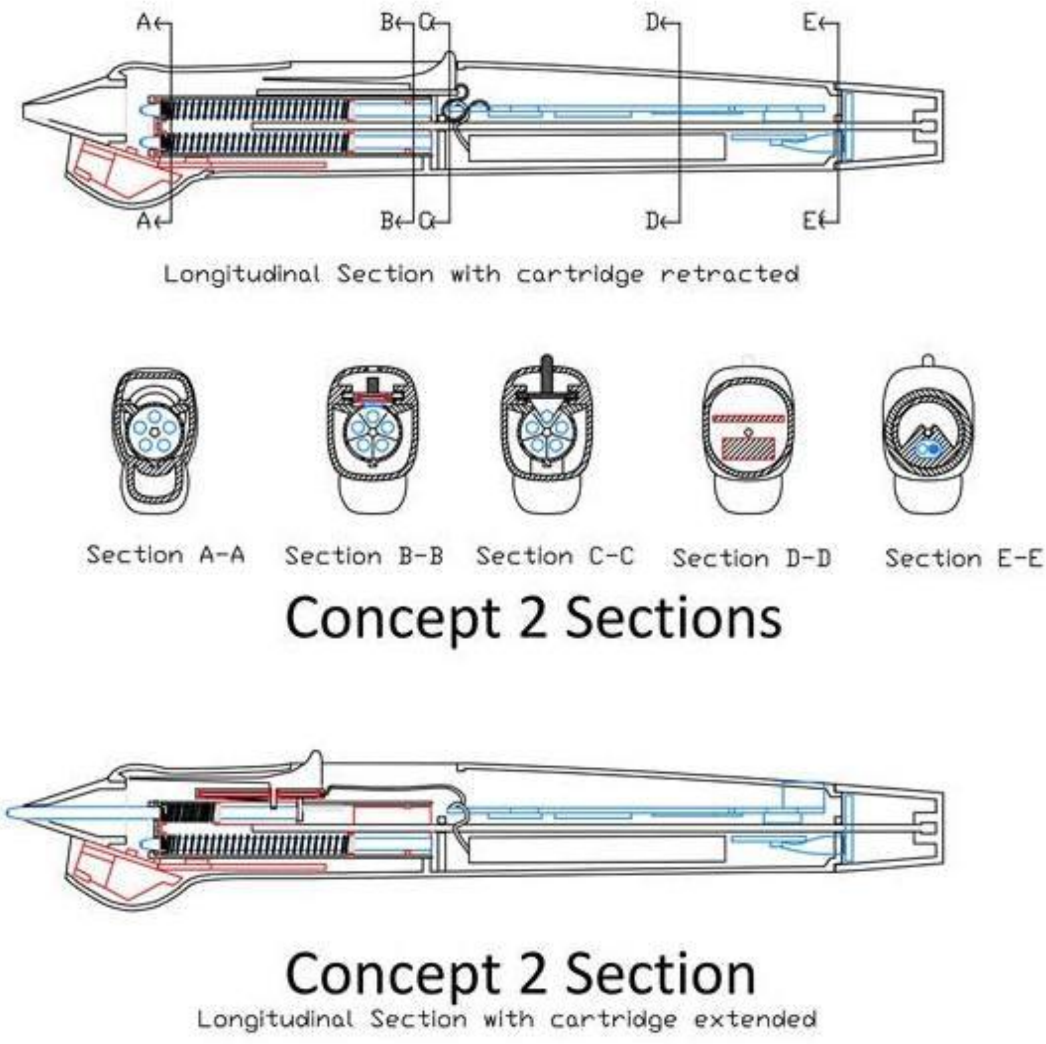

Figure 66: 2D sections

7.3.3.2 3D modelling

The 3D modelling was done using PTC Creo Parametric 2.0. This is a helpful tool to illustrate what the product will look like in reality, and to see if any parts in the model collide with each other. It also makes it possible to print parts, using a 3D printer, at a later stage.

When the 28 parts of the multicolour digital pen were assembled, it was possible to simulate how the mechanical components interacted with each other. By spinning the top of the pen, one could see how the assembled parts behaved. In this way the group verified that the mechanisms worked.

7.3.3.3 Rendering

Rendering is a process for converting a 3D model into a realistic photo image. The software takes account the types of materials, lighting, shadows, and reflections, among others.

In this project KeyShot 4 was used to get a sense of what the product would look like with a particular material.

7.3.4 Parts and functions

The pen consists of 28 parts. The parts were assembled into two sub-assemblies. One assembly for rotating the revolver segments (7.2.4.1 Rotating revolver), and one assembly to push down the chosen revolver segment (7.2.4.2 The tab).

7.3.4.1 Rotating revolver

These are the parts of the rotating sub assembly. There are five cartridges that hold four different colours including a stylus for tablets (see illustration). The cartridges are secured in the revolver segments and go through the springs and a supporting wheel. When the springs are compressed, they will provide the force needed for the revolver segments to return to its original position (7.3.4.2 The tab). The purpose of the supporting wheel is to stabilize the cartridges so they will not bend or get damaged by the pressure. The both ends of the springs are attached to the supporting wheel and the revolver segments.

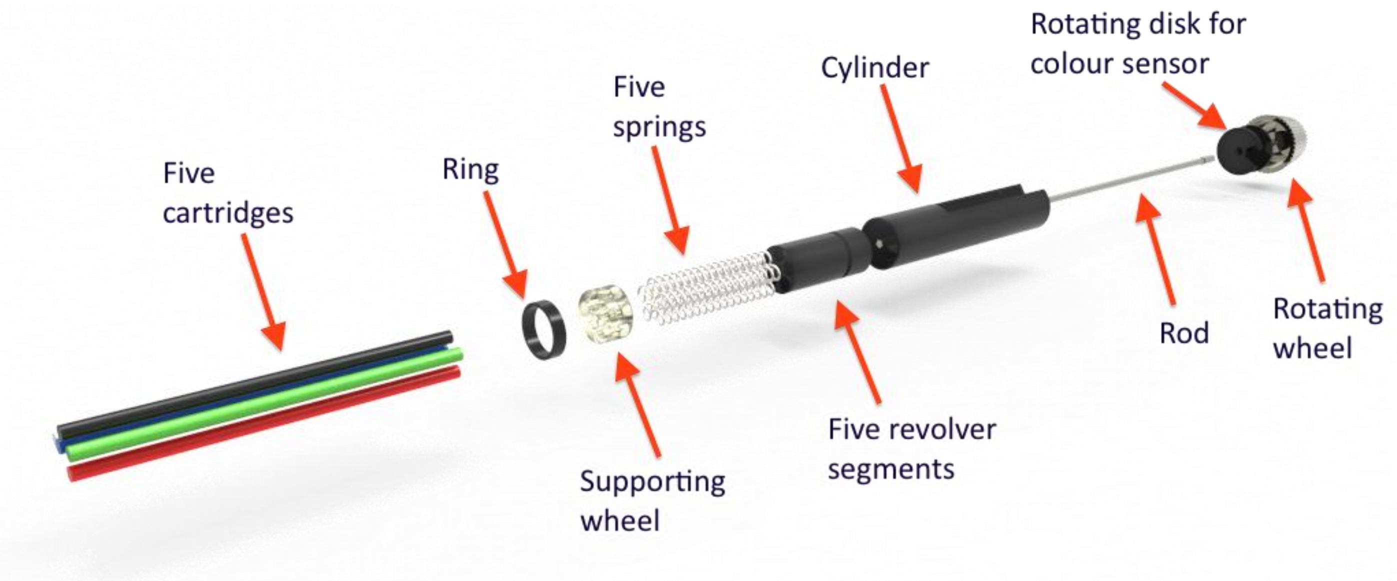

Figure 67: Exploded view of the rotating revolver

The pen consists of five different revolver segments, one for each cartridge. It has a 360° track along the curved periphery of the segments. This is where the tab slots in. The purpose of the track is to hold the segments in place and a catch the tab when it's pushed down.

Figure 68: Revolver segment

The cylinder around all these components is to keep them together and prevent them from snagging or damaging cables and electronics. According to the picture (figure 67) 1/5 of the cylinder is open. This is for the tab to be able to slide down along the cylinder taking with it a revolver segment.

The rotating wheel (colour selector) is located at the top of the pen. Each colour is marked on the wheel so that the user easily can see which colour is ready to be pushed down. The surface is grooved to improve the users grip on the wheel.

Between the rotating wheel and the revolver segments is a pentagon-shaped rod.

The pentagon shape makes it possible for the five revolver segments to slide down when they are pressed down. Each revolver segment can slide along the flat side of the pentagon-shaped rod. This pentagonal shape also allows all the segments to grip to the rod when the rod is rotated via the rotating wheel. The rod is 135 mm long.

7.3.4.2 The tab

These are the components of the tab (see figure 70). When the tab is pressed down, it travels along a rail that is integrated into the body of the pen. Two circular arms and two square-shaped arms slide along the rail, keeping it on track. When the tab is pushed down enough for a cartridge to come out (21mm) the square shaped arms hook into a notch in the rail. This prevents the springs in the revolver barrel from pressing the tab upwards and releasing the mechanism.

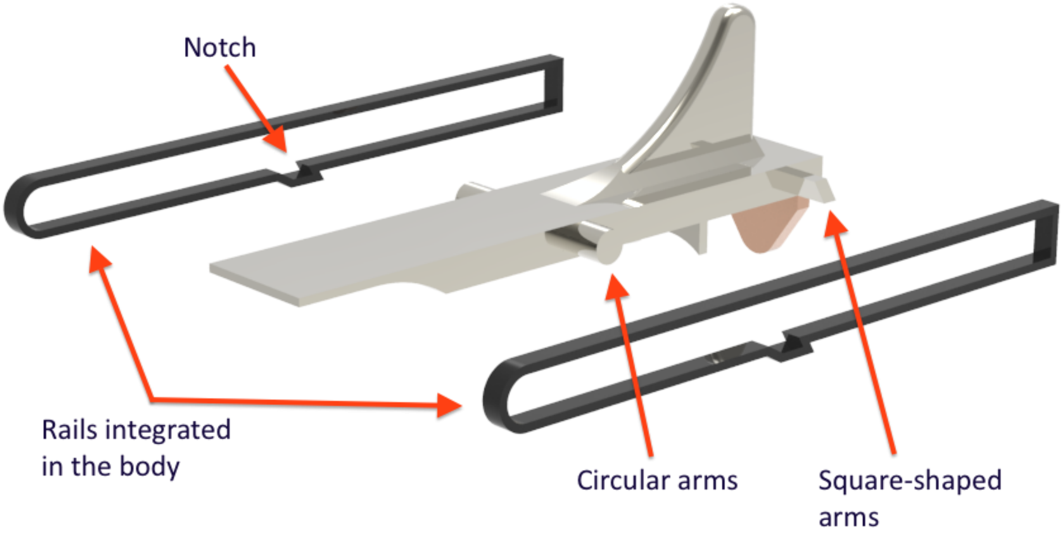

Figure 69: Exploded view of the tab mechanism

The torsion spring located underneath the tab constantly wants to push the tab up. This is prevented when the square shaped arms go down into the notch on the rails. To get the tab up again, the user must push the tab down a bit, in order to make the arms jump out of the notch. The torsion spring creates a shear force that makes the tab to jump out of the notch.

The pressure sensor is located on the upper end of the tab. It is the pressure sensor that detects if the pen is in use or not. When the pen is in use, the sensor will always be in contact with the cartridge from the current revolver segment. More of this in 3.1.4 Force Resistive Sensor.

