AcceloPrint: Fabricating Accelerometers with Multi-Material 3D printing

Doga Ozbek
Aarhus University
The Department of Computer Science
Aarhus, Denmark
doga.ozbek@cs.au.dk

***Abstract—* AcceloPrint is the vision of fully 3D-printed acceleration sensors that can be fabricated in one pass alongside a 3D object and report on its angular orientation or acceleration. In this concept, AcceloPrint sensors utilize capacitive sensing to track a 3D printed swinging mass inside the 3D printed object. Unlike other accelerometers, they can be printed with only minimal user intervention and can be seamlessly integrated during the design. I envision a digital design tool that automatically generates the sensor geometry according to the user's requirements on their acceleration sensing range and accuracy. I plan to develop a computational model which generates the geometric conditions for this sensor including the elasticity of the swinging beam and converts the deflection into an acceleration value.**

I. Introduction

There is no widely accepted definition for personal fabrication at present. In 2005, Neil Gershenfeld [1] described personal fabrication as the capacity to design and produce one's own items at home, utilizing a machine that combines consumer electronics with industrial tools. Although only a small number of individuals, specifically technology enthusiasts, have the means to engage in personal fabrication in their homes [2]. The 3D printing industry is growing day by day, it has potential to revolutionize fabrication methods by giving each individual the means to manufacture their desired products at home and custom to their own needs. Therefore 3D printers hold a significant place in the personal fabrication space.

However, 3D printers are nowadays mainly used for generating plastic-like geometries without functionality which limits their use for consumers. It is a significant challenge for future fabrication systems to also integrate functional components such as sensors, batteries and microcontrollers that can fully 3D printed. This project is about devising a fully 3D printable accelerometer, which can be easily designed by changing the parameters on a user-friendly interface. This interface will be implemented for one of the common 3D editor like Blender. The goal of this project is to enable everyone to fabricate interactive devices without expert knowledge by integrating an accelerometer, wiring and a microcontroller into designed 3D objects.

II. Related Work

Sensors hold significant importance across diverse research and industrial sectors. The sensors of the future will necessitate cost-effective, highly efficient manufacturing, and they must deliver reliable performance in areas like mechanical sensing, biomedical applications, and optics. Recent advancements in 3D printing have ushered in a new era for sensor production, offering precision, customization, and a seamless manufacturing process [3].

With conductive filaments being available for end-consumers, it is possible to use additive manufacturing methods for devising sensing systems utilizing resistive and capacitive sensing method [4]. For instance, MechSense presents a fully 3D printed rotary encoder based on tracking a floating capacitor [5]. MetaSense shows a fully 3D printed smart meta-material which can sense deformation [6]. 3D printing is also extensively used in robotics. For example, researchers print strain gauges with conductive filament to sense obstacles through the robots feet (M-Squad [7], ScoReR [8]).

Complex sensing systems like IMU sensors or GPS receivers, are still challenging to fully 3D print. However, researcher made advances in 3D printing other sensor types. Recently, Arh et al. [9] demonstrated a 3D printed 3-axis accelerometer via FDM technology. However, the sensor needs to be printed with structural support which requires manual cleaning of the print.

The idea behind AcceloPrint is creating accelerometers in one print pass and without any additional support material. To enable a broader audience to use AcceloPrint we develop a user-friendly interface on Blender that automatically generates the sensor geometry and outputs fabrication-ready print files.

III. First Prototype

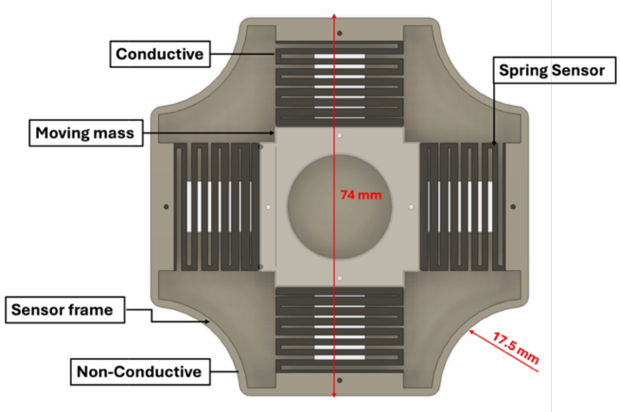
My first design concept for such a sensor relied on resistive sensing. Figure A shows the first iteration of this sensor. A swinging mass is mounted on a frame with four springs that allow the mass to move on two axes when accelerated in a specific direction. Each spring was printed with conductive PLA filament while all other components were printed with non-conductive PLA

Our hypothesis was that when a spring gets compressed, we observe a linear increase in conductivity. In that case, we would match the change in resistance to the acceleration through a series of experiments.

