Design and Implementation of a 3D Plastronic Prototype

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Abstract

In a world where electronics and materials science increasingly converge, this project explores the prototyping of a smart system integrating 3D plastronics and embedded electronics. The goal is to design and fabricate two functional shells—a vehicle and its remote controller—featuring capacitive touch interfaces and RGB lighting controlled by an Arduino. Using KiCad for circuit design and the MPR121 sensor for touch detection, we implemented a fully interactive, programmable prototype. This report details the engineering process, from schematic design to PCB realization and programming, highlighting the challenges and potential of integrating mechanical, electrical, and software components into a cohesive plastronic system.

I PROJECT CONTEXT, PROBLEM AND OBJECTIVES

The goal of this project is to develop a functional prototype of a car using 3D plastronics technology. We are competing with two other teams and in the end, only one will remain. The challenges we face include:

- Creating an innovative and original product
- Exploring scientific and technical complexity in design
- Trying to make as much progress as possible

II INTRODUCTION

At the intersection of plastics and electronics, plastronics represents a powerful lever of innovation for various industrial sectors. It paves the way for new advances in connected devices and embedded electronics, driving fields such as autonomous vehicles and connected health toward new horizons. This emerging field requires specialized technical skills, combining multiple disciplines such as electronics, materials science, and chemistry, and offers new career opportunities [4].

Also known as *Molded Interconnect Device (MID)*, it is a rapidly growing field that merges plastics processing and electronics. Its aim is to integrate electrical and mechanical functions directly onto 3D plastic parts. Several plastronics manufacturing methods exist, depending on criteria such as technology cost estimates, performance range, associated connectors, and target applications, etc. [1] [6].

Two-shot molding (called *2K-molding* in English) is a method that involves using two different materials in the injection process. This enables the creation of parts with specific characteristics by combining the advantages of each material. For example, one material may provide necessary structural strength, while the other offers electrical or thermal conductivity. While it requires a high initial investment, it becomes more cost-effective for large-scale production. One of its main advantages is the excellent freedom it offers for 3D shapes. This method is widely used in various industries to produce complex and functional components efficiently and precisely.

Laser ablation (called *Laser Subtractive Structuring / LSS* in English) involves initially molding the plastic substrate, followed by depositing a conductive metallic layer over the entire part. A laser is then used to remove the unwanted metal areas, leaving only the electronic circuit on the part. Finally, the thickness of the metal tracks is adjusted via electroplating. This method has several advantages, such as not requiring additives in the substrate material and offering high-resolution conductive paths. It is used in various fields, from low to high precision applications.

Overmolded Structural Electronics (called *IME – In Mold Electronics* in English), derived from printed electronics, involves creating the electronic part using inks printed on thin plastic films. These films are then shaped and cut to fit the geometry of the molded product's surfaces. Once the film is formed, it is placed in the injection molding tool and overmolded onto the plastic part. Its advantages include enhanced aesthetics, efficient and fast production, and the ability to use standard screen-printing machines for electronic printing, allowing component placement. Target applications include automotive, photovoltaics, and sensors [5].

This last method, as described, will be partially explored in the scope of this project. The equipment used and all subsequent steps were carried out in the AMPER laboratory.

As third-year students in electronics, electrical energy, and automation, this initiative represents a valuable opportunity to apply our theoretical knowledge while developing practical skills in the design and fabrication of electronic prototypes. That's why our team is excited about this challenge.

III PROJECT PRESENTATION

As part of our project, we used the *Overmolded Structural Electronics* (OSE) method, which can be summarized in 6 steps described in Figure 1, to complete the mold of our project or any given mold.

