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CHARACTERIZATION OF 3D PRINTED SENSOR

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Abstract

A joystick set for controlling different degrees of freedom was designed, materialized and characterized. The joystick was designed for 3D printing, improved through several iterations, producing multiple samples using multi-material additive manufacturing. Two different materials (one structural and another conductive) were used in the filament material extrusion process to obtain resistive-based sensing unit elements. The sensor was put into operation through a voltage divider circuit. Testing has been carried out on a testing bed (analogic sensor), in real life (binary mode) and on a simulation platform (multiple-state signal)for controlling a robotized wheelchair. The final design is able to fulfill the requirements in terms of reducing the amount of material used and the times needed for printing. Results highlight the possibility of Using 3D printed resistive-based sensing units in the implementation of binary signals as well as multi-state signals and the sensor set has been tested by way of controlling a robotized wheelchair.

Keywords— joystick set, 3D printing, robotized wheelchair, 3D printed

1.Introduction

In recent years, growing interest as well as improving the achieved results in a range of functional-graded material applications for the realisation of active parts by use of technologies of

3D printing. Many achievements are classified as those resulting in metamaterials: some of them feature quite extraordinary physical capacities-in uniaxial cases-what is known nowadays: they can have for instance, negative elastic moduluses, or achieve super stiff-to-weight mass-ratio and high-toughness as well as elasticity. In this case, the possibility of depositing conductive materials by further 3D printing techniques onto non-flat surfaces allows achieving parts that can be active and passive electrical components. Pursuing this goal, relevant studies are focused on combining conductive materials with other structural non-conductive ones for the achievement of new electronic designs. Furthermore, some authors have approached the use of this technology in order to obtain sensor elements in the form of antennas, liquid level meters, or other parts based on architectures of functional composites. In many of these cases, however, the electronic devices are obtained by integrating a sensor into a substrate previously obtained through different conformation process other than 3D printing. Several methods can be adopted to utilize the conductivity properties of the conductive composites used concerning the working principle of the 3D printed electronic parts.

for example, the working of some devices can depend on the values of their resistivity or capacity parameters. For instance, the parts are susceptible to some external conditions like application of a certain stress state that will determine the levels of resistance or capacity they to reveal. Piezoelectric sensors were prepared by 3D printing, mostly through photo-optical routes, by introducing processing along with a former, simultaneous, or even later poling step.From the perspective of ME-based additive manufacturing methods [23], some researchers studied the creation of flexible circuits through printing of a conductive material over a flexible substrate already processed with a technology other than 3D printing. For example, the exploitation of a composite of PLA and second thermal reduced graphene [24], produces strong adhesion forces between the various layers. Furthermore, several significant experiences have shown that multi-material 3D printing directly processes electrochemical flow cells with commercially available PLA and graphene-PLA materials, achieving successful rigid sensors materialization. Other experiments with multi-material additive manufacturing by material extrusion have even more dissimilar materials, such as pure PLA and PBT (graphene-based polybutylene terephtha late) incorporating carbon nanotubes CNT, which can have different glass-transition temperatures Tg and even vary by their thermal expansion coefficients. In such cases, much attention must be paid to choose properly the processing pa rameters required by each material. For instance, the 3D printing.

Printing bed temperatures must change according to the material distribution in the zones.

When conductive filaments are used, it has been suggested that the most relevant parameter to yield higher tensile strengths is the infill percentage, as the densest parts yield higher tensile strengths. In this case, another important parameter reported is the printing orientation. In compression efforts, the infill type is a second main important factor, as the honeycomb is the most appropriate pattern to achieve higher performances. Except these two factors, the layer height demonstrated to play less important roles. On a totally different plane, the highest conductivity achieved in 3D printed filament use was reportedly achieved with extruder temperatures in the higher end of the temperature ranges proposed by the material provider. Moreover, the conductivity is highly improved in cases where theconductive filament incorporates conductive nanotubes, and can be tuned

From tens of ohms (for example, 53±1 Ω) to dozens of kiloohms (for example, 29.40±3.69 kΩ) when mixing various ratios of CNT with PLA. The durability of the circuits produced by 3D printing conductive filaments is discussed below. From the stress tests, the electrical properties can be very stable over relatively long time periods, and it keeps its functionality for sensors that are used in wearable technology.

