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, 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.

I. INTRODUCTION

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 to 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.

To achieve the goals, the project team has 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 made via manuals, product descriptions and on the Internet.

Creo Parametric and Solid Edge were 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.

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.

II. 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 a tablet. 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)

III. STATE OF THE ART

A. *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).

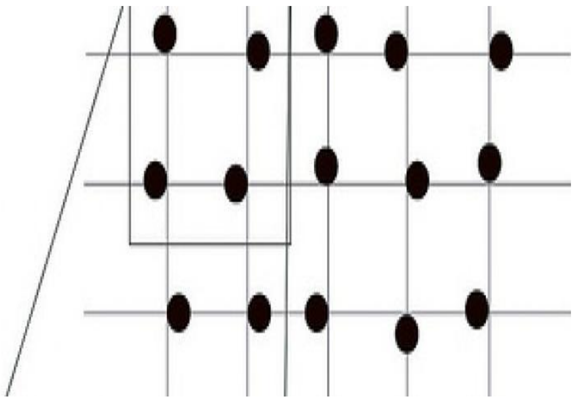

Figure ¡Error! Secuencia no especificada.:

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 will have problems seeing the dot pattern where the two contents have been overlaid.

B. 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. Some solutions have been proposed in order to solve this matter.

B.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 2).

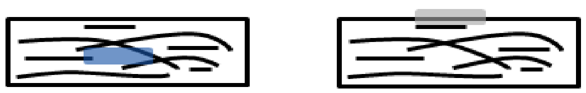

Figure 2: Difference of location between Ink (left) and pencil, carbon particles (right)

A graphite refill can be inserted into the pen, as shown in figure 3, 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 4).

Figure 3: Graphite refill

Figure 4: Rubber plugged into an Anoto standard reservoir

B.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 5). 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.

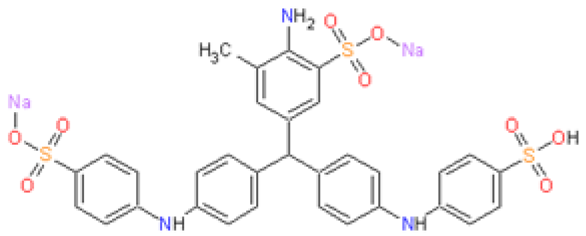

Figure 5: Reduction sites of blue aniline

B.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 6 and 7).

Figure 6: Frixion rubber ball being cut

Figure 7: 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 8.

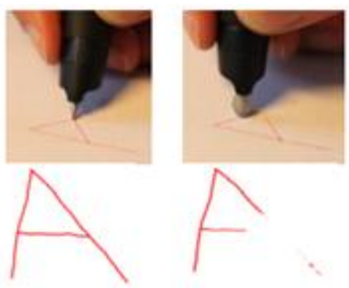

Figure 8: Users writes with the heat-sensitive ink (above left) and then erases (above right) with the erasing tip. The software application recognizes the erasing of the letter (below)

IV. CONCEPT DESIGN

Three concepts were designed and only one selected as a prototype. In the section below is shown the chosen concept and its evolution into a final concept to prototype.

A. 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.

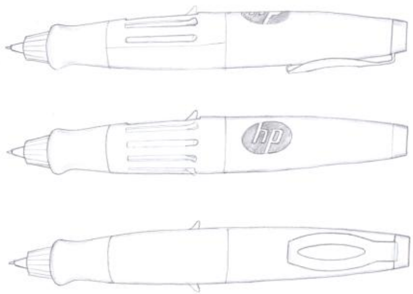

Figure 9: Multiple tabs for changing colours

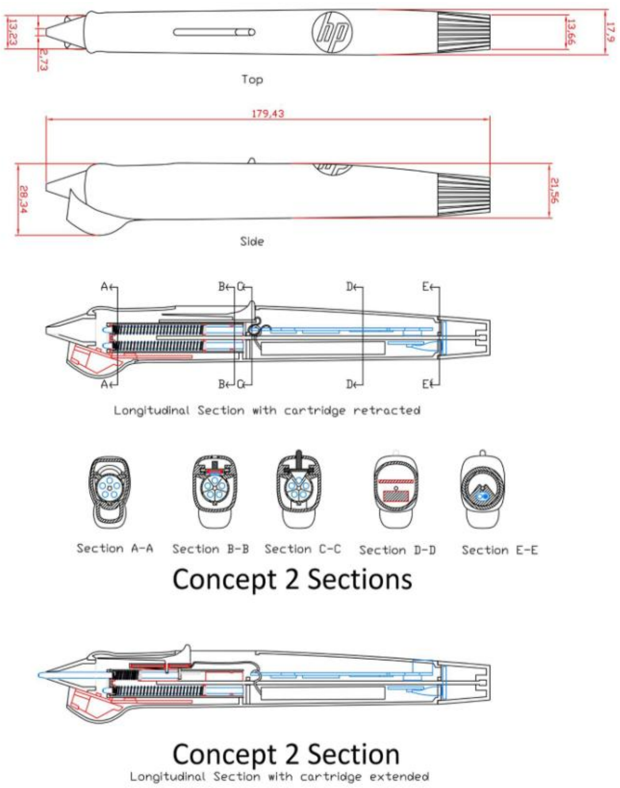

Figure 10: Sketches for the new version of concept 2

D. EVOLUTION OF THE CONCEPT

After the midterm report, the team presented the concepts to HP. The chosen concept was 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 (see figure 10).