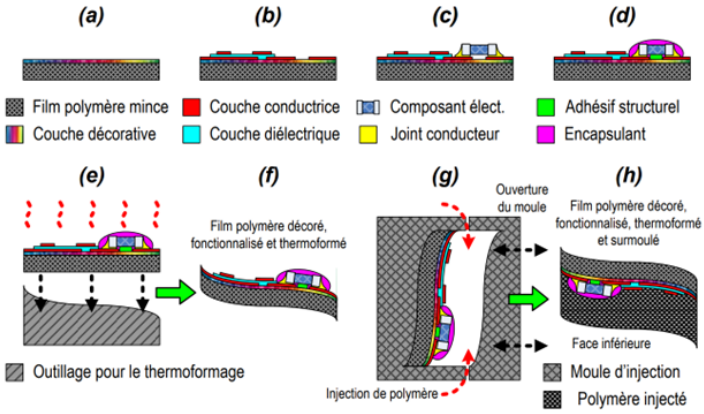


Figure 1: Manufacturing steps of a typical OSE plastronic process – (a) printing a decorative layer on a thin transparent polymer film; (b) successive printing of conductive and dielectric layers; (c) placing and assembling SMD electronic components on the conductive network; (d) structural bonding and/or encapsulation of components; (e) thermoforming; (f) trimming the system; (g) overmolding by injection; (h) final functionalized part.

A thin transparent polymer film with a thickness of around 200 to 400 µm, typically polycarbonate (PC), is used as the base substrate.

On one side of the film, successive printings — mainly using inks — are carried out to: deposit a decorative layer for aesthetic appeal (Fig. 1a), and deposit conductive and dielectric layers to build the circuit's conductive network (Fig. 1b). Typically, the number of conductive layers is limited to two. The printing is usually done via screen printing, which allows significant material deposition (a few µm/pass), with a resolution around 50–200 µm. Other techniques or combinations may be used: digital printing, offset, pad printing, etc.

SMD components are then placed using conventional placement machines onto the 2D interconnect network (Fig. 1c). They are mounted on pads previously coated with conductive glue (screen printed or point-to-point deposited), suitable for the PC's glass transition temperature (Tg 140°C). To strengthen their hold and minimize detachment or "wash-out" issues during later steps, the components can be structurally glued and/or encapsulated (glob-top) (Fig. 1d). This increases mechanical adhesion and reduces the risk of detachment during overmolding.

The entire film is then thermoformed in 3D over a master mold (thermoforming mold) shaped to match the final object. Once trimmed (Fig. 1f), a functional polymer "shell" is obtained. It is then placed into a mold and overmolded with thermoplastic polymer (Fig. 1g). For material compatibility, the injected material is typically of the same nature as the base film.

The final result is a 3D printed circuit sandwiched between two protective polymer layers.

In this example, it's worth noting that the decorative layer is on the same side as the conductive network. Although it could be on the opposite side, placing it on the same face offers better protection from external damage, as it's shielded by the thickness of the (typically transparent) film. Variants or combinations of processes can be applied at each step — for instance: placing components after thermoforming; with or without overmolding using injection or casting (e.g., resins), etc.

The reference polymer (substrate + overmolding) is polycarbonate (PC), which offers good technical compromises. Other materials are also possible and/or being studied (Polypropylene – PP; Polylactic Acid – PLA; etc.).

The OSE process is an industrial method experiencing rapid growth. Its main advantages include:

- Production of both technical and aesthetic parts;
- A technology derived from printed electronics, using standardized 2D tools (printing and component placement) already mastered by the electronics industry;
- A technology using well-known plastic transformation techniques (thermoforming and overmolding);
- Functionalization of large flexible substrates without initial 3D shape complexity;
- Possibility of multiple conductive layers, though limited to one side of the film.

Some limitations include:

- Geometrical complexity of 3D parts is limited by thermoforming capacity (low aspect ratios and voluptuous surfaces);
- Use of conductive inks and glues with higher resistivity, and mechanical constraints during forming (stretching) and injection (wash-out);
- The Tg of commonly used polymers makes soldering difficult and limits use in high-power electronic applications;
- Difficult repair or intervention in case of system failure (due to overmolding);
- Low versatility with high tooling costs if design changes occur [3].