The use of conductive flexible filaments is mostly related in the literature to the preparation of wearable technology, such as electronic textiles. In this sense, the use of TPU-based conductive flexible filament has been reported to give successful results in 3D printing over textile support thus revealing that it can keep being active if used in different states of deformation. laboratory setting [2]. Its goal is to ensure that newly created assays meet clinical governance and risk management requirements and comply with standard laboratory systems. Annex 15 of the European Union (EU) Guide to Good Manufacturing Practice2, which discusses certification and validation, provides helpful context. Certain test details specify which protocol variations may be considered significant and, thus, require revalidation of the assay with adequate evidence to guarantee comparable performance. Sometimes the scope of validation gets narrowed, requiring the repetition of only a portion of the validation tasks.

About the case study analysis, a joystick set is covered. The set consists of two main components--a joystick lever with four end-effectors--and a multi-material base containing four different sensing units. The set must be able to provide two separate signals indicating different states in each of them, that is, at least a null value and two more (different values high and low). This means that the 3D printed part will include several sensing elements in one device. This setup is expected to generate signals that could be used to control different degrees of freedom of robotic systems. As a proof of its feasibility, it has already been applied as the control interface for steering a motorized wheelchair. The scope of the implementation in the paper includes conceptual design, detailed design, and prototyping of This is the solution, conducted in design iterations, where the features and results achieved are continuously improved step by step.

2. Materialization of Joystick Set

This paper focuses on the design, fabrication, and testing of a 3D printed multi-material resistive-based joystick set able to command multiple degrees of freedom. Materialization of the set was therefore followed from the initial conceptual design based on a resistive-based working principle namely, piezoresi sensitive a sensor unit. Detailed design and manufacturing were then made, and at each stage of manufacturing completion, a critical functionalities screening was performed as the basis for arising improvement items for a subsequent iteration. Once a viable prototype had been achieved, the joystick set was ready for proceeding with experimentation of its functionality.