V. ERGONOMICS

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. 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. 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. 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.

A.REDUCING THE CAMERA SIZE

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.

VI. MECHANISM DESIGN

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

The mechanical limitations of the project were 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.

A. TWO STEP OPERATION

The mechanism that the group chose to proceed with was influenced by a revolver barrel. The process of getting out 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 indication (See fig. 11). The second step is to push down a tab and thus get out the selected colour. The operation is now complete and the pen is ready to use.

To bring the cartridge back inside the pen, the user has to push the tab about 5mm down. What happens is that an arm on the tab snaps out of a notch. This causes the tab to return to its original position and it's possible to change the colour using the rotating wheel again.

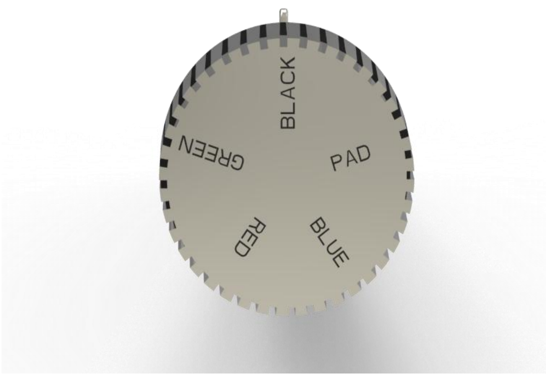

Figure 11 Colour selector

B. 3D RENDERING

This is a helpful tool to illustrate how the product will look like in reality, and 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 was 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.

C. PARTS AND FUNCTIONS

The pen consists of 28 parts. The parts were assembled into two sub assemblies. One assembly is for rotating the revolver segments and one assembly is to push down the chosen revolver segment.

C.1 ROTATING REVOLVER

These are the parts of the rotating sub assembly (See fig. 12). There are five cartridges that hold four different colours including a stylus for tablets. The cartridges are secured in the revolver segments and goes 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.

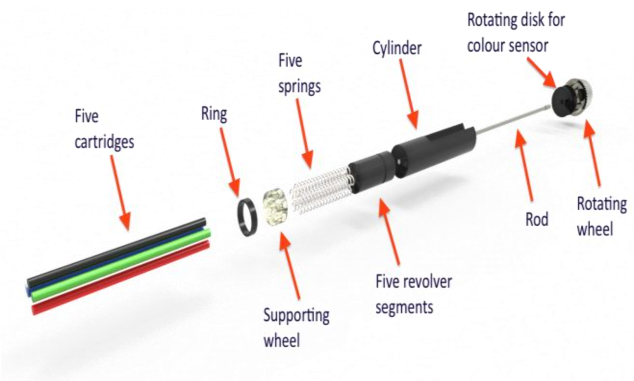

Figure 12 Exploded view of the rotating revolver

The pen consists of five different revolver segments, one for each cartridge. It's a 360° track along the 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.

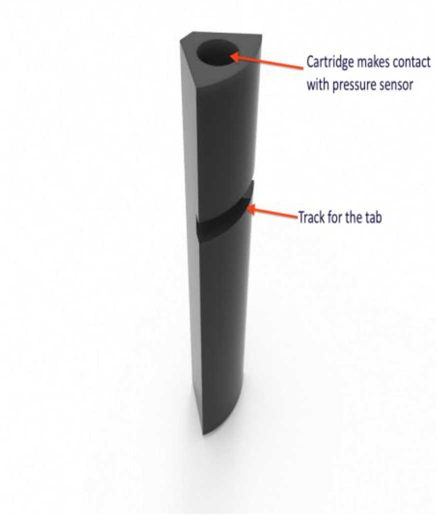

Figure 13 Revolver segment

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

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. The shape also allows all the segments to spin around the rod when you turn the spinning wheel. The rod is 135 mm long.

C.2 THE TAB

These are the components of the tab (See fig. 14). 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 run 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 hooks onto a notch in the rail. This prevents the springs in the revolver barrel from pressing the tab up.

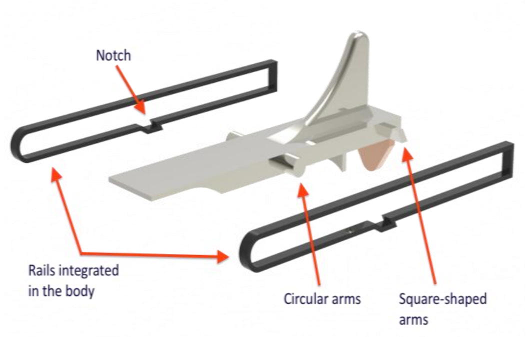

Figure 14 Exploded view of the tab

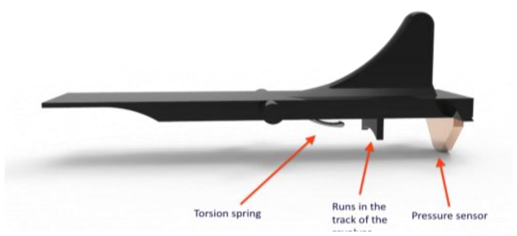

Figure 15 The tab

The torsion spring located (See fig 15) 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.