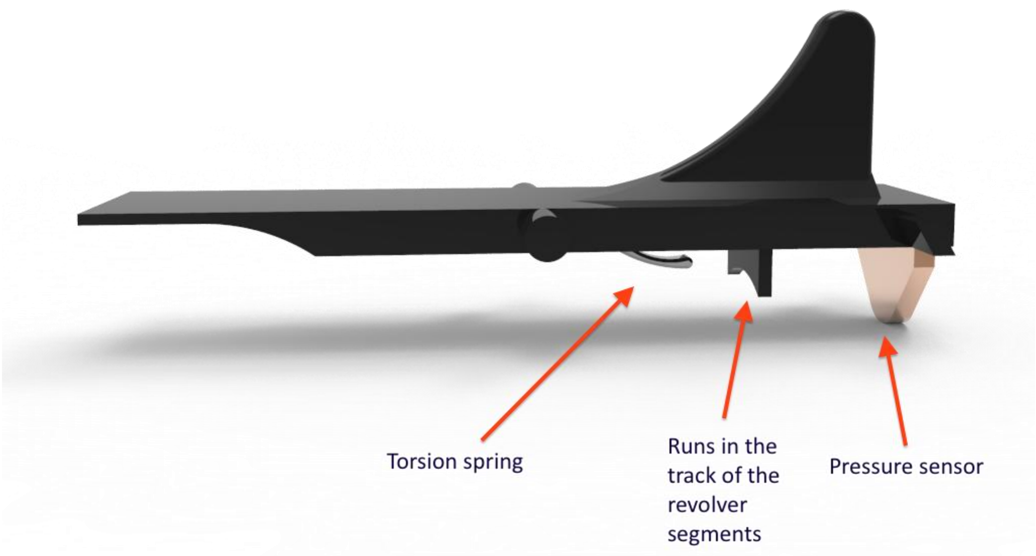

Figure 70: The tab

7.3.4.3 Rotating discs

Close to the rotating wheel, there are two discs. One of them is spinning with the rotation wheel and the other is fixed in the body of the pen. The rotating disc has different colours and works as a colour indicator. More on this in Chapter 7.4.2 Recognition system proposal.

7.3.5 Replacement of cartridges

It is important that the cartridges are exchangeable, so that the users do not have to buy a new pen every time the ink runs out.

Since the cartridges are only attached in the revolver segments by a small amount of friction, it is relatively easy to pull out a cartridge by hand. The user must, however, be careful not to put the wrong cartridge in the wrong revolver segment. If this occurs, the user will notice that the physical colour on the paper is not the same as the digital colour represented on the screen. To make this operation easier, there will be an encoded pattern for each cartridge, like a key, so they only fit in the right revolver segment. This way, the cartridge swap cannot go wrong.

The pen is designed in a way that makes all internal parts fixed inside, even if the cartridges are removed.

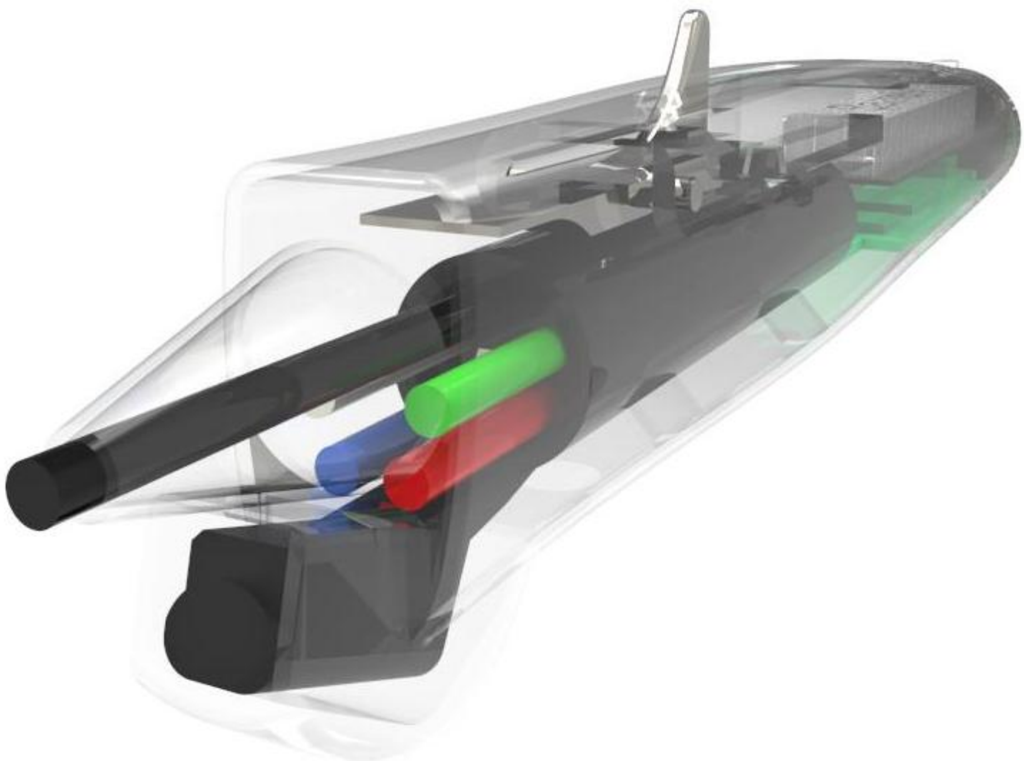

Figure 72: Frontal view with a transparent body to show the cartridges

7.4 Electronic design

7.4.1 Arduino Board

Arduino is an open-source hardware and software development platform based on a simple microcontroller board. The microcontrollers commonly used by the Arduino platform are the 8-bit Atmel AVR.

The Arduino board selected for this project is the Arduino Pro Mini. This board comes in different models depending on the microcontroller used and the operational power needed to run the board. In this case, the selected model is the Arduino Pro Mini 328 – 3.3V/8MHz.

The features of the board, as listed by the manufacturer, are as follows:

- ATmega328 running at 8MHz with external resonator (0.5% tolerance)
- Low-voltage board needs no interfacing circuitry to popular 3.3V devices and modules (GPS, accelerometers, sensors, etc)
- 0.8mm Thin PCB
- USB connection off board
- Weighs less than 2 grams!
- Supports auto-reset
- 3.3V regulator
- Max 150mA output
- Over current protected
- DC input 3.3V up to 12V
- On board Power and Status LEDs
- Analog Pins: 8
- Digital I/Os: 14

7.4.1.1 Why Arduino?

There were three main reasons for choosing the Arduino Pro Mini board. The first one was related to the time constraint of the project as the Arduino boards have a set of libraries, specially created, and this makes them ideal to do fast prototype testing without having to be concerned with learning the microcontroller architecture. The second reason concerned the size limitation for a possible prototype. The Arduino Pro Mini is small enough to be put in a 2:1 or 3:1 prototype (figure 73 :arduino dimensions) and can be used as a development board. The last reason was due to a budget constraints, as the price for this board was only €6.63.

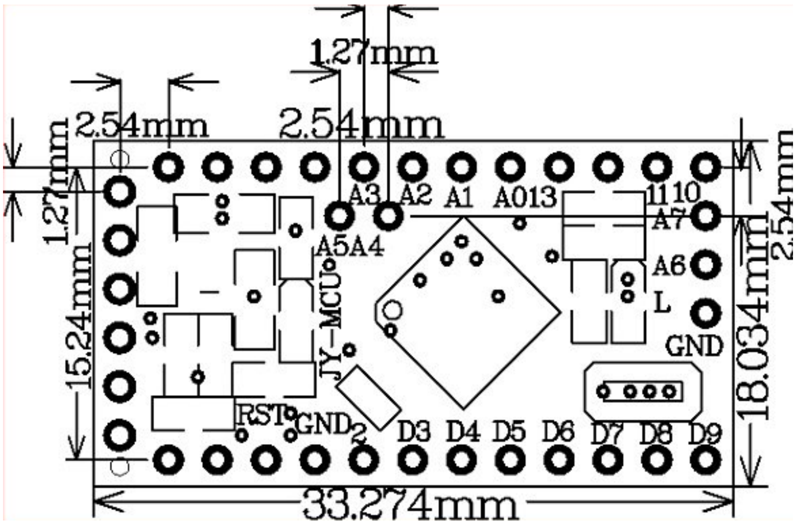

Figure 71: Arduino minipro dimensions

7.4.1.2 Arduino Pro Mini microcontroller

The ATmega328p is an 8-bit microcontroller based on the AVR enhanced Reduction Instruction Set Computer (RISC) architecture. The AVR uses Hardvard architecture with separate memories and buses for program and data (figure 72).

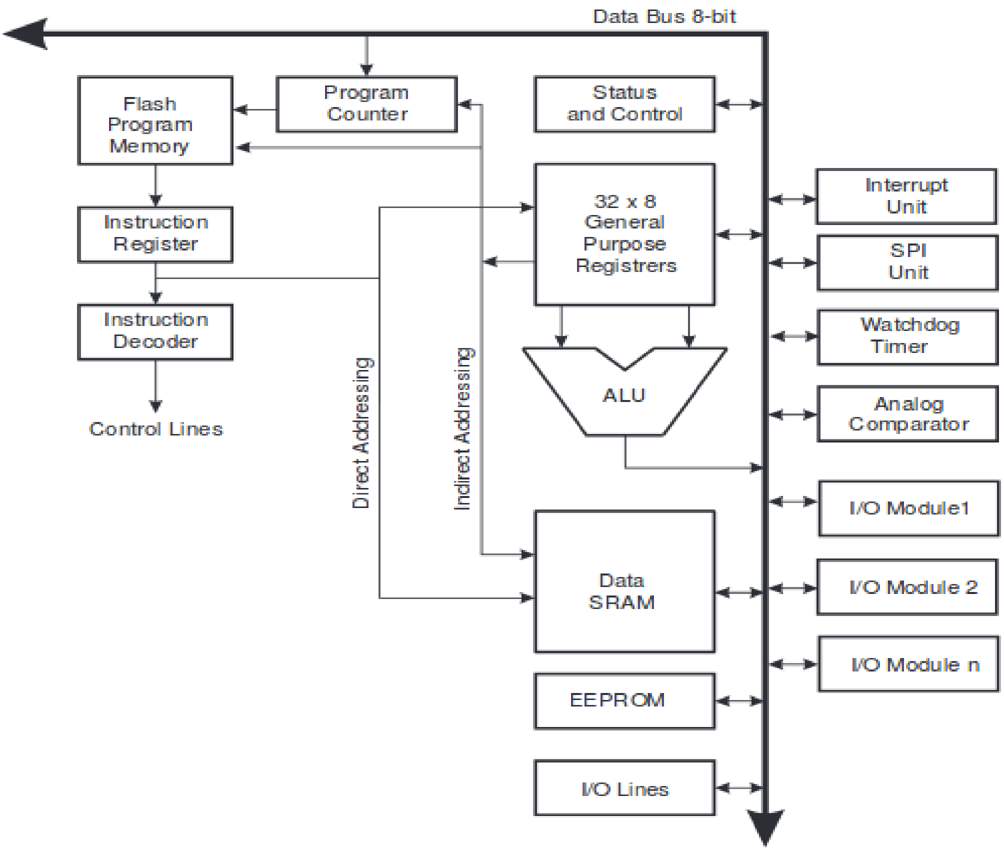

Figure 72: AVR architecture block diagram

For the design of the system, some features of the microcontroller are going to be used, namely, Interrupts, Input and Output (I/O) ports and Analog to Digital Conversion (ADC) ports. These features are common to all microcontrollers; therefore, in the sections below, an explanation of how the ATmega328p handles these features is going to be provided.