2.1.Concept Design and Working Principle

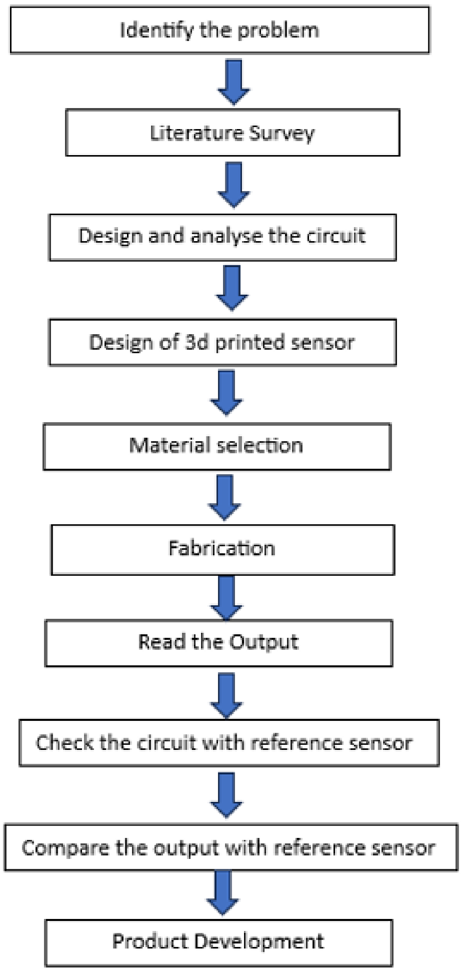
The joystick set foreseen must be able to provide two output signals in multiple states, which correspond to different signal levels. These signals can be assimilated to commands along two cartesian directions on a horizontal plane of move ment, namely: forth-back and right-left, which will be referred as the main directions of the joystick. With this disposition, the signals will be enabled to be generated one by one or in pairs, for example "back" or "forth and left". What it is not expected is to receive contradictory signals within a main direction, as it could be "forth and back" or "left and right". These different signals are aimed at commanding different degrees of freedom, in this case of a robotized wheelchair. For for example, the way forward can be used to send a command to the car to move forward (by actuating over a pair of traction wheels) or also to send a command to the backrest to move in some direction for example, to move from a leaning position to a sitting position Taking into account these requirements, the conceptual design of the joystick lever is shown in Fig. 1. With regards to the working principle, it is envisioned that the four cardinal points will contain piezoresistive sensor units Conceptual design of the joystick set. that will be fabricated from the use of conductive filament mate rial to produce resistive pads. Such resistors are connected to a circuit with the classical voltage divider circuit which has a fixed and well-known Vin of 10 V and a variable level of voltage Vout. In this case, where the usually encountered strain gauges are replaced by part of the multi-materially designed element, R1 and R2 are composed of. The resistivity level 'e' of the utilized conductive material is always a value characterized and presented by the material manufacturer itself. From there, each resistor design's effective 'R' can be determined determined with Eq. (1), knowing the values of the geometrical parameters for length 'l' and section 'S' of the prototype. When being actuated, the end effectors contained in the joystick lever will deform one or the two resistors, which will imply a variation in the values of its (or their) specific resistance(s). For each direction forth-back and right-left, the variable voltage Vout will depend upon the function of 'Ri' (where i = 1, 2, the relative resistors in one direction) as per Eq. (2). Based on Eq. (2), and since R1 and R2 will tend to take on very large values when they are under deforma\ tion, the maximum expected value for Vout will be 10 V (when R2 tends to infinity) and the minimum expected value will be 0 V (if R1 approaches infinity)

$$R = \rho \cdot \frac{l}{S}$$

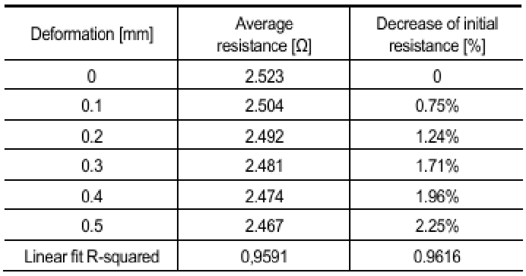
$$V_{out} = \frac{R_2}{R_1 + R_2} \cdot V_{in} \ .$$

3.Joystick Design And Manufacturing

The preliminary design of the joystick set is determined to be produced as a composite of two parts: a base and a lever. The lever will be characterized by relative movement regarding the base, and it will have four end effectors that deform the resistors (conductive pads) held in the base (See Fig. 2). The base is a multi-material part designed to be attached to a flat surface, such as in the case of a motorized wheel chair, an armrest. Since it contains sensor units, it must include two accessible points of connection to permit the connection of resistors to the circuit. The technology used to produce the parts is ME.