In our project, we were constrained to a shell mold. This shell will be used twice: once for a model resembling a car (Figure 2), and once for a controller described in detail in the project specifications.

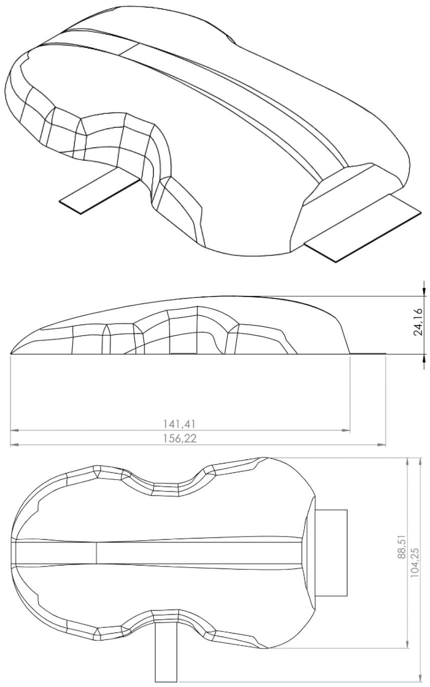


Figure 2: Actual dimensions of the car shell and controller

In our project, we used two similar shells to implement lighting functions on the "car" shell (from now on, we'll refer to one as the car and the other as the controller), with the controller controlling the car shell.

The circuits of both shells were entirely designed using the KiCad software. KiCad is a multi-platform tool that uses the open-source wxWidgets library. It allows all steps necessary for PCB design: schematic capture, footprint assignment, layout routing, and Gerber export [2].

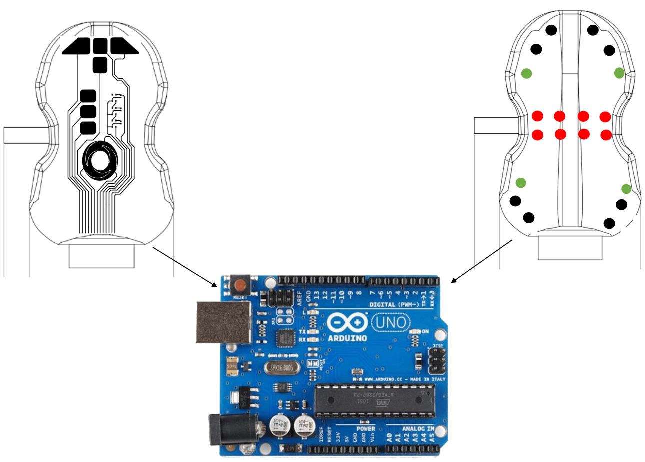


Figure 3: Complete demonstration of the project

IV COMPONENTS USED

Figure 4 shows all the electronic components used to complete this project, excluding the routing ink.

Each LED must be accompanied by a capacitor to handle micro-outages or voltage drops, as they act as small energy sources located near the load to help stabilize voltage during rapid changes in energy demand.

Each path coming from an Arduino pin must include a resistor (0805 package) to limit strong current flow.

Bridge resistors (1206 package) of 0 Ω are used in printed circuit boards to resolve routing conflicts, especially when there are space constraints. These help bypass obstacles without redesigning the PCB and help avoid short circuits.

Capacitive touch sensors are used to control a device. The principle is based on the fact that our finger is a conductive object that alters the electrical capacitance when it approaches or touches the sensor electrode.

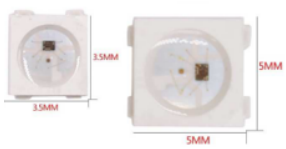
Initially, the sensor electrode and ground form a small capacitor with a baseline capacitance. When touched, the finger and electrode form a new capacitor in parallel with the original, increasing total capacitance. The change is measured and converted into digital values for processing by a microcontroller. In our case, we use the MPR121 (detailed in the programming section).