.

7.4.1.3 Interrupts

In order to enable the interrupts, the Global Interrupts Enable (GIE) bit needs to be set to 1. The GIE is the seventh bit of the Status Register (SREG), as shown in figure 75. When this bit is 0, then all interrupts are disabled regardless of the individual interrupts configuration. This bit is cleared by hardware after an interrupt has occurred and then set once the interrupt has finished. This means that no priority can be assigned to interrupts, therefore, making it necessary, if using a PWM in the system, to program the interrupts to be as short as possible.

Bit	7	6	5	4	3	2	1	0	
0x3F (0x5F)	I	T	H	S	V	N	Z	C	SREG
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Figure 73: AVR Status Register

7.4.1.4 External interrupt request

In the Arduino Pro Mini the external interrupts are in pins 2 (INT0) and 3 INT1). When enabled, the interrupts can be triggered in four different ways.

The first way is by 'low level'. Whenever the level of the interrupt is low, or a logical '0', then the interrupt is triggered.

The second way, is when the pin detects the signal changes from 'low' to 'high' level (logical '0' to logical '1'), or from 'high' to 'low' (logical '1' to logical '0').

The third way is called 'falling edge'. This means that the interrupt is triggered only when the pin detects a signal change from 'high' level to 'low' level (logical '1' to logical '0').

Finally, the fourth way is the opposite of the third way and it is called 'rising edge', this happened when the pin detects a signal change from 'low' level to 'high' level (logical '0' to logical '1').

To select the way the interrupt pins behave, the External Interrupt Control Register A (EICRA) has to be programmed, the register is shown in figure 76.

Bit	7	6	5	4	3	2	1	0	
(0x69)	–	–	–	–	ISC11	ISC10	ISC01	ISC00	EICRA
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Figure 74: External Interrupt Control Register A

Bits 7 – 4, from figure 76 are reserved bits and should not be taken into account when configuring the interrupts. Bits 3 and 2, ISC11 and ISC10 respectively, configure how the interrupt from pin 3 (INT1) is going to behave as shown in table 4. Bits 1 and 0 from the EICRA register configure how the interrupt from pin 2 (INT0) is going to behave as shown in table 5.

ISC01	ISC00	Description
0	0	The low level of INT0 generates an interrupt request.
0	1	Any logical change on INT0 generates an interrupt request.
1	0	The falling edge of INT0 generates an interrupt request.
1	1	The rising edge of INT0 generates an interrupt request.

Table 4: INT1 configuration logic

ISC11	ISC10	Description
0	0	The low level of INT1 generates an interrupt request.
0	1	Any logical change on INT1 generates an interrupt request.
1	0	The falling edge of INT1 generates an interrupt request.
1	1	The rising edge of INT1 generates an interrupt request.

Table 5: INT0 configuration logic

To make INT0 and INT1 active, the External Interrupt Mask Register (EIMSK) (figure 77) has to be programmed. Bits 7 to 2 from EIMSK are reserved bits and should not be taken into account when writing the register. Bit 1 and bit 0 program INT1 and INT0 respectively, when bit 7 from SREG is set to '1' and bit 1 from EIMSK is set to '1', then INT1 is enabled. When bit 7 from SREG is set to '1' and bit 0 from EIMSK is set to '1', then INT0 is enabled.

Bit	7	6	5	4	3	2	1	0	
0x1D (0x3D)	–	–	–	–	–	–	INT1	INT0	EIMSK
Read/Write	R	R	R	R	R	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Figure 75: External Interrupt Mask Register

The Arduino provides a function within its libraries to set and configure the interrupts in only one line of code. This function is 'attachInterrupt(interruptNumber, interruptFunction, interruptMode)', where: 'interruptNumber' is the number of the interrupt that wants to be programmed ('0' for INT0 and '1' for INT1); 'interruptFunction' is the name of the interrupt function that wants to be activated; and 'interruptMode' is the way the interrupt is to be configured, as explained in the first paragraph of this section, ('LOW' for low level configuration, 'CHANGE' for detecting a change in level of the pin, 'RISING' to detect levels from 'low' to 'high' and 'FALLING' to detect levels from 'high' to 'low').

7.4.1.5 Digital and Analog Inputs and Outputs

Inputs and Outputs are used by the microcontroller, and programmed by the designer of the system, to detect a logical state (Digital Inputs), to output a logical state (Digital Outputs), to read a voltage value (Analog Inputs) or to send a voltage value to an external device (Analog Outputs). All pins in the Arduino Pro Mini can be configured as Inputs or as Ouputs. The Arduino libraries provides a function to set the pin as an input or as an output pin as needed by the system. The function is 'pinMode(pinNumber, Mode)' where pinNumber is the pin wanted to be configured, and Mode is the configuration of the pin (INPUT or OUTPUT). What this function does is to write the DDR register of the microcontroller (figure 76). To set a pin as an Input a logical '0' has to be written to any of the available bits of the port, and in contrast, to set a pin as an Output a logical '1' has to be written to any of the available bits of the port.

DDRB								
bit	7	6	5	4	3	2	1	0
pin	-	-	D13	D12	D11	D10	D9	D8
DDRC								
bit	7	6	5	4	3	2	1	0
pin	-	-	A5	A4	A3	A2	A1	A0
DDRD								
bit	7	6	5	2	4	3	1	0
pin	D7	D6	D5	D4	D3	D2	D1	D0

Figure 76: DDRx I/O port

7.4.1.6 Reading or writing a digital value

To read a digital value in the Arduino Pro Mini, the function 'digitalRead(pinNumber)' is used, where 'pinNumber' is the number of the pin wanted to be read. To write a digital value through a pin, the function available in the Arduino libraries is 'digitalWrite(pinNumber)', where 'pinNumber' is the number of the pin to be written. Both function read and write the same register of the microcontroller, register PORTB is used for pins 13 – 8 (figure 77) and PORTD for pins 7 – 0 (figure 78).

PORTB								
bit	7	6	5	4	3	2	1	0
pin	-	-	D13	D12	D11	D10	D9	D8

Figure 77: PORTB register

PORTD								
bit	7	6	5	2	4	3	1	0
pin	D7	D6	D5	D4	D3	D2	D1	D0

Figure 78: PORTD register

7.4.1.7 Reading an analog value

In this subsection only reading an analog value is going to be examined, since there is no need in the programming of this system to 'write' an analog value to an external device.

To read an analog value, Arduino provides the function 'analogRead(pinNumber)', where 'pinNumber' is the pin number where the value is going to be read. The Arduino Pro Mini has four 10-bit ADC converters, this means an analog pin can give a 1024 bit resolution for a conversion, therefore, a value read from one of these pins will be in the range of 0 – 1023. To read the values of the pin, PORTC has to be read (figure 79).

PORTC								
bit	7	6	5	4	3	2	1	0
pin	-	-	A5	A4	A3	A2	A1	A0

Figure 79: PORTC register

7.4.2 Recognition system proposal

The recognition system for the position of the cartridge is based on a rotary optical encoder (figure 82). An optical encoder can have one or several light sources and one or several photo detection elements, when the shaft rotates it moves the code disc, thus allowing, or not, light to go to the photosensitive elements through the capture plate. The information in the photosensitive elements is then sent to a processing unit to decode the position of the plate.
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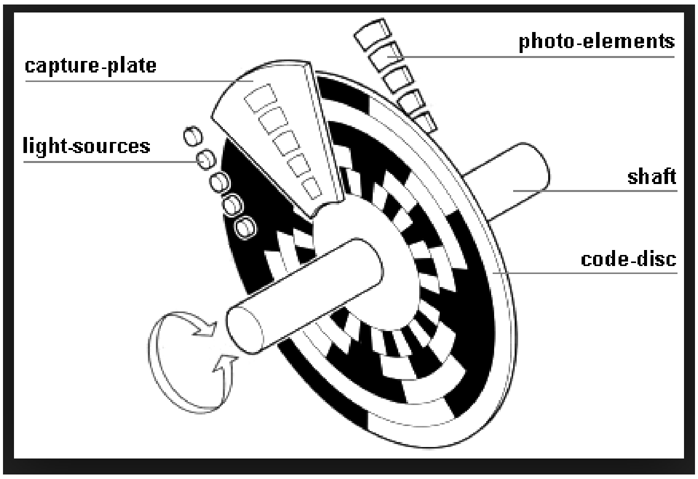

Figure 80: Rotatory optical encoder

Since the pen for this project stores only five cartridges, therefore only five positions to detect, there is no need for such a complex detection system. Instead, the proposed solution consists of a colour disc (figure 81) placed around the twisting shaft of the pen, with a photoresistor sensor and a RGB LED connected to the microcontroller. Every colour on the disc will be associated to one cartridge position, and so, when the microcontroller detects which colour is being sensed, it will be associated with the correct coloured cartridge being deployed..

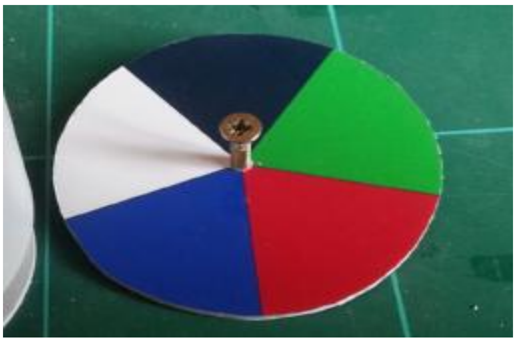

Figure 78: Colour disc

7.4.2.1 System design

7.4.2.1.1 How the system works

The system works by using the RGB colour model, that state that the adding together red, green and blue light, wavelength by wavelength, a broad array of colours can be reproduced (figure 82). The resulting colour will tend to the colour of the dominant intensity. This means, that a colour can be sensed by determining which intensity is the predominant one (red, green or blue). No intensity for each component will indicated absence of light (black colour) and full intensity will indicate white light.

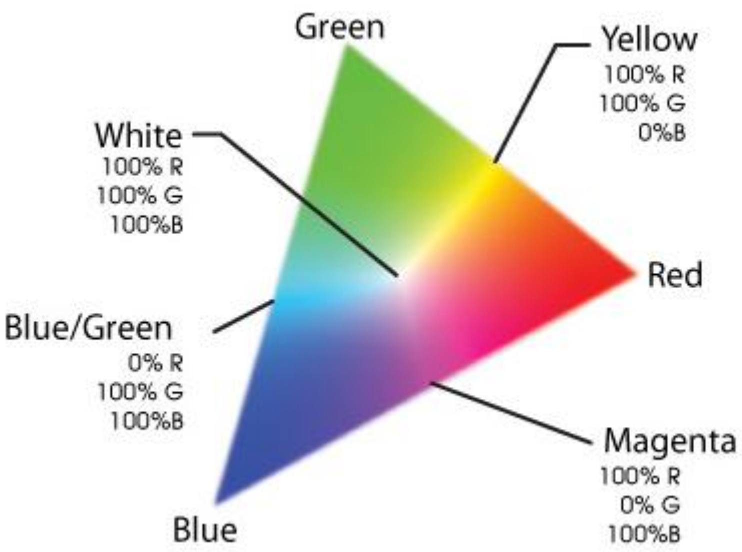

Figure 79: Creating colour with RGB

In this proposal, an RGB LED flashes red, green and blue light onto a colour of the colour disc (figure 81), the reflection of the intensity of each colour is measured by a photoresistor, then, depending on the measurements, the system can detect which colour of the disc is being sensed.

- Creating a code with RGB

To determine a position, every colour of the colour disc has to be encoded. In Table 6, a possible codification can be observed.