D. REPLACEMENT OF THE CARTTRIDGES

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

Since the cartridges only are attached in the revolver segments by friction, it's 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 isn't the same as the digital colour. 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, it can't go wrong.
The pen is designed in a way that makes all internal parts fixed inside, even if the cartridges are out.

VII. ELECTRONIC DESIGN

A. ARDUINO BOARD

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.

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 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.

B. RECOGNITION SYSTEM

The proposed solution consist of a colour disc (figure 16) placed around the twisting shaft of the pen, with a photoresistor sensor and a RGB LED connected to the microcontroller. Every colour of the plate will be associated to one cartridge, therefore, when the microcontroller detects which colour is being sensed, it will associated with a cartridge being deployed.

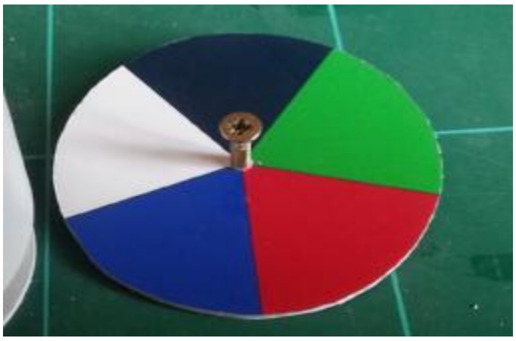

Figure 16: Colour disc

B.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 17). 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.

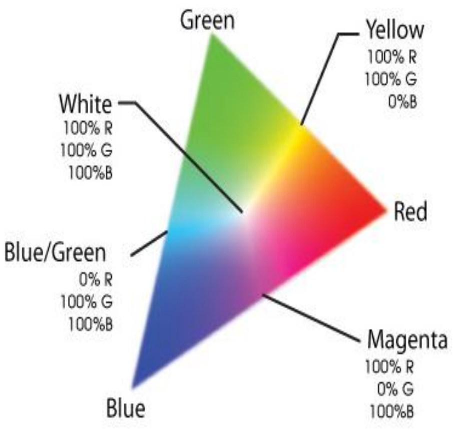

Figure17: RGB colour system

In this proposal, an RGB LED flashes red, green and blue light onto a colour of the colour disc (figure 16), 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.

B.2. CREATING A CODE WITH RGB

To determine a position, every colour of the colour disc has to be encoded. In figure 18, a possible codification can be observed.

R	G	B	Colour	Code	Position
0	0	0	Black	000	1
0	0	10	Blue	001	2
0	10	0	Green	010	3
10	0	0	Red	100	4
10	10	10	White	111	5

Figure 18: 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.

B.3 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 19), 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 20).

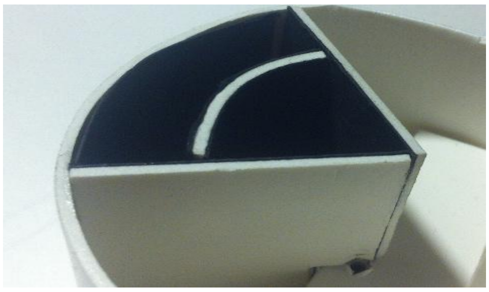

Figure 19: Case for testing the photoresistor and the RGB LED

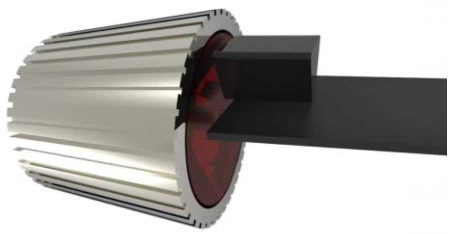

Figure 20: Case for the colorimeter integrated in the pen

B.4. PROGRAMING THE SYSTEM

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 1.4.2 for information about this range), therefore, to make the value easier to analyse a change of scale needs to be done.

B.5. 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 21 the readings on the microcontroller and the detection can be observed.

```
R= 7 G= 8 B= 8 Position= 1 Code= 111 Cartridge= Stylus
R= 0 G= 0 B= 0 Position= 2 Code= 000 Cartridge= Black
R= 7 G= 0 B= 4 Position= 3 Code= 100 Cartridge= Red
R= 0 G= 5 B= 2 Position= 4 Code= 010 Cartridge= Green
R= 0 G= 0 B= 5 Position= 5 Code= 001 Cartridge= Blue
```

Figure 21: Position detecting done by the microcontroller

VIII. 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.

A. USER INTERFACE

- **Turn on the pen:**

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

- **Turn off the pen:**

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

- **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.

- **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.

- **Change color:**

To change color 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.

- **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.

- **Write on paper:**

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

- **Write on tablet:**

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

B. 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).

IX. RESULTS AND CONCLUSIONS

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 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.

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