A Modular Framework for Smart Garment Design

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Introduction: Designing and developing smart garments involves technical, functional, and aesthetic challenges that can create a burden for designers. According to Perry et al. (2017), many designers view "solving technical problems" as a major challenge and priority. Dunne (2010) also argues there is little motivation for companies to overcome technical obstacles when there is no "high-potential application", and companies with the resources to overcome obstacles are either apparel companies or tech companies, with little intersection in both. Furthermore, according to Perry (2017), few smart garment creators have "knowledge related to all fields of smart clothing". Currently, the education of wearable technology leans closer to electrical engineering and computer science. While literature exists on wearables in engineering, such as Lau et al. (2009), there is little literature on wearable technology education in fashion. This reflects the tech-heavy reality of smart garment education and the lack of design education. A modular system for smart garment design could mitigate technical challenges and allow designers to focus on aesthetic and function. This research developed a modular framework for smart garment design. This process began with the identification of technical burdens and perceived challenges. Then, these burdens and challenges were addressed through the proposal of a modular framework. Finally, the extent to which these burdens and challenges were mitigated was assessed with a prototype modular toolkit.

Method: The first action item was to understand smart garment designers and their perceived challenges. This data was collected through focus group interviews. Nine design and engineering students were interviewed for their perceptions and experiences with the smart garment design process. These interviews were used to establish priorities for the modular framework to address. Some priorities included the development of a central module-peripheral module structure, the creation of an integrable component attachment system, and the establishment of an electrical connection procedure. An IRB reviewed and approved the focus groups.

The modular framework consisted of a centralized computing module and various use-case specific peripheral modules. The central module incorporated all powered components while peripheral modules incorporated passive components. Off-the-shelf components were selected and modified to fulfill the modules. To facilitate integration with existing garment construction practices, sew-on substrates were used for component attachment. A component substrate consisted of a sheet of flexible plastic backing with cutouts for sewing, and an electrical component secured using epoxy. Here, small holes and thin long cutouts allowed bar tacks or zigzag stiches to secure a substrate to fabric. Then, the secured components needed to be connected. This framework divided the intra-garment connection system into the endpoint, exit, midpoint, enclosure, and wire. Here, wires that facilitated electrical signals were covered by enclosures. Midpoints connected wires together. Exits allowed for the transfer of wires from the inside to the outside of the garment. Finally, the endpoint interfaced the in-garment electronics with the central computation module. Various heat-shrink connectors were surveyed for connection midpoints. A standardized magnetic pogo-pin substrate was created for connection endpoints. Next, various wires, including conductive thread and electrical wires were assessed for their thermal and electrical characteristics. Finally, the effect of connections on fabric rigidity was assessed using a standard method (ASTM, 2018).

A prototype toolkit was developed to demonstrate the framework's modular components and evaluated. The central computation module was manufactured and encased in a 3D-printed enclosure. Various analog and digital components related to motion sensing and microclimate monitoring were prepared with substrates. Toolkits with connectors were also assembled. Then, 14 students were recruited to participate in rapid prototyping workshops. Half reported as being in a design program and half reported as being in an engineering program. From these 14 participants, 7 teams were formed, and 7 two-hour workshops were conducted. Following each workshop, each team was interviewed. The exit interview began with a rating and comparison activity where participants rated the toolkit's ease and function with modular connectors, component placement, and wire connections. Then, teams were asked about their overall experience and feedback. An IRB reviewed and approved the workshops.

Results: From focus groups, the primary concern among participants were the technical content and challenges involved. Technical issues accounted for 40 quotations, the highest amount among smart garment design topics. Among these technical issues, participants reported apprehension about combining electrical components and textile materials, selecting appropriate electrical components, creating electrical connections, and ensuring durability. Participants expressed difficulty interfacing hard electrical components with soft textile materials, with 23 quotes. Participants also indicated that they had trouble identifying necessary and usable electrical components. Furthermore, participants expressed interest in using modules in smart garment design, which accounted for 21 quotes. Participants also experienced difficulties with electrical connections in the garment. Finally, participants all recognized the importance of having a balanced design process informed by both design and engineering.

Through workshops, 7 teams evaluated the prototype toolkit that addressed the above concerns. Figure 1 pictures the workshop process, and in-progress smart garments. During the workshop, the most common process-related issues teams encountered included order of operation (13), preparations (7), and communication (5). Analysis of participants' ratings showed statistically significant improvements in function across all rated criteria, including electrical connections ($\Delta = 4.78$, $p = 0.0001$), secure component placement ($\Delta = 3.75$, $p = 0.0006$), and wire connections ($\Delta = 3.59$, $p = 0.0009$). Analysis also showed statistically significant difference in ease of wire connection ($\Delta = 2.69$, $p = 0.0006$). Teams identified top benefits of sew-ability (6), simplified electrical connections (6), and added flexibility (3).

Figure 1: Workshop Process and Outcomes

Discussion and Conclusion: With the increasing prevalence of smart garments, it is more important than ever to empower designers with the necessary tools. This modular framework presented a novel approach that alleviated many technical challenges. Further study could evaluate and improve durability. Since washability was a top concern, this framework considered water resistance at the element level: the central module was completely wireless and could be sealed. Electrical connections with the heat shrink connector also had some water resistance. However, considerations such as sew-ability took priority. Further study could also assess the modular framework's application in longer-term and academic settings, such as in a class.

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