A Review on 3D printed force sensors

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Abstract:
A force sensor plays major role in robotics, wearable electronics and meteorological applications. Three dimensional (3D) printing is an exceptional technology and provides easy and economical fabrication process for the force sensors. Some salient features of 3D printing and development of force sensors in recent times have been represented in this paper. All possible forms of force sensors, for instance flexible, transparent, stretchable and highly sensitive can be developed using 3D printing technologies in an economical, quick and environmental-friendly approach. Over the years, fused deposition modeling (FDM) is gaining attention for the fabrication of force sensors. Also, due to advancements in materials and fabrication process, these sensors are being developed with enormous benefits. Some recent developments include flexible capacitive force sensor, wearable sensor and tactile sensor that are popular with 3D printing.

Keywords: 3D printing, force sensors, fused deposition modeling (FDM)

1. Introduction

Force sensor is an important measuring tool that converts the applied force into a corresponding output (electrical) signal. Depending on the required applications, there is a vast range of force sensors, ranging from few Newton’s to mega Newton’s. They have been used in various applications, including measurement of cutting forces in machining processes, thrust measurement, electronic weighing machine and transportation[1-2]. They include different measuring devices or indicators, including dial gauged, digital dial gauged, strained gauged, tuning fork etc for the realization of applied force. Among these, strain gauges have been prominently utilized [2-3].

Three dimensional (3D) printing (additive manufacturing) is utilized to fabricate geometrically and functionally complex objects and have various advantages, including time saving, cost effective and economical manufacturing process. Using this technology, force sensor has been utilized in various areas, like robotics, biomedical environment, and meteorological applications [3]. Also, it can be utilized to develop new, cost effective and custom-made force sensor. In recent times, it is possible to manufacture force sensor with small size and in an inexpensive manner in the field of robotics [4-6].

This paper represents an overview of various 3D printed force sensors; developed using fused deposition modelling (FDM) in recent times. The paper has been organised as per following particulars. In section 2, followed by section 1, a brief introduction of 3D printing has been described. A general discussion on 3D printed force sensors has been represented in section 3. Next, discussions and conclusions have been narrated in section 4 and 5 respectively.

2. 3D printing : a brief introduction

3D printing (also termed as additive manufacturing) is a resourceful procedure that performs manufacturing of physical items from 3D computer-aided design (CAD) model in an additive (usually, layer) approach. Numerous features can be addressed, including better utilization of materials, customized products on demand, development of multipart structure with easy fabrication and quick prototyping [7]. In every manufacturing method, CAD files can be exchanged among users from one end to other. Furthermore, significant developments in the 3D printing lead to develop customized electrical passive components with easy approach [8-9].
Fused deposition modelling (FDM) and inkjet printing method pave the way to manufacture a number of sensors in different forms in many applications. Moreover, FDM is popularly used due to its features, like simple, high speed and cost-effective manufacturing process. Also, other techniques play essential role, including selective laser sintering (SLS), stereolithography (SLA), laminated object manufacturing (LOM) and direct energy deposition (DED). Figure 1 shows various steps in a 3D printing technique.

In the first place, the product concept has been transformed into a 3D model using any popular CAD software, like CATIA or AUTO CAD. A standard tessellation language (STL) file is commonly termed as standard in each 3D printing method. It converts the continuous geometry in the CAD file into small triangles [10-11]. It is sliced into thin cross-section layers using precise software. Then, the part is fabricated using one of the 3D printing technologies. With post-processing, the final product is prepared [12]. Table 1 lists numerous advantages and challenges of 3D printing.

**Table 1: 3D printing at a glance [12-13]**

| S.No. | Advantages                                                                 | Disadvantages                                      |
|-------|-----------------------------------------------------------------------------|----------------------------------------------------|
| 1.    | Manufacturing of customized and complex products                            | Limited availability of materials for production. |
| 2.    | Material wastage is minimum; reduction in weight and size of final product. | Generally post processing is required to get final product. |
| 3.    | 3D CAD model data can be shared.                                            | Some intellectual property rights issues associated with products. |
| 4.    | Some cost effective and simple printing techniques for force sensors, for example FDM. | Material for support structure is wasted. |
| 5.    | Development of capacitive force sensor, flexible force sensor or tactile sensor, sensors for electronics industry. | Conductivity issue in electronic sensors |
| 6.    | It allows functional design and a great time saving in product development.  | The multifunctional products are in development stage |
7. A good approach towards zero waste manufacturing.
8. Some applications: aerospace, robotics, architecture, chemical and biomedical

3. Application of 3D printing: force sensors

Due to significant developments in 3D printing, it is possible to incorporate force sensing elements into an array of parts and objects. In a study [5], low cost force and tactile sensors have been designed and developed that can be incorporated into 3D-printed robot parts. Moreover, in the next study [6], a low-cost fingertip 3D-printed force sensor has been presented for robotic manipulation. In recent times, force sensors have been manufactured in a number of ways with attractive properties including sensitivity, flexibility and stretchability. Table 2 lists development of different force sensors.

4. Discussions

3D printing technology pave the way to manufacture cost effective, reliable and durable force sensors. Moreover, 3D printing technologies, including FDM and microextrusion method have been utilized to manufacture flexible force sensors with an inclusion of sensitivity and stretchability. Also, they have been commonly utilized in various areas, such as stretchable electronics, robotics, biomedical, health care sector etc.

