Design and implementation of an electronic textile jumpsuit

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Abstract

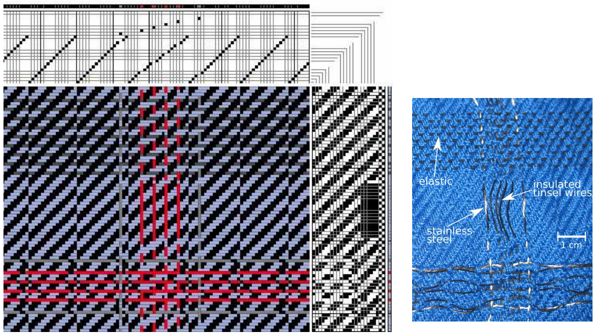
This paper provides a case study of the construction of an electronic textile jumpsuit with an on-fabric digital network of sensors, including details of the weave, garment construction, and network bandwidth.

1. Introduction

This paper presents a case study of a prototype e-textile jumpsuit for motion capture and context-awareness, focusing on the interaction of weave design, seam construction, and on-fabric networking. The prototype described in this paper is intended to allow us to explore sensor types, numbers, and locations, as well as implementation techniques. Thus aspects of the jumpsuit are not as they would be in the deployed version, but even this prototype illustrates several novel approaches to constructing an e-textile garment. First, we have designed a custom fabric weave that accounts for the garment's textile requirements and the hardware requirements of attaching sensors. Second, the fabric was woven on a fully automatic, commercial loom. Third, in assembling the fabric pieces of the garment, we have devised a way of making electrical connections in seams that could be a basis for a commercial process. Fourth, the garment provides a proof-of-concept of a two-tier hardware architecture with an on-fabric digital network that allows us to quickly add new sensors and reprogram the garment for a new application.

2. Fabric Design and Garment Construction

A major design issue is that the jumpsuit should fit and feel like everyday garments, i.e., relatively loose-fitting, flexible, and durable. Aesthetically, this will likely lead to a higher adoption rate, and such garments are easier to don than form-fitting garments. The target applications require sensors ("e-tags" [1]) to be located at many points on the wearer's body, implying that a power/communication bus must be available throughout the garment. E-tags should be fixed relative to the wearer's body, which competes with being loose-fitting. Finally, the fabric design should allow for construction on commercial textile equipment.



(a) (b)

Figure 1. (a) Weave design for jumpsuit fabric, including the chain and harness drafts. Tinsel wires are shown in red, stainless steel in light gray, elastic in dark gray, and cotton yarns in blue. (b) A photograph of the fabric, showing roughly the same portion of the pattern as (a).

We designed a denim-like fabric of mainly cotton fibers to meet these goals. Other yarns in the fabric include elastic (to reduce the movement of the e-tags), insulated tinsel wire (power and communication bus), and uninsulated stainless steel (to sense pressure). The fabric was woven on a 24-harness AVL Industrial Dobby Loom, which is computer-controlled by a weave design specified using commercial software. The weave (Figure 1a) has the repeat pattern split into three sections, each with its own set of harnesses: the selvage, the wires, and the base fabric. This division allows the power/communication bus to be woven in a different pattern than the selvage and base. The design has a four-wire power/communication bus repeated every four inches in both directions, which provides the bus at suitable locations for a range of typical garment sizes. At regular intervals, the bus is "floated" above the fabric to allow for e-tag attachment. Each bus wire has its own harness, allowing an identical pattern of wires to be repeated in the warp and weft directions and providing flexibility in float positions. The separate patterns are used to reduce interlacings of the wires with the base fabric, reducing stress on the wires. The resulting fabric (Figure 1b) is a 36 EPI, 24 PPI broken twill.

The garment is based on a generic, commercial pattern. The spacing of the busses and floats in the weave allows for the pieces to be cut such that sensors can be placed consistently on a range of people. The location of the pattern on the fabric is selected so that the weave is "matched" across sections of the assembled garment. When the pieces are sewn together, the pieces must also be electrically connected at the busses. The matching of the cut pieces simplifies making these connections. Figure 2 shows the

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This material is based upon work supported by the National Science Foundation under Grant No. CNS-0447741 and CNS-0454195.