We also considered capacitive sensing as another sensing method. Figure B shows another sensor design. We printed a swinging mass on a cantilever that bends on one axis closer towards or further away from a sensing patch if accelerated in one or the other direction (e.g., when moving the sensor or due to earth's gravity) shown in Figure B. This sensing patch uses projected capacitance to estimate the distance between the swinging mass and the sensor patch. If the swinging mass gets closer, we can measure a higher voltage and vice versa.

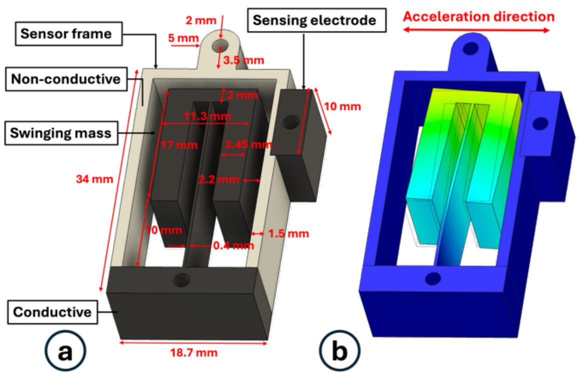
A. Primary Design

This figure shows the CAD design of the first conceptual design. Black parts: conductive, white parts: non-conductive.



B. Last Design

Figure B(a) shows sensor size, and nomenclature. Figure B(b) represents the heat map shows the displacement of the swinging mass under acceleration. The swinging mass bends towards the sensing electrode under acceleration to the left.

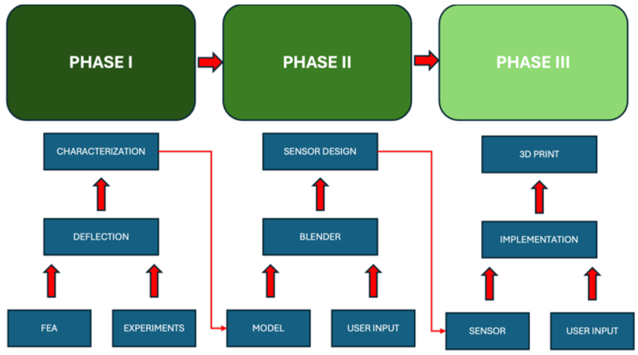


IV. Envisioned Prototype Iteration

The design of the AcceloPrint introduced above is now at the proof of concept stage. The project will consist of three main phases as shown in Figure A. First phase is characterization of the sensor parameters. To do that, the Finite Element Analysis (FEA) is planned to be conducted and the experiments to find the correlation between the deflection of the swinging mass and the voltage readings will be designed. Then FEA results and experimental results will be evaluated. Then correlation between the change in sensor parameters and the deflection will be found. The second phase of the project is building a blender extension for users to convert their sensor requirements like size, maximum reading, minimum reading and resolution of the sensor into sensor design. Third phase of the project is implementing this sensor design into the 3D object that user input to Blender. Here is the planned road map to achieve the complete prototype of AcceloPrint.

A. Planned Roadmap of the project

This figure shows how the flow of the project is planned with respect to the considered project phases.



V. Responsible Innovation

AcceloPrint will not only be a 3D printable sensor generation tool. We want to support makers and novice users to integrate their sensor into any 3D designs. For example, the user could place a 3-axis accelerometer into sports wear for activity tracking, prosthesis in rehabilitation, or even for 3D printing a drone controller that controls the drone via direct hand movement.

For almost all electronic component, there is environmental cost. We will research an environmentally friendly sensing method to sense acceleration and orientation by relying on a fully bio-degradable plastic, i.e., carbon-based conductive PLA. This PLA can be recycled more easily than the electronic components. Therefore, the idea of having 3D printable accelerometers has potential to revolutionize the sustainability of a wide range of interactive devices.

Author bio(s) / experiences

I am a researcher and engineer focused on human-computer interaction, specifically in 3D printing, haptic devices, and soft robotics. My research aims to merge technical expertise with creative design to innovate hardware solutions that enhance usability, engagement, and sustainability. My skills include designing interactive systems, developing novel sensing and display technologies, and rapid prototyping.

I have extensive experience in electronics design, PCB layout, and 3D mechanical design. My programming skills cover embedded firmware development in C, C++, and Python. My projects span various domains, including personal fabrication, 3D printing technologies and novel 3D printable sensing and actuation systems.

My research explores how 3D printing technology can be more effectively integrated into daily life, making it more accessible and beneficial. I have developed tools and experiences that push the boundaries of what is possible in the fields of robotics, human-computer interaction and computational fabrication

For further information and my publications, here is my personal website, dogaozbek.com

VI. Acknowledgements

In the Acceloprint project there will be collaboration between MIT C-SAIL media lab and Aarhus University. MIT C-SAIL media lab will help us on mathematical modeling and simulation part of the project.

VII. References

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