R	G	B	Colour	Code	Position
0	0	0	Black	0 0 0	1
0	0	10	Blue	0 0 1	2
0	10	0	Green	0 1 0	3
10	0	0	Red	1 0 0	4
10	10	10	White	1 1 1	5

Table 6: Encoding the colour disc

The value '0' corresponds to no intensity at all of the red, green and blue frequency, whether the value '10' corresponds to the highest intensity possible. The system working can be observed in figure 86 subsection 7.4.2.3 "determining a position".

7.4.2.1.2 Components

- RGB LED

An RGB LED contains three different LED in one case (figure 83), this means that by controlling what signal is sent to the LED it can flash different colours. For this particular application, the LED is going to be used to flash Red, Green and Blue light into the colour disc.

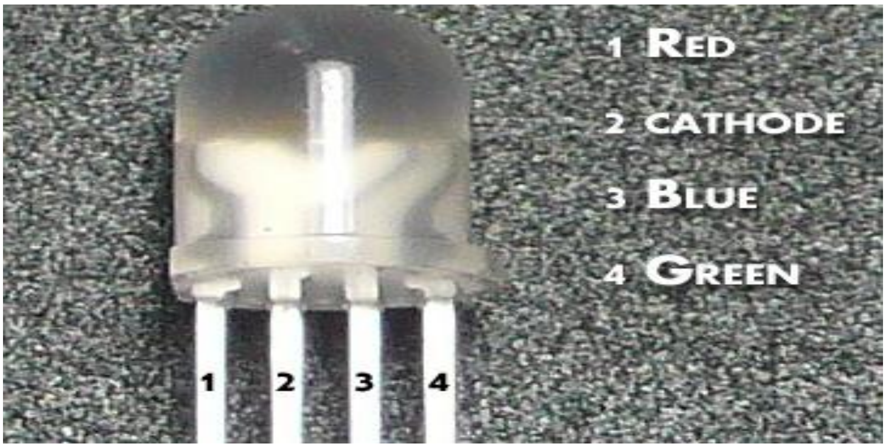

Figure 80: RGB LED

- Photoresistor sensor

A photoresistor sensor detects light intensity, the resistance of the sensor decrease when light intensity is higher allowing more current to flow through the sensor. In figure 84 a photoresistor sensor can be observed.

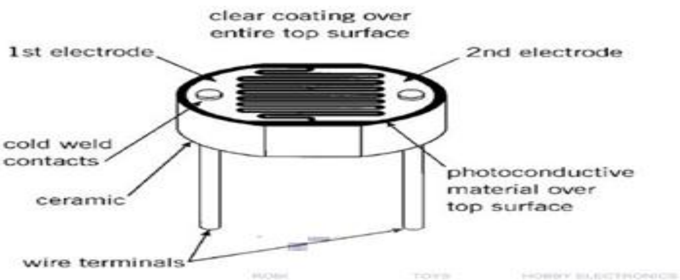

Figure 81: Photoresistor sensor

7.4.2.2 Creating the colorimeter

To create the colorimeter, the RGB LED and the photoresistor sensor needs to be put in a closed case separated by an inner wall (figure 85), with a little breach at the top of the wall allowing the reflected light to go to the sensor. To prevent ambient light from affecting the sensors measurements, the interior of the case should be a black colour and the colour disc should be as close to the case as possible (figure 86).

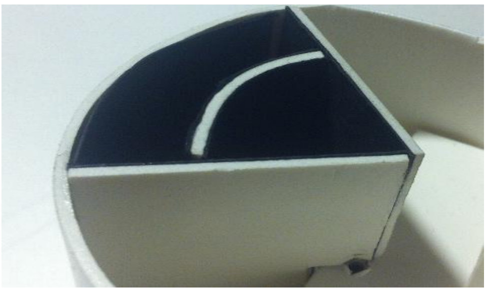

Figure 85: Inner wall of colorimeter prototype

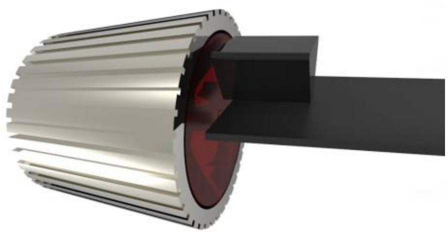

Figure 86: Colorimeter close to the colour selector

7.4.2.3 System programming

In order to establish a reference level for the intensity of the light being reflected, the sensor needs to be calibrated. To do so, the reflection of the red, green and blue LED over a black surface will serve as a reference for the minimum intensity the sensor can receive, and a white surface will serve as a reference for maximum intensity (the calibration only needs to be done once with only one pen, afterwards the values measured can be programmed into the other pens without the need for further calibration).

To detect the colour on the disc, the RGB LED flashes in succession the red, green and blue colour onto the surface of the disc, the three reflections are taken by the photoresistor and analysed by the microcontroller. The three values from the photoresistor go into one of the microcontroller analog inputs and will give a value in between 0 and 1023 (refer to subsection 7.4.1.7 for information about this range), therefore, to make the value easier to analyse a change of scale needs to be done.

In order to make the change of scale, some considerations need to be taken into account. Firstly, the values, for every iteration, need to be within the range of the minimum and maximum values of the calibration. In order to do this, the Arduino libraries provides the function 'constrain(sensorValue, minimumBlack, maximumWhite)' where 'sensorValue' is the value to be constrained. 'MinimumBlack' and 'maximumWhite' are the values obtained in the calibration process for the minimum and maximum intensity respectively. Once 'sensorValue' is constrained between the calibration values, the change of scale can occur. To change the scale to the desired one, Arduino library provides the function 'map(sensorValue, minimumBlack, maximumWhite, toLow, toHigh)', where 'sensorValue' is the constrained value, 'minimumBlack' and 'minimumWhite' are the value calibration values and the low and high values respectively from the current scale. The 'toLow' and 'toHigh' values become the minumum and maximum desired values of the new scale. What this does is to set the 'sensorValue' into a scale from 'toLow' to 'toHigh'. The values selected in this application for 'toLow' were zero, and for 'toHigh' were 10, therefore, the value from the sensor is changed from a value between 0 and 1023, constrained to a value between the calibration values, and then changed to a value between 0 and 10

- Determining a position

In order to determine a colour, and taking into account that the values will be between 0 and 10, it was established that any value over 5 (5 included) will be considered a high level, and every value under 5 a low level. Therefore, when the values in the readings are over 5, the position will correspond to the one associated with the white colour in the disc. When the values are under five, the position will correspond to the position associated to the black colour in the disc. When only one value is over 5, and the rest are under 5, then the system has to determine if the position is the one associated for the red, green or blue colour in the disc. In figure 87 the readings on the microcontroller and the detection can be observed.

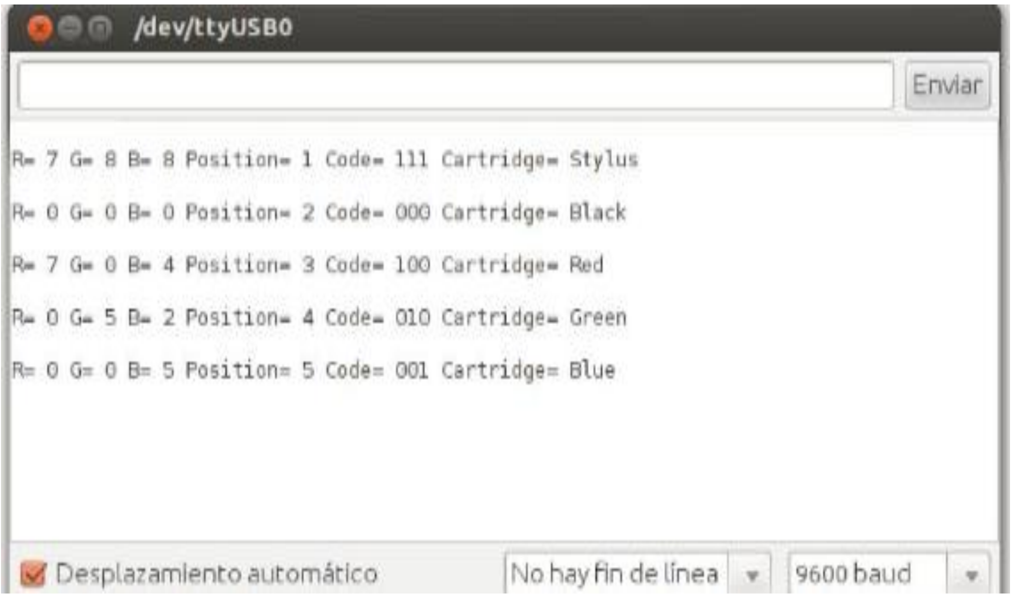

Figure 82: Position detecting done by the microcontroller

The robustness of the system can be observed in the readings for the position 4 and 5 in figure 87. Even though the highest readings are not near the maximum value, the predominant frequency can still be detected without any errors.

7.4.3 Prototype boards

In order to test the circuitry of the system and program the microcontroller and a protoboard was used with the Arduino Pro Mini (figure 88).

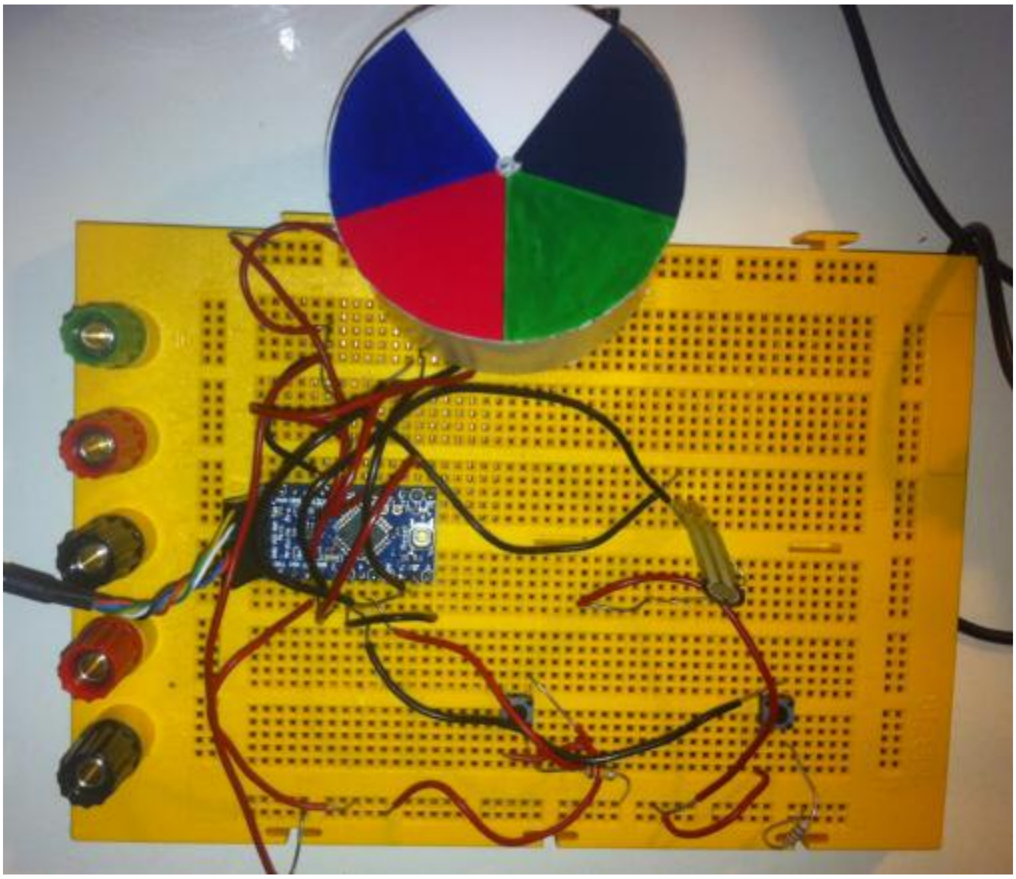

Figure 88: Protoboard with the Arduino Pro Mini, and the main electronics

7.4.3.1 Motherboard

When the system had been tested and was ready, a PCB board was design using the software EagleCAD. First, the circuit had to be drawn in the Eagle schematic (figure 89), once the circuit was finished, the PCB was created using the same software (figure 90).