The materials used in the designs are two different types of filaments of 2.85 mm of diameter, namely, rigid PLA (BCN Three Dimensional Printers SL, Barcelona, Spain) and flexible conductive TPU (Filaflex, Recreus Industries SL, Elda, Spain). The main physical properties of the two materials utilized, as disclosed by the material manufacturers [41, 42], can be retrieved in Table 1. The rigid PLA could provide good tensile strength and relatively good surface quality [43] to the characteristics required in multi-material products such as the one object of the present application. The conductive TPU has a shore hardness level of 92 A, being this value at the lower elasticity end of the commercially available ME raw materials. The conductive filler, in the case of the Conductive TPU are carbon black pellets in form, which is a filler that has already been used highly effectively in multi material printing of electronic components [13]. Similar to numerous other piezoelectrical research applications it was chosen in trying to obtain relatively high, to be fair, levels of conductibility in the 3D printed specimens [44]. The parts are printed with this material appropriately levels of conductivity and deformability to be used as piezoresistive elements included in multi-material parts. The additive manufacturing machine used is a 3D printer model BCN3D Sigma R18 (BCN Three Dimensional Printers, Barcelona, Spain), which is based on independent extruding technology (IDEX), and it is placed at UPC-ETSEIB in Barcelona. The nozzles in both extruding heads were chosen of 0.4 mm of diameter. For the rigid PLA volumes of the parts, processing \ parameters were based on the material provider speci\ fications. Specifically, infill density was set at a 20 % to save material in construction. \ For creating the resistor pads, or the conductive material, ex\ truder temperature was set at 245 °C and the print speed at 20 mm/s, again based on the suggested values by the supplier of the material [42]. In this case again, the infill density was set to the highest value aiming at a 100 % fully dense part (100 %). The printing orientation of the conductive material was set at 45 % in the plane X-Y, according to literature [46].



Deformation [mm]	Average resistance [Ω]	Decrease of initial resistance [%]
0	2.523	0
0.1	2.504	0.75%
0.2	2.492	1.24%
0.3	2.481	1.71%
0.4	2.474	1.96%
0.5	2.467	2.25%
Linear fit R-squared	0,9591	0.9616

Feasibility Analysis

3D printing strain sensors for joysticks presents an innovative approach with significant potential. The use of additive manufacturing allows for the creation of customizable, lightweight, and flexible sensors, tailored to specific designs. A key advantage is the rapid prototyping capability, reducing lead time and cost. Materials like conductive filaments (e.g., graphene) enable the integration of sensing elements directly into the structure.However, challenges include the durability and sensitivity of printed sensors. Traditional strain sensors often use materials with high accuracy and longevity, whereas 3D printed versions might have limitations in these areas due to material properties and printing resolution. In conclusion, while feasible, 3D printed strain sensors for joysticks need advancements in materials and reliability to compete with traditional manufacturing methods for large-scale production.

Need for the Current Study

The development of 3D-printed strain sensors for joysticks is a growing area of research, driven by the increasing demand for precise control systems in fields like robotics, gaming, and medical application. These sensors can detect the deformation or strain on the joystick, translating it into electrical signals that control movements. Traditional strain sensors often rely on complex manufacturing processes and materials, but 3D printing offers a more accessible and customizable solution.

One of the key advantages of 3D-printed strain sensors is their ability to be integrated directly into the design of a joystick, reducing the need for external components and simplifying the assembly process. Conductive materials, such as graphene or carbon-based composites, can be used in the printing process to create the sensor's sensitive elements.

These sensors provide high sensitivity and accuracy, crucial for applications requiring fine-tuned control, such as in assistive devices or advanced gaming controllers. The approach is cost-effective and scalable, making it a promising solution for enhancing joystick functionality across industries.

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Conclusion

This study successfully evaluated the use of material extrusion in fabricating a functional, multi-material, two degrees-of-freedom, multi-state joystick sensor set. The sensor integrates non-planar circuitry with deformed elements to activate the piezo-resistive effect, effectively capturing and differentiating between five discrete states. The joystick comprises a 3D-printed base with four embedded resistor pads and a lever, with the design requiring no support structures. Iterative design refinements reduced material usage and printing times, and tests confirmed the joystick's sensitivity to variations in resistance, accurately distinguishing multiple states (e.g., five directional commands). Potential applications include controlling degrees of freedom in assistive devices like a robotized wheelchair, and simulation tests demonstrate its viability for personal mobility control. Future work will focus on enhancing durability, studying hysteresis effects, examining surface finish impacts, and integrating signal processing to reduce noise and improve response accuracy.

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