(a) 1206 resistor — 1.3mm x 1.75mm

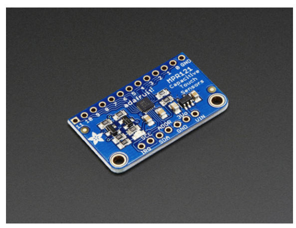
(b) 0805 resistor — 1.2mm x 1.4mm

(c) Clincher

(d) 0805 capacitor — 1.18mm x 1.45mm



(e) RGB LEDs SK6812 — 5mm x 5mm



(f) Touch sensor MPR121

Figure 4: Components used in this project

V THE CAR SHELL

At this stage, we began implementing our ideas into a functional schematic and a PCB ready for fabrication using the KiCad software.

V.1 Creating the Circuit Schematic

We start by creating a schematic file in KiCad. We select the components that will be part of the PCB circuit and define their connections. To generate the PCB file correctly, specific footprints must be assigned to each component, as previously explained. All these steps are illustrated in Figure 5.

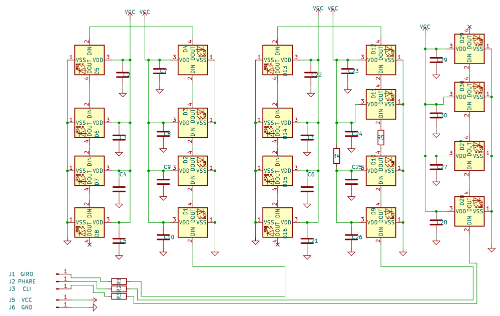


Figure 5: Schematic of the car shell's LEDs

V.2 PCB Design

We first select and place the components and other elements needed for the lighting functions.

After assigning footprints — a reminder: we used the SK6812 package for the 5mm x 5mm RGB LEDs, the 0805 package for capacitors and resistors, and 1206 package 0Ω bridge resistors. Since there were no constraints on external connectors, we used D-type pin connectors (D0.7mm, L6.5mm, W1.8mm FlatFork) in the circuit, along with a routing track width of about 0.6 mm, as shown in Figure 6.

Routing is one of the most important steps in PCB design. It involves placing components and connectors and drawing the electrical traces between them. This step required special attention, especially to minimize interference.

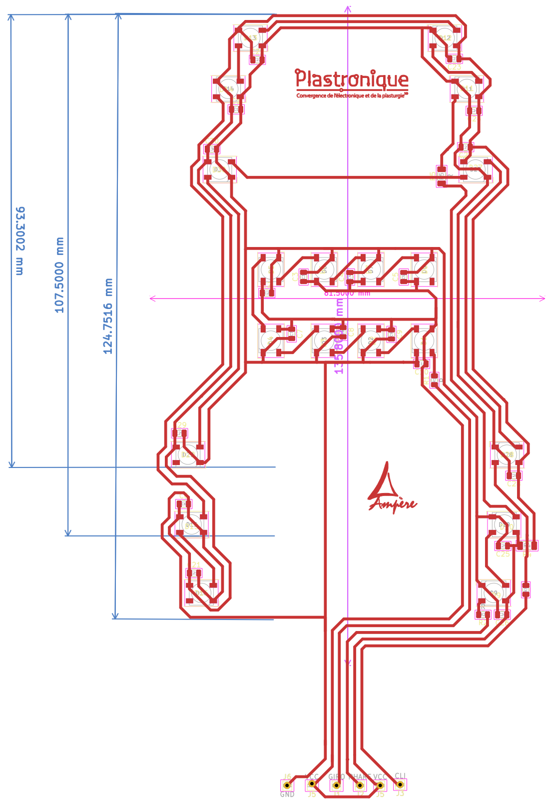


Figure 6: PCB layout of the car shell's LEDs

VI THE REMOTE CONTROL SHELL

The design of the remote control shell requires the use of capacitive touch buttons based on the *MPR121* component shown in Figure 4. The MPR121 transmits information about the activated touch pads to the Arduino via the I2C interface in the form of digital data. Each touch pad is represented by a bit in specific registers of the MPR121. When a pad is pressed, the corresponding bit is set to 1; when the pad is released, the bit returns to 0. The Arduino reads these registers to determine which touch pads are active, receiving this information as binary values (bits) instead of analog voltages.