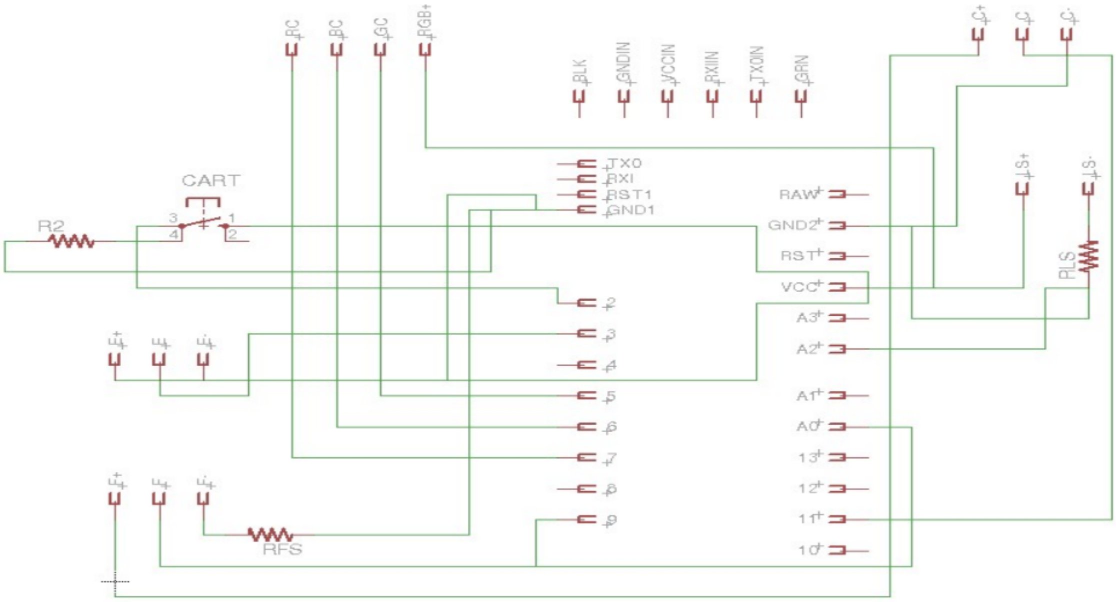

Figure 89: Motherboard circuitry

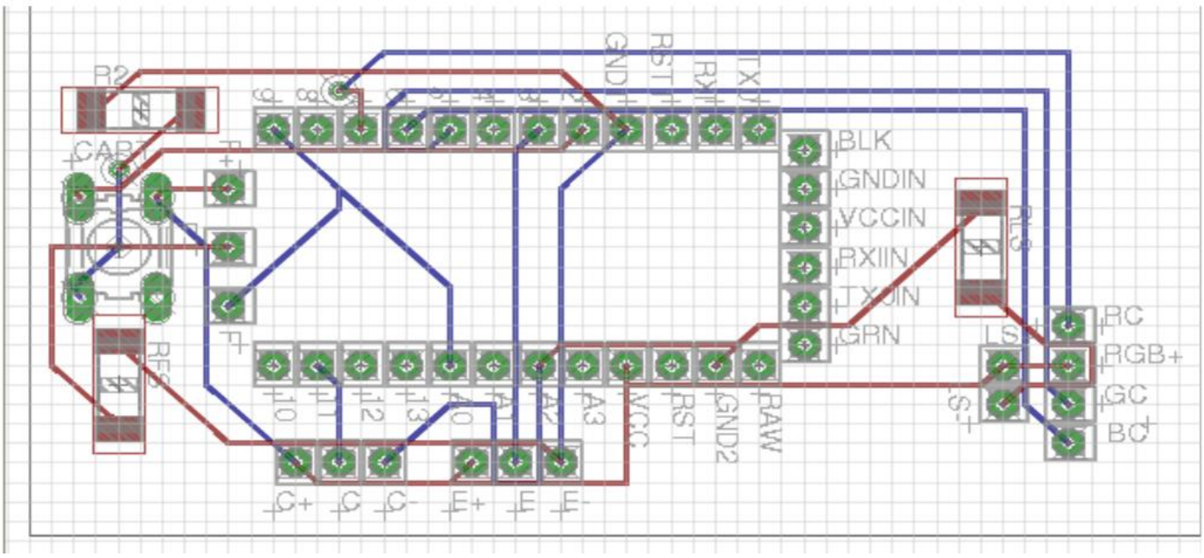

Figure 90: Motherboard PCB design

7.5 System design

The device must be able to respond to the inputs of the user through a physical UI. It must be capable of allowing the user to take advantage of the pens functions.

7.5.1 User interface

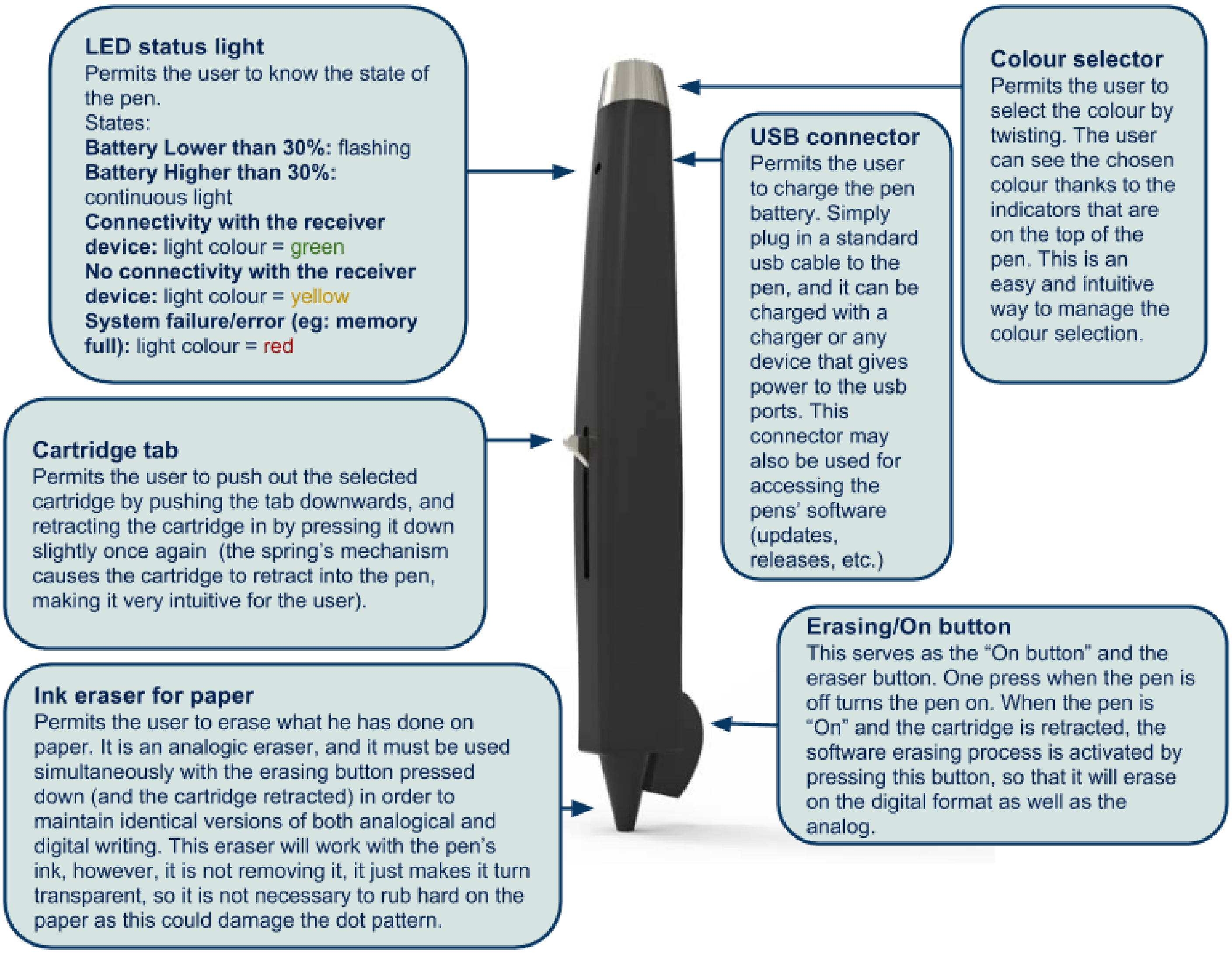

Figure 91: User interface

7.5.2 User actions

1. Turn on the pen:

To turn on the pen the user has to push the erasing button.

2. Turn off the pen:

The pen turns itself off after a short time of inactivity.

3. Extend the cartridge:

There is a tab that allows the user to push the cartridge out. The user has to slide the tab down slightly until it sticks in its out position in an inner slot on the cartridge track.

4. Retract the cartridge:

Once the cartridge is in the out position, pushing the tab again will make it return to its previous position, this happens because of a spring mechanism that causes the tab to spring back to its original position.

5. Change colour:

To change colour the user has to retract the cartridge, if it is not already retracted, and then twist the colour sector at the end of the pen to the position of the desired colour.

6. Erase:

To erase the user has to turn on the pen using the “On/eraser” button, then retract the cartridge if necessary and press the button while rubbing the pointed end of the pen against the paper.

It is important to stop pressing the button when you are finished erasing, otherwise it could continue erasing.

7. Write on paper:

The user has to turn on the pen, if it is not already on, choose a colour, and then write on paper like a normal pen.

8. Write on tablet:

The user has to choose the stylus cartridge and then he can write on touch sensitive screens.