Table 2: Development of 3D printed force sensors [14-21]

| S. No. | Force sensors | 3D printing methods | Working principle and materials | Research findings |
|--------|---------------|---------------------|---------------------------------|------------------|
| 1.     | Capacitive force sensor | 1) FDM filament extrusion 2) Fibre encapsulation additive manufacturing (FEAM), thermoplastic elastomer additive manufacturing (TEAM), 3) Multifunctional and multi material printing | 1) Parallel plate capacitor; 2) Sense the change between plates with the application of force 3) BendLay (ABS-based material), thermoplastic elastomer, copper wire | 1) Formation of composite capacitor using FEAM and TEAM. 2) FEAM enables the production of integrated electrical circuit path such as fibre, metallic wire inside 3D printed parts. TEAM is used to produce soft thermoplastic elastomers for dielectric material. 3) Linear response, between change in capacitance and applied force. 4) Post processing has been done to avoid preloading of the sensor. |
| 2.     | Flexible force sensor | 3D printing | 1) Parallel plate capacitor filled with sensitive silicon rubber as dielectric layer 2) Poly lactic acid (PLA), silver conductive ink, silicone rubber Ecoflex 00-30 | 1) Silicone rubber is found to be main material for the fabrication. 2) It has attractive features, including good elasticity and performances, easy commercial availability and fabrication, versatile, large deformation, and integration into different sensors structures. 3) The sensor can measure force up to 4N. |
| 3.     | Fully FDM flexible capacitive and resistive transducer | FDM | 1) Capacitive sensing principle 2) Resistive temperature detector (RTD) principle 3) Thermo-Plastic polyurethane (TPU) and semi-rigid carbon based polylactic acid (PLAcb) | 1) FDM allows fabrication of all components of transducer, including substrates, electrodes and active elements and it is called as full printable device. 2) FDM process affects the thermo-electro-mechanical properties, such as resistivity and dielectric constant due to process parameters, like printing temperature, speed and flow and the thickness of the layer. 3) A non-linear behaviour between resistance and temperature was observed for resistive transducers. |
4. **Flexible tactile sensor**  
- 3D printing mold and electrospinning  
- 1) Piezoelectric System  
- 2) Polydimethylsiloxane (PDMS), piezoelectric nanofiber mat and gold sputtering electrode.
- 1) The sensor system consists of PDMS substrates and a piezoelectric nanofiber mat, developed by casting process.  
- 2) Finger tip and wrist form sensor with high sensitivity to micro scale deformation.

5. **Whisker Inspired Flexible tactile sensor**  
- 1) FDM  
- 2) 3D multi-material printing  
- 1) Piezoelectric System  
- 2) Conductive TPU  
- 3) Ninjaflex
- 1) The sensor is used in contact imaging and 3D position measurement.  
- 2) It is used to determine force acting on whisker and its direction.

6. **Cost effective Flexible capacitive force sensor**  
- FDM  
- 1) Parallel plate capacitor  
- 2) Flexion X60 Ultra-Flexible Filament and Conductive thermoplastic poly-urethane (PI-ETPU)
- 1) FDM is used to print flexible capacitive force sensor using conductive TPU.  
- 2) The change in capacitance due to applied force in measured using an LCR meter and microcontroller based read out circuit.  
- 3) Read out circuit is cost effective and the sensor is used in soft robotic and prosthetic devices.

7. **Transparent, flexible, highly sensitive and biocompatible force sensor**  
- Microextrusion 3D printing method  
- 1) Piezoresistive Principle  
- 2) Resistance change of hydrogel during a force is applied to the sensor.  
- 3) Slow-gelling alginate hydrogel and PDMS
- 1) Highly sensitive and stable due to its sandwiched structure.  
- 2) The zig-zag patterned hydrogel and PDMS layer provide stable water content and recording.  
- 3) The sensor can be fabricated as wearable sensor for improvement in skin sensory capability of patients.  
- 4) It can be used as wearable sensor for skin sensory recovery.

8. **3D Printed Stretchable Tactile Sensor**  
- A multimaterial, multiscale, and multifunctional 3D printing  
- 1) Silver nanoparticle and modified silicone ink, Dragon Skin 10
- 1) The sensor has been designed and fabricated using the combination of nanocomposite ink optimization, 3D imaging, and multimaterial 3D printing.  
- 2) It is capable of detecting and differentiating human movements, including radial pulse, finger pressing and bending.  
- 3) Further work: optimization of the inks, including incorporation of semiconducting materials and devices  
- 4) Development of other crucial devices such as, temperature sensors to monitor tissue

### 5. Conclusions

In the development of force sensors, 3D printing provides design freedom, simple and cost effective printing process, better utilization of materials etc. Furthermore, efforts have been made to develop a family of economical force sensors that are useful for 3D-printed robot objects and other industrial applications. Under stressful circumstances, these sensors perform well with a fair amount of reliability and robustness. In table 2, development of force sensors in various types using FDM and other techniques has been represented along with working concept, different materials or inks and research findings. It can also be shown that FDM has a great potential in the cost effective fabrication of stretchable force/tactile sensors, capacitive force sensors etc. 3D printed force sensors include not only traditional mechanical properties, but also embedded optical and electrical properties. Some of the challenges include conductivity issue in wearable sensors, material types and processing issues.

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