# Digital Fabrication Pipeline for On-Body Sensors: Design Goals and Challenges

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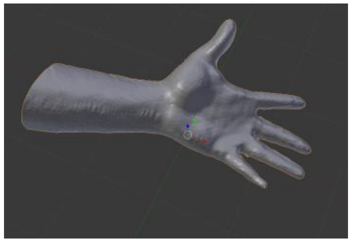
## Abstract
In this paper, we propose a digital fabrication pipeline for designing on-body sensors. We discuss the various steps in our envisioned pipeline and present the technical and research challenges that exist at each of the steps. The research and technical challenges span across various areas, including human computer interaction, computer graphics and computer vision. Our fabrication pipeline and the research challenges can inform the community about the various issues that one might encounter when realizing such a fabrication pipeline.

## Author Keywords
On-Body Interaction; Skin interfaces; Interactive skin; Wearable Computing

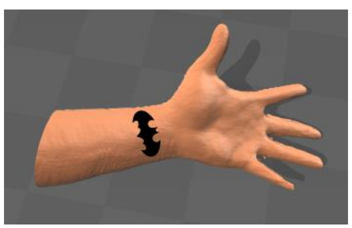
## ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

## Introduction
Recent advances in technology have enabled us to interact with mobile devices that are worn on the human body. Miniaturization of electronics and sensor form factors has redefined how we use our body to



a) User imports a hand model into a 3D modelling environment.

b) User annotates the area of the sensor on the hand.



c) The final rendering result which shows the sensor applied onto the geometry.

Figure 1 : Initial version of the digital Design Tool for Fabricating on-body sensors

interact with technology. Miniaturized on-body sensors enable users to perform a wide variety of interactions with wearable devices. For example, iSkin [8] enabled touch input directly on the skin. Skintillates [5] and TattIO [3] use temporary tattoos to create displays and NFC tags that can be worn directly on the body.

While these technologies open up a large design space for interactions, they raise a number of novel challenges which must be considered for the fabrication of on-body sensors. In this paper we discuss a unified fabrication pipeline for the design of personalized on-body sensors. We discuss the various steps in the pipeline and then address the various research and technical challenges that exist in each of these steps.

## Digital Fabrication Pipeline for Personalized Design

Digital design tools have been previously designed for various workflows in physical computing. Tactum [2] and Exoskin [1] proposed a skin-based approach for digital fabrication. They enable users to perform gestures directly on skin to design custom non-interactive 3D accessories that conform to the body. Foldio [6] contributed a design and fabrication approach that enabled designers to create interactive foldable objects. PaperPulse [7] contributed a design and fabrication approach that enables designers without a technical background to produce standalone interactive paper artifacts by augmenting them with electronics. Even though these tools and systems propose digital fabrication approaches, they do not specifically apply for the fabrication of on-body sensors. Liu et al. [4] proposed wearability factors for on-skin interaction. However, to the best of our knowledge there are no design systems, tools, or fabrication pipelines for wearables that abstract from the lower level sensor realization to a higher level interface design. We envision that a robust fabrication pipeline can enable the designers to focus on the design of highly personalized sensors, reducing the workload on lower level issues of sensor fabrication.

We propose a digital fabrication pipeline which enables users to design and fabricate on-body sensors that can conform to the user's body. Our fabrication pipeline has the following steps:

1) *Digital Model Acquisition*: Individual body geometry is acquired. 3D models of the body and body parts could be acquired from popular online 3d model repositories. However, for a more precise acquisition of individual body geometry, a 3D body scan or RGB-D camera based scan should be captured.
2) *Hybrid Design Environment*: We propose a hybrid design environment which enables designers to design on-body sensors. The hybrid design environment we envision enables the users to design physically on their body and also supports digital design through a 3D design environment. This enables the users to perform rough "on-body sketching" physically on the body and more detailed intricate designs could be performed on the 3D digital models. Such a unified hybrid design environment has the following advantages:
a. It offers flexibility to the designers between rapid prototyping on the body and more sophisticated prototyping on digital models.

b. It allows for aesthetic customization of various sensors and their locations on the body.