7.5.3 Use cases

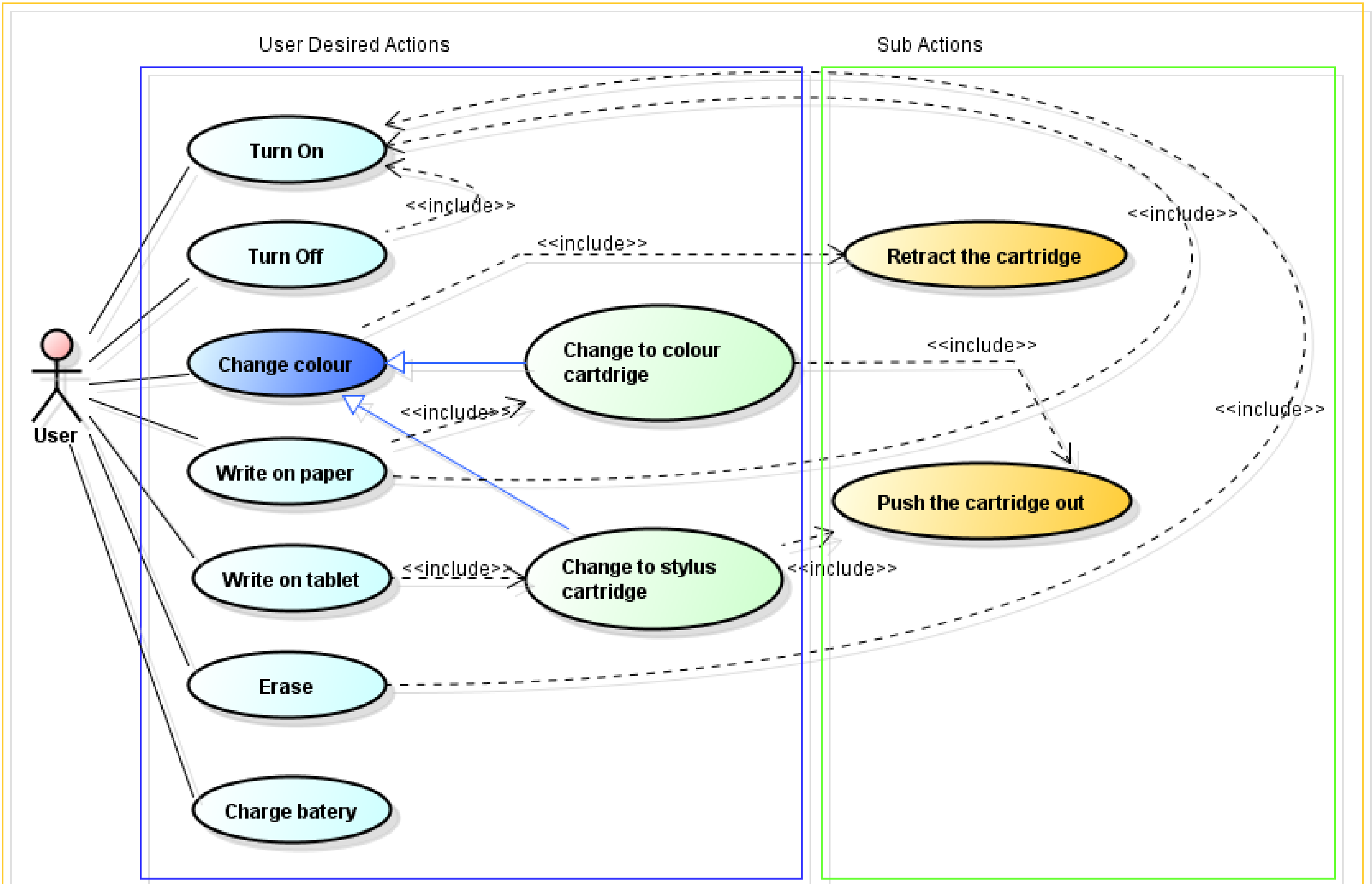

Figure 94: Use cases

- When we say that a User Desired Action (UDA) includes another action, this means that for a particular User Desired Action to take place, the included actions will take place before or during the process (as “Sub User Actions” or “SUA”). However, in other cases, we can find the “Sub User Actions” can occur as User Desired Actions.
- The “Change colour” UDA can be different in two different ways. We distinguish between these two, because for “Writing on paper” we need to include the selection of a colour, but it cannot be the stylus cartridge that is selected; and in the “Write on tablet” it is the opposite, we need to include the changing to the stylus cartridge before it can be used on a tablet (otherwise, the tablet screen could be damaged if another cartridge was selected).
- “Retract the cartridge” and “Push the cartridge out” are considered directly SUA, because by themselves they don’t have any functionality for the user, they are only steps that have to be followed in order to prepare the pen for other actions (for example: pushing the cartridge out in order to write with the pen).

7.5.4 System vision

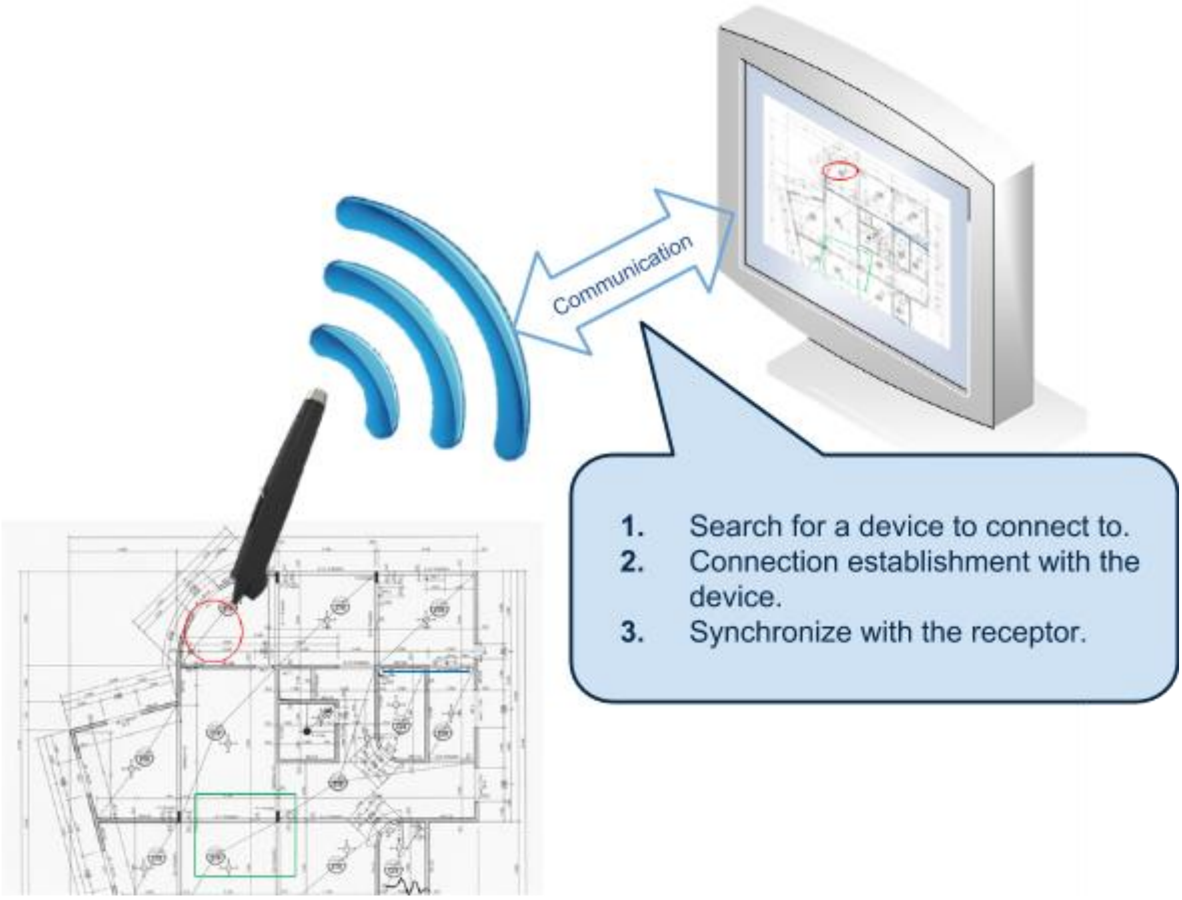

Figure 92: With the receiver device

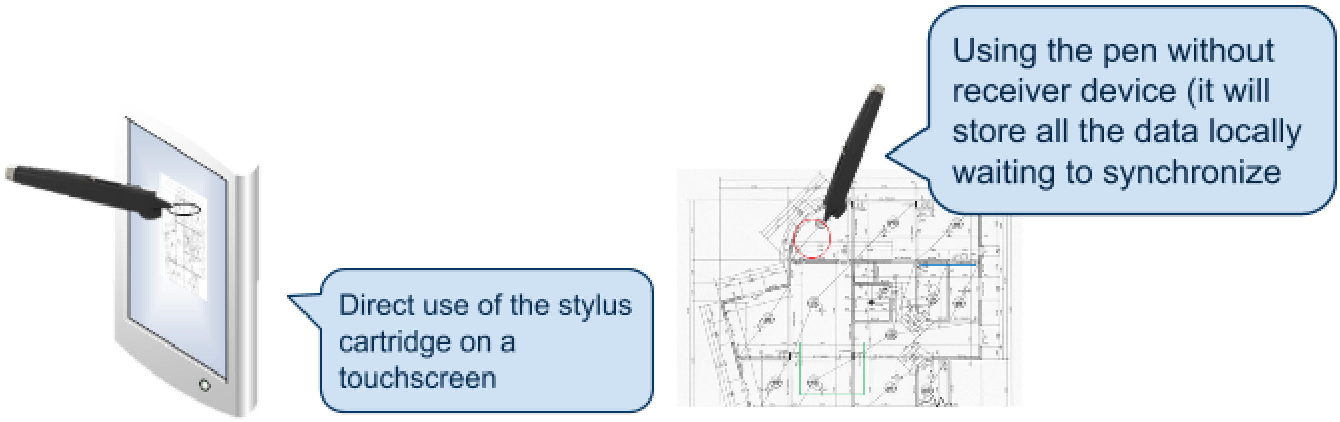

Figure93: Without the receiver device

7.5.5 Flow Chart Diagram

This is the flow chart diagram showing how the program processes in the pen will work.

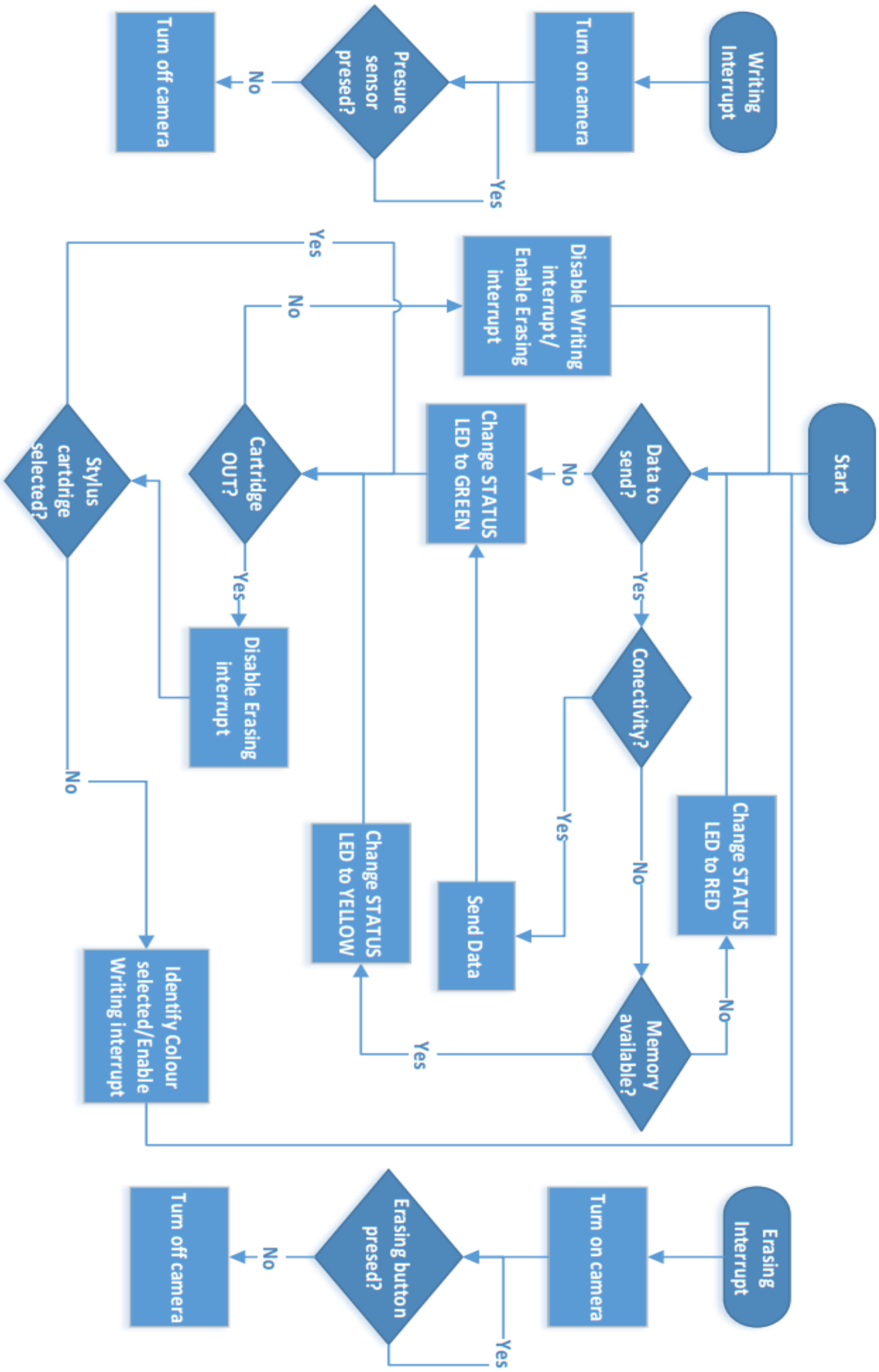

Figure 94: Flow chart diagram of the program processes

8 Results, Further research and Conclusion

The pen mechanism was always going to be the biggest challenge for this project. The complexities involved left us perplexed in the beginning, as the difficulty in combining five cartridges with the necessary electronics became clear, and we realised that we would not be able to design a mechanism like those in existing pens. We studied other pens mechanisms for inspiration, and then took a different path. Our concepts were varied, from the avant-garde to the simplistic for users and lastly, the multiple component design.