The register from which the Arduino retrieves the number of the pressed touch pad is called the touch status register, specifically registers TS1 and TS2. These registers contain bits indicating the status of all 12 touch inputs (each bit corresponds to a pad: 1 if pressed, 0 if not) .

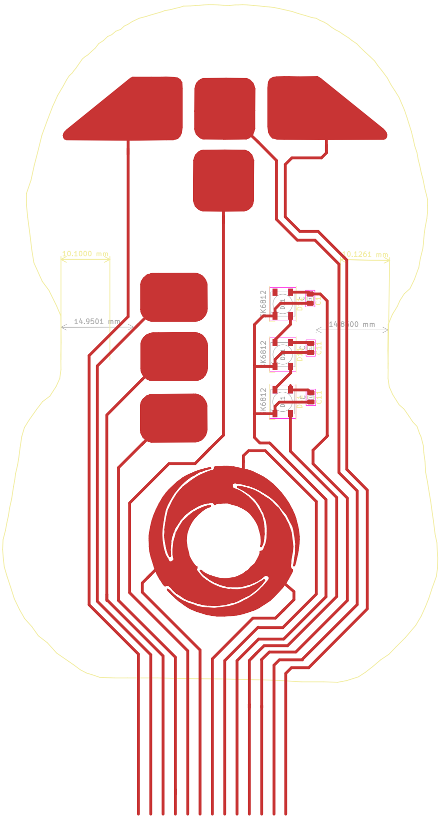


Figure 7: Schematic of the remote control shell

The lighting effects on the car shell as well as the behavior of the remote control shell can be programmed with various functionalities, since both are connected to the Arduino and their behavior depends primarily on the implemented code. One such example will be presented in the programming section.

VII CONCLUSION

This project allowed us to explore the design and fabrication of a functional electronic prototype using 3D plastronics, from schematic creation to PCB realization and integration of capacitive touch control. By combining mechanical and electronic design, we implemented a complete system composed of two functional shells — a car and a remote control — communicating through an Arduino.

We successfully applied key concepts such as the use of the MPR121 touch sensor, I2C communication, RGB LED control, and PCB design with KiCad. This hands-on experience strengthened our understanding of circuit integration, component selection, and manufacturing constraints related to embedded

References

[1] jade edu. *Qu'est-ce que la plastronique ?* 2021. URL: https://jade-edu.org/quest-ce-que-la-plastronique/ (visited on 05/26/2024).

[2] *Logiciel KiCad*. URL: https://fr.wikipedia.org/ (visited on 05/26/2024).

[3] Philippe LOMBARD. "Etude et réalisation d'un projet dans le domaine de la platronique 3D". In: (2024), 5 et 6.

[4] LYON1. *Plastronique 3D*. 2021. URL: https://www.universite-lyon.fr/ (visited on 05/26/2024).

[5] Olivier BARROSO et Pierre JOLY. *Etude bibliographique / Etat de l'art Plastronique*. NC. URL: https://www.nae.fr/wp-content/uploads/2019/11/Etude-plastronique-Final.pdf (visited on 05/26/2024).

[6] Lionel TENCHINE. *Plastronique - Fonctionnalisation électronique des pièces plastiques*. 2023. URL: https://www.techniques-ingenieur.fr/base-documentaire/materiaux-th11/applications-des-plastiques-42141210/plastronique-am3610/ (visited on 05/26/2024).