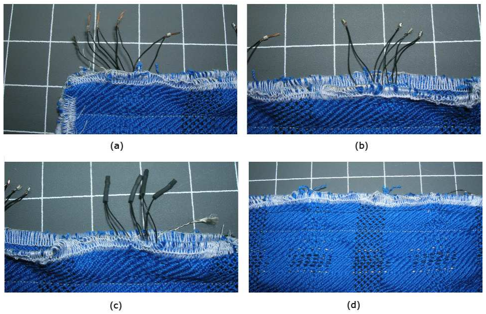

Figure 2. Steps in connecting networks between fabric pieces: (a) Stripped wires from each side of the seam connected are using jewelry crimp beads, (b) soldered, (c) insulated, and (d) tucked into the seam and the seam is sewn closed. The grid shown is 1 inch per square.

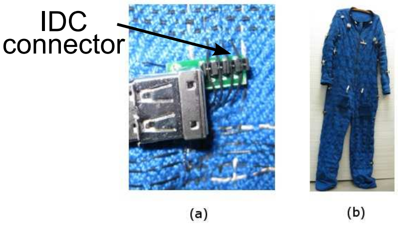

Figure 3. (a) Closeup of the IDC connector on the jumpsuit. (b) The jumpsuit prototype.

process for connecting wires in the seams using metallic jewelry crimp beads. This process provides durable, unobstrusive connections in a way that can be performed on a commercial scale. The two steps of the process that should be modified for commercial garment-making are soldering and insulating with shrink tubing. We soldered because the diameter of commercially available beads is not correct for our wire. However, a bead of the proper diameter with exterior insulation would eliminate both steps.

After the seams are formed, an e-tag is attached to the bus using an insulation displacement connector (IDC) which is inserted beneath a float in the bus and crimped onto the wires (Figure 3a). Because this is a prototype, sensors must be easily and repeatedly attached, removed, and re-located, so we use a USB style connector (Figure 3a) so that an e-tag can be removed while leaving the IDC in place. The USB connectors would not be in a final version. Figure 3b shows the prototype with eleven sensors in place (two on each arm and leg, two on the hips, one on the torso).

3. On-Garment Network

This section describes the on-fabric digital network, a two-tier hardware architecture [2]. Tier 1 consists of sensors with microcontrollers to convert sensor data to digital form and connect to the on-fabric network. Tier 2 consists of more capable processors that control the Tier 1 nodes and execute applications. This architecture forms a flexible, scalable computing/communications structure that can be used for a wide range of sensor numbers/locations/types and application processing requirements without modifying the architecture. Compared to a single processor tied to all of a garment's sensors, our architecture has the benefits of lower noise for sensor data and easier addition of new sensors because they can connect to the existing network without requiring new I/O channels. The current version of the jumpsuit has eleven Tier 1 nodes and one Tier 2 node, but it is constructed to allow for a range of node numbers and placements. The Tier 1 nodes have a 3-D accelerometer, a 1-D gyroscope, and an Atmega8L microcontroller. The single Tier 2 module, a Gumstix Verdex 400xm-bt, allows for autonomous operation. While an e-textile-specific network is likely to be the best choice for the large-scale production, we use the I^2C network standard as an interim solution. The garment could have multiple I^2C busses that communicate with one another while remaining electrically isolated.

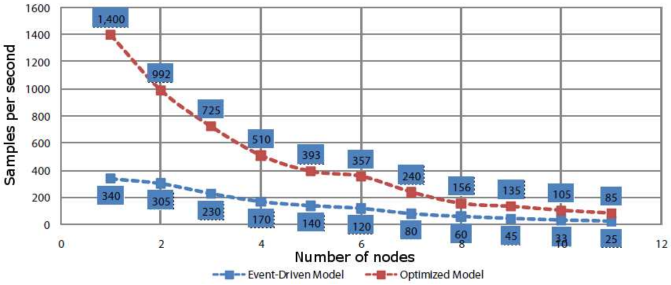

Figure 4. Experimental global sample rates (per second) as a function of the number of Tier-1 sensor nodes.

To investigate the capability of this architecture in a realistic scenario, we measured the performance of an activity recognition application as a function of the number of Tier 1 nodes operating on a single jumpsuit I^2C bus. We built two versions of the Tier 1 node software: (a) a general-purpose, event-driven system, similar to [3], and (b) software optimized for the specific application. Figure 4 shows the performance of these two implementations as a function of the number of Tier 1 nodes. The rates in Figure 4 are the data packets that are sent to the Tier 2 node. The system can provide sample rates that support most applications that sense phenomena related to human motion, and the bandwidth of the system can be expanded by internetworking multiple I^2C busses on the garment.

References

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