After the Mid Term report, our supervisor chose the concept that is simplistic for users, what we refer to as Concept 2. This design is easy for the user to use; however, its design required quite unusual solutions to the many internal mechanical and electrical problems that we faced.

The first problem that came into view was the pressure sensor. This sensor sends the information that the pen is writing, so it was vital that the cartridge presses against it with enough force. As there are five cartridges, we decided to avoid the need for five pressure sensors, by having only one that gets used by all of the individual cartridges at different moments. This saves on space, and electronic complexity within the pen. To ensure that the sensor receives accurate readings the sensor must directly touch the rear of the cartridge.

We came up with the idea of a revolving barrel mechanism. This would only need one pressure sensor, and would allow the cartridges to rotate to a precise upper point, from which they could be extended until they protrude from the end of the pen, for writing. This barrel would be divided into 5 equal segments, and each could slide downwards separately. To stop the segments from loosely falling around the inside of the pen, we designed a cylinder to bind them together, with a gap on one side of its curved edge which allows each segment to be pushed downwards to its fullest extent.

To push the segment downwards we decided on a tab that the user would slide downwards, and that would grip the topmost segment, and the two would travel together. The tab would need to incorporate the pressure sensor, as the sensor must work only when the tab and segment are fully extended. When the cartridge and segment are retracted the sensor does not detect any pressure.

To ensure that the segments retract easily, we decided to add springs to the mechanism. This was not a difficult choice as springs in pens are very common; however, we needed to invent a retaining system for the springs. It was clear that they would need to be fixed to a wall at one end while the other end could press against the individual segments. A disc was designed that the tips of the cartridges would poke through, and that would rotate freely within the lower end of the cylinder. This disc would have slots that the end of the spring would sit into, and similar slots were put into the lower end of the segments as well, so that the springs would not fall out.

The rotating colour selector was then considered, and how it could make the segments rotate. It would be attached into a metal rod that would have a pentagonal shape at its lower end. This would allow the segments to slide downwards or be rotated by turning the colour selector.

The space inside the pen needed to be large enough to accommodate all the necessary circuit boards, sensors, IR camera and a battery. The scale 2D drawings we made with Autocad gave us initial ideas about how much room was necessary. We did a reverse engineering study of an existing product, the Livescribe 3, and we allowed space inside our design for the components of the Livescribe 3. The biggest challenge here was the camera placement. The IR camera that the Livescribe 3 has is very bulky, and fits only because of the very high position of the cartridge within the Livescribe 3's body. In our pen it would need a large bulbous protrusion, something that would affect the ergonomics of the pen and is talked about in the ergonomics study.

A 3D computer model was made using the specifications from the 2D drawings and rough pencil sketches. This 3D model demonstrated very clearly how the parts relate to each other and this model enabled us to make some 3D photo realistic renders, some videos of mechanical movements and most importantly a 3D printed 2:1 scale prototype. A 1:1 scale model of the pen was also made to test the ergonomics and test some graphic designs and finishes. The ergonomics showed that the pen was too large for small hands, but was adequate for larger hands and left and right-handed people.

Once the majority of the design had been thoroughly discussed and defined, we looked towards the electronic and programming systems.

There would need to be a sensor to know when the user is writing, and a sensor so the microprocessor knows what colour has been selected. Initially, we thought of a series of tiny switches that would touch against small bumps on the curved edge of the segments, however, this system would likely fail over time as the switches would be small and fragile, and would suffer greatly from wear and tear. The switches would also be around the cylinder, which was already an area that was too bulky. A frictionless system was proposed, which would use a colorimeter to "see" what colour had been chosen. It would use a colour disc, RGB LED and a photoresistor sensor connected to a microcontroller. This sensor could be put into the upper part of the pen, next to the rotating colour selector. This solution is ideal as it removes mechanical parts, reduces friction and wear, and most importantly does not make the pen any more bulky in the critical lower cylinder area. A thorough study of the colorimeter was made, which included a mock-up of the colorimeter and a colour disc. The results were successful, and a computer program verified that this system would work in our pen.

The programming used in pens such as the Livescribe 3, is not possible to be studied or replicated for our pen. So instead, we looked to design an interface from scratch using flow diagrams to design how the programming would work. The programming took into account all of the uses of the digital pen, and how the user would interact with it. Carefully, we traced every input to reach the desired outcome. Multiple coloured LEDs had been considered as a user interface, but were rejected in favour of a single RGB LED what could produce any colour necessary, and also flash intermittently to signal the pens status.

The digital pen we have created is a good first draft. It paves the way for many improvements. We can see its weaknesses and learn from them. In the future, the pen can be improved and refined in many ways. The body of the pen needs to be reduced in size, and made more ergonomic and stylish. The mechanisms need to be refined and adjusted for maximum efficiency. The circuits and sensors need to be miniaturised and adapted to fit into the pen. The program to make the pen work needs to be developed. An instruction manual, online support and packaging will need to be designed.

9 Acknowledgements

We would like to take this opportunity to thank everyone who helped us with this project. It was a very big task, and thanks the organisational skills of our supervisor Eva Marin Tordera and the support of the University Director Frederic Vilà, we have accomplished more than we had thought possible. Thanks to all the staff working for the EDP and IDPS course who helped guide us (and corrected our English mistakes), and lastly, a huge thanks to Hewlett Packard and our contact there, Marina Talavera, who offered us this project and gave us vital feed-back and insights into product development and the design process.

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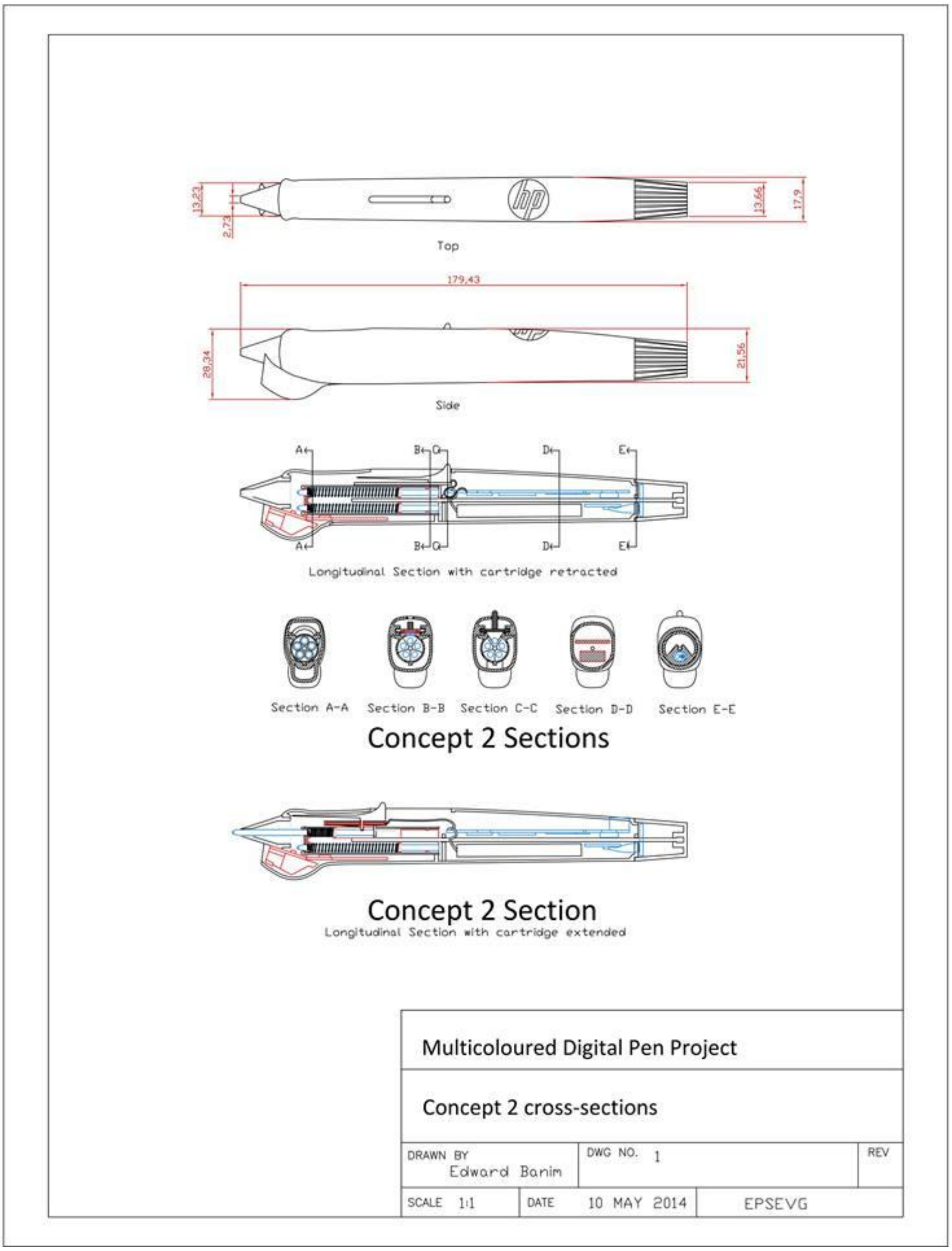
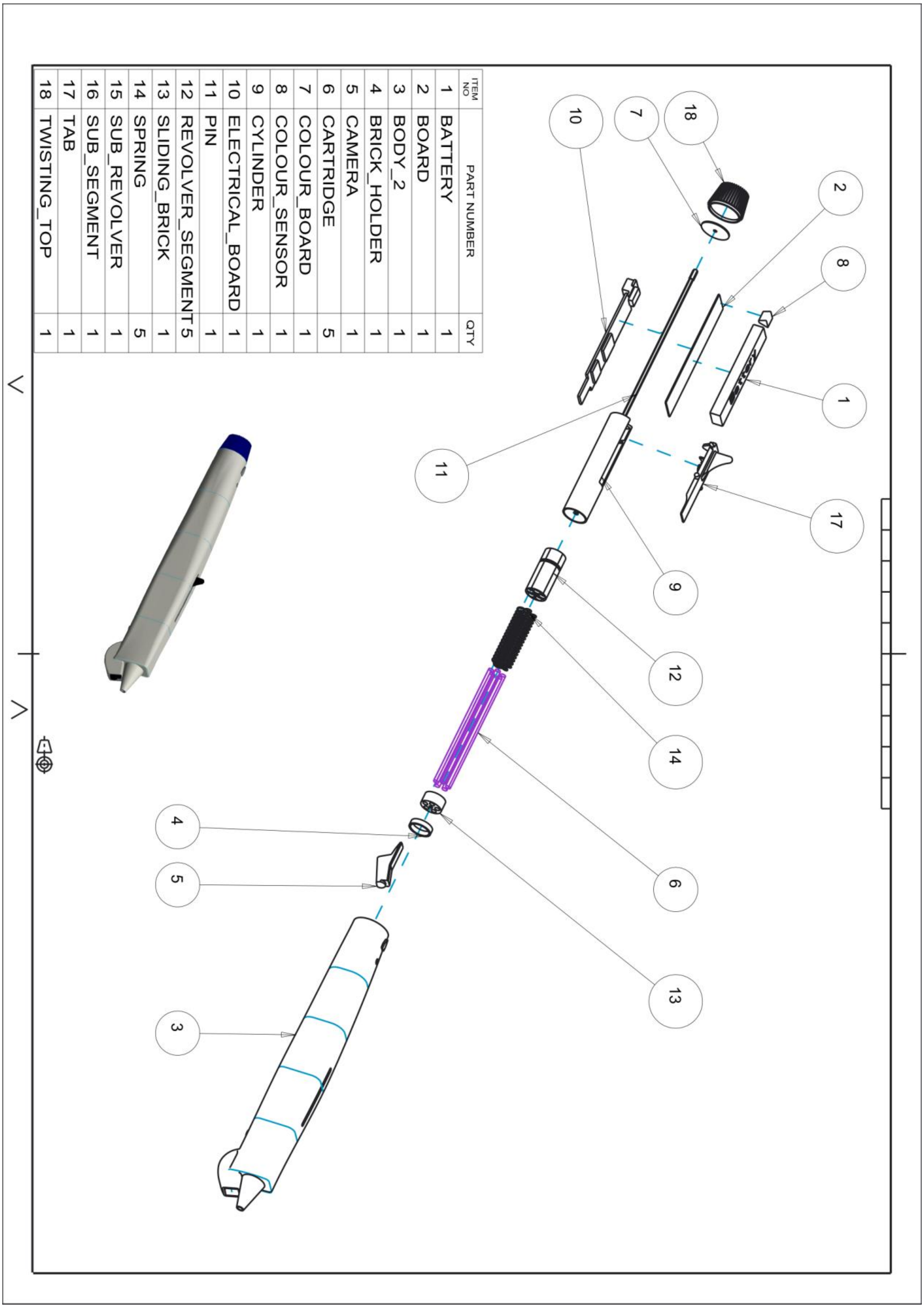
11 Appendixes