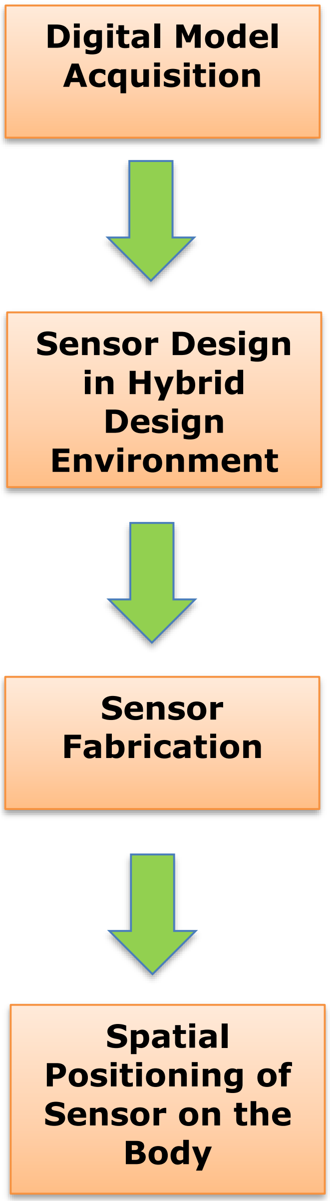



Figure 2: Four-step fabrication pipeline

c. Connections and wiring of on-body sensors is a challenging task. The digital tools could provide suggestions or intelligently route the connections of the sensors taking into account the geometric properties of the body.

An initial version of the tool which we envision is shown in Figure 1.

3) *Sensor Fabrication*: The sensors designed on the body in step 2 are fabricated. The design environment takes care of the various issues for fabricating, such as automated creation of masks for screen printing [9] etc.

4) *Application of Sensors on the Body:* The sensors fabricated in step 3 are applied on the body and can be used for interaction.

Having introduced the fabrication pipeline, we now discuss the various challenges that exist at each of these steps. These require a cross-disciplinary effort, demanding contributions from human computer interaction, computer graphics and computer vision.

*Robust and Accurate Geometry Acquisition*

Step 1 in our fabrication pipeline requires acquiring body geometry. Acquiring individual body geometry is a challenging task. 3D scanning and RGB-D camera based scanning can be few of the approaches. The scanning approaches can vary from a full-body 3D scan to scanning individual body parts.  Both approaches have their own benefits and problems. The full-body 3D scan can enable comprehensive geometry acquisition but might not be accessible to designers due to their cost and bulkiness. On the other hand, cheaper solutions such as RGB-D camera based tracking can be used for acquiring individual body parts, but they suffer from a quite low accuracy. Another simple approach is to acquire the models from online repositories, however these models do not represent the individual body characteristics and have varying resolutions which might not provide the best personalized design.

*Designing for Individual Body Characteristics*

Each user's body is unique. While the overall structure, such as the skeletal system, is similar, the proportions and the textural properties, such as skin elasticity, vary from person to person. Designing tools that can leverage these unique properties of the individual human body is an open challenge. Computational models for individual skin characteristics need to be developed which is an open research question in computer graphics. Apart from this, acquiring textural characteristics such as stretchable and non-stretchable areas in a body or body landmarks is another challenge which needs to be addressed. These challenges need to addressed for realizing the design environment envisioned in step 2.

*Precise Spatial Positioning of Sensors*

Typically, most of the previous on-body sensors such as iSkin, TattIO, Skintillates applied sensors on surfaces that are easy to access and which do not comprise fine landmarks. However, it is an open question how to support users in precisely positioning sensors on more challenging areas of the body We identify the following opportunities for precise spatial positioning of sensors:

1) Visual guidelines can be provided which guide the users to align the sensors on the specific body area. Augmented reality based tools can be designed which can provide real-time visual feedback on the positioning of the sensor.
2) Positioning the sensors in visually inaccessible areas (e.g. ears, spine, neck etc.) is another issue which needs to be addressed.

## Conclusion

In this workshop paper, we presented our vision of a unified fabrication approach for the design of personalized on-body sensors. We discussed the challenges that exist in each of the stages of the pipeline. We hope that these design factors and challenges inform the community in working towards these challenges, for creating more personalized experiences with on-body sensors.

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