11.1 Design





ITEM NO	PART NUMBER	QTY
1	BATTERY	1
2	BOARD	1
3	BODY_2	1
4	BRICK_HOLDER	1
5	CAMERA	1
6	CARTRIDGE	5
7	COLOUR_BOARD	1
8	COLOUR_SENSOR	1
9	CYLINDER	1
10	ELECTRICAL_BOARD	1
11	PIN	1
12	REVOLVER_SEGMENT	5
13	SLIDING_BRICK	1
14	SPRING	5
15	SUB_REVOLVER	1
16	SUB_SEGMENT	1
17	TAB	1
18	TWISTING_TOP	1


Battery

11.2 Electronics prototype code skeleton

```
/**
@Description:   "Arduino" code for the electronics prototype of the Multicolour Digital Pen project, an EPS
project with HP
@authors:       Julia Camps
                Joaquin Ruda
*/
// (All the "variables" that have to go in an interrupt code, must be "volatile")
volatile boolean dataStored = false;
volatile boolean userErased = false;
volatile boolean userWritten = false;
volatile boolean connectivity = true;
volatile boolean memFull = false;
volatile boolean eraseMode = false;
volatile boolean writeMode = false;
volatile boolean memErrorTag = false;

//COLOUR DETECTION START
/**
Pins used for the RGB LED
*/
int led[] = {8, 7, 12};
/**
Calibration values
*/
int white[] = {904, 799, 885};
int black[] = {663, 445, 680};
/**
Colour state values
*/
int colour;
int rgbds[] = {10, 10, 10};
int cartposition = 0;
String cartucho, codigo;
//COLOUR DETECTION END

//CARTRIDGES CODIFICATION
int STYLUS = 0;
int RED = 1;
int BLUE = 2;
int GREEN = 3;
int BLACK = 4;

int leds = 3;

int memCount = 0;


byte cameraLED = 13;
byte bCartridge = 4;
```

```
// The erase and sensor buttons goes to a digital input
// as well as the interrupt input
byte bErase = 9;
byte bSensor = 11;

/**
This function is called when the erasing action is called (the function is called when the erasing button interruption occurs),
and is responsible for deciding which action should take place next and manage the interruption process.
*/
void intErase ()
{ // Starts erase int
		if(eraseMode)
	{
				while(digitalRead(bErase))
		{ // While erasing button is ON
					digitalWrite(13, HIGH); // Turns on camera LED
				} // user release erase button
				dataStored = true;
				userErased = true;
				digitalWrite(13, LOW); // Turns off camera LED
	}
} // ends erase int

/**
This function is called when the writing action is called (the function is called when the pressure sensor interruption occurs),
and is responsible for deciding which action should take place next and manage the interruption process.
*/
void intWrites ()
{ // Starts writing int
	if(writeMode)
	{
		//int colour = digitalRead(); //READ COLOR
				while(digitalRead(bSensor))
		{ // While sensor is pressed
					digitalWrite(13, HIGH); // Turns on camera LED
				} // user stops writing
				dataStored = true;
				userWritten = true;
				digitalWrite(13, LOW); // Turns off camera LED
	}
} // ends erase int

/**
This function is responsible for setting the default values necessary to run the program,
and enabling and programing the interruptions that we want to use.
*/
void setup ()
{ // Starts set-up
  Serial.begin(9600);
  pinMode(bSensor, INPUT);
  pinMode(bErase, INPUT);
```

```
  pinMode(cameraLED, INPUT);
  pinMode(bCartridge, INPUT);
  attachInterrupt(0, intWrites, RISING); // Int0 = sensor int
  attachInterrupt(1, intErase, RISING); // Int1 = erase int

  //COLOURDETECTION_START
  pinMode(led[0], OUTPUT);
  pinMode(led[1], OUTPUT);
  pinMode(led[2], OUTPUT);
  //COLOURDETECTION_END

} // ends set-up

/**
Function for calibrating the maximum and minimum reference values for
for filling the calibration of the white and black arrays
*/
void calibration()
{
  Serial.println("White");
        for (int i=0; i<leds; i++)
        {
                        digitalWrite(led[i],LOW);
                        delay(100);
                        white[i] = analogRead(A3);
                        digitalWrite(led[i],HIGH);
                         Serial.print("White : ");
                        Serial.println(white[i]);
              }
              delay(5000);
              Serial.println("Black");
              for (int i=0; i<leds; i++)
        {
                        digitalWrite(led[i],LOW);
                        delay(100);
                        black[i] = analogRead(A3);
                        digitalWrite(led[i],HIGH);
                        Serial.print("Black : ");
                        Serial.println(black[i]);
               }
}

/**
This function is responsible for reading the current colour, and
storing the values on global attributes
*/
void readColour()
{
  for(int i = 0; i<leds; i++){
               digitalWrite(led[i], LOW);
               delay(100);
               colour = analogRead(A3);
               rgbds[i] = constrain(colour, black[i], white[i]);
```

```
			rgbds[i] = map(rgbds[i], black[i], white[i], 0, 10);
			digitalWrite(led[i],HIGH);
	}
	if(rgbds[0] >= 5)//R or W?
	{
			if(rgbds[1] >= 5)//W
			{
					cartposition = STYLUS;
					codigo = "111";
					cartucho = "Stylus";
			}
			else//R
			{
					cartposition = RED;
					codigo = "100";
					cartucho = "Red";
			}
	}
	else//G B or K?
	{
			if(rgbds[1] >= 5)//G
			{
					cartposition = GREEN;
					codigo = "010";
					cartucho = "Green";
			}
			else//B or K?
			{
					if(rgbds[2] >= BLUE)//B
					{
							cartposition = BLUE;
							codigo = "001";
							cartucho = "Blue";
					}
					else//K
					{
							cartposition = BLACK;
							codigo = "000";
							cartucho = "Black";
					}
			}
	}
}

/**
Print screen all the parameters of the colour detection
*/
void printColour()
{ //function for checking the configuration
 Serial.print("R= ");
 Serial.print(int (rgbds[0]));
 Serial.print(" G= ");
 Serial.print(int (rgbds[1]));
```

```
 Serial.print(" B= ");
 Serial.print(int (rgbds[2]));
 Serial.print(" Position= ");
 Serial.print(cartposition);
 Serial.print(" Code= ");
 Serial.print(codigo);
 Serial.print(" Cartridge= ");
 Serial.print(cartucho);
 Serial.println(" ");
 delay(5000);
}


/**
This function is responsible for managing the data sending task
*/
void sendData()
 { // sends data
   Serial.println("Sending data");
   dataStored = false;

} // ends data transmission

/**
This function is responsible for checking the connection state, the function
returns a boolean that indicates the connection current state (true if there is
a connection established or false if not)
*/
boolean lookConnectivity()
{
   return connectivity;//Here we check the connectivity, if serial bluetooth activated return true, else return
false
}

/**
This function is responsible for checking if there is data to be synchronized, if there is,
the return value will be true, if not, false will be returned instead.
*/
boolean checkDataStored()
{
   return dataStored;//Here we check the tag for data, return true when there is data to be sent
}

/**
Check if the buffer is full, this may occur when no connection has been established,
if the buffer is full it will return true, otherwise false will be returned.
*/
boolean checkMemFull()
{
   return memFull;//Here we check the buffer size with the data stored, return true when the buffer is full
}

/**
```

```
This function is responsible for returning the selected colour when called
*/
int detectColour()
{
  readColour();
  return cartposition;
}
/**
Main loop, it will repeat this section of the code as a loop once it has been
turned on, until it turns off or an interrupt occurs.
*/
void loop ()
{ // Main loop
  if(checkDataStored())
  {
        if(lookConnectivity())
        {
              Serial.println("Connection");
              sendData();
              dataStored = false;
        }
        else
        {
              if(!checkMemFull())
              {
                    Serial.println("Continue without sending the stored data");
              }
              else
              {
                    Serial.println("Error has occured! Memory full, not able to send
the pending data");
                    delay(1000);
                    memErrorTag = true;
              }
        }
  }
  else
  {
        Serial.println("No data stored");
  }

  if (!digitalRead(bCartridge) && !memErrorTag)
  {   // waits for int
        Serial.println("The cartridge is up, ERASE MODE");
        writeMode = false;
        eraseMode = true;
        // do nothing or sleep mode
  }   // end while waits for int
  else
  {
        if(!memErrorTag)
        {
              eraseMode = false;
```

```
                if(detectColour()==STYLUS)
                {
                        Serial.println("The cartridge is down");
                }//do nothing
                else
                {
                        eraseMode = false;
                        writeMode = true;
                        Serial.println("The cartridge is down, WRITE MODE");
                }

        }
  }
}// ends main loop
```