Smart fabrics that think, sense, and act.

A scalable, modular approach to in-place printed strain sensors

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Date of submission: September 3, 2025

1. Review: Gutachter 1
2. Review: Gutachter 2
Darmstadt

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Contents

1. Introduction

Smart everything is on the rise. Increasingly, approaches to smart fabrics are being explored, offering new possibilities for materials that provide more functionality than their predecessors, such as actuation on a miniaturized scale, adjustable properties, or new sensing capabilities. Many approaches focus on deploying new sensors embedded directly into the fabric to enable measurements over the entire area of the fabric[15]. Distributed sensing is vital in the medical field, sports, robotics, and even our daily lives, for example, to support sign language translation[31]. Pulse, muscular activity, joint articulation, and pressure/touch sensing are just a few of the sensed properties that have been explored. We aim to provide an easily reproducible, adaptable, scalable, and modular approach to the distributed sensing of a fabric's articulation, specifically the degree to which it is stretched and bent in certain areas. If the articulation of a fabric is known, that offers many use cases: Very adaptable measuring of joint articulation of a broad range of robotic joints, measuring deformation of whole planes as in crash tests or medical chairs[26], connecting multiple moving robots and enabling them to know their relation to each other by connecting them with such a fabric.

This work will examine the existing literature and propose a novel approach to developing modular, scalable smart fabrics. This new approach focuses on the reading of sensor outputs throughout the fabric and passing them to a reader in a way that is more scalable than all currently available alternatives. To demonstrate the functionality of this approach, a small smart fabric is produced. In this context, a basic strain sensor is designed to measure its strain and bending angle. Additionally, a compute node prototype is developed and built to measure the fabric and communicate the results.

2. Related Work

Smart fabrics as a broad field

Hassabo et al.[8] provide a comprehensive overview of the extensive field of research in smart fabrics. Smart fabrics can be an umbrella term for various approaches to creating smart functionality on any type of fabric. The ”Fabric” in smart fabrics does not necessarily need to be a textile, but can be any composite material consisting of smart components. Additionally, ”Smart” lacks a concrete definition. It may involve computation, sensing, actuation, modification of the fabric’s responses or behavior, or passively provided features beyond the norm.

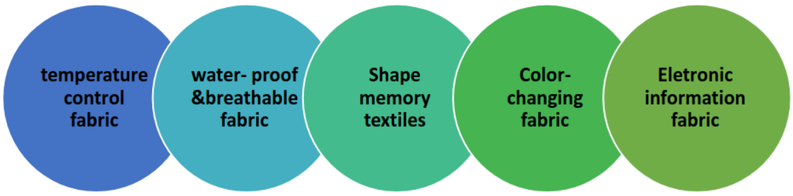
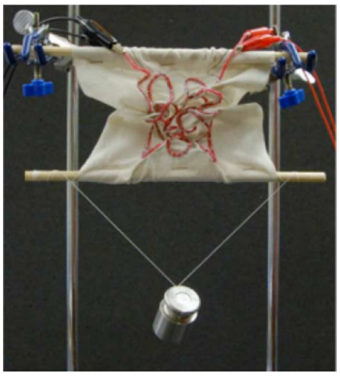


Figure 2.1.: Applications of SMART fabrics, from Hassabo et al[7]

Examples of these different smart features might include materials with varying stiffness, as demonstrated by Yuen et al.[32], or shape memory materials, as developed by Huan et al.[12]. Passive features might be better temperature regulation[13, 10] or water evaporation[5, 14], for example.

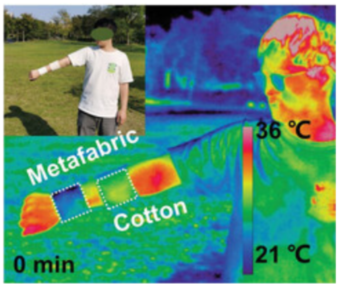
Sensing smart fabrics

Many approaches to smart fabrics, classified as passive smart fabrics, focus on sensing the environment of the fabric in a new way and making these measurements accessible to

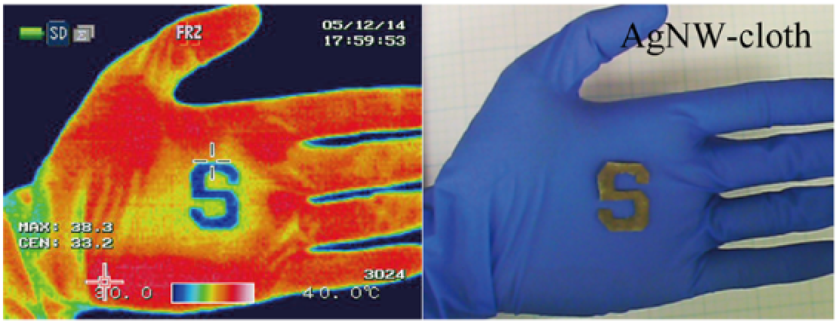


(a) Fabric with variable stiffness by Yuen et al[32]

(b) Shape memory fabric by Yuen et al[12]



(c) Fabric with improved vater evaporation by Fan et al[5]



(d) Fabric with better heat dissipation than skin by Hsu et al[10]

Figure 2.2.: Four smart fabric domain examples: a) varying stiffness; b) shape memory; c) temperature control; d) water evaporation

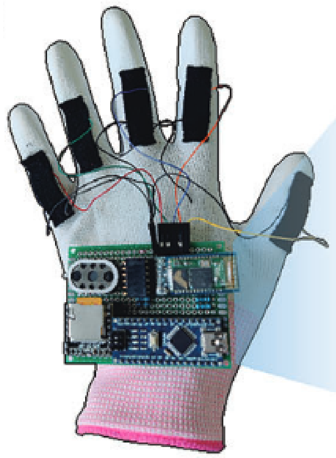
the user or further components. For this, various new technologies are being explored to enable smart fabrics to measure the desired properties. In this field, a significant concern are strain sensors, as they are crucial for measuring the activity of the human body[9]. While flexible strain sensors are already commercially available, stretchable strain sensors represent a new level of wearability, as most fabrics and wearables are stretchable themselves. Trung et al.[29] built a very easily attachable, intrinsically stretchable, and transparent strain sensor from multiple layers of different polymers to measure strain and temperature. Souri et al.[25] provide an overview of additional wearable strain sensing technologies, including some utilizing carbon nanotubes, nanofibers, conductive polymers, and strain sensors in the form of optical fibers, among others.

This work focuses on the development of a highly scalable, modular robotic fabric incorporating flexible strain sensors. While most papers in this domain focus on creating a single sensor to be integrated into its area of operation, this work presents an adaptable and easily reproducible strain sensor, along with an approach to a scalable network comprising multiple sensors. Scalable sensor networks are crucial for smart fabric applications, as sensors in smart fabrics, in theory, often offer a high sensor density that needs to be supported by a network to read and process all these measurements. There is literature about easily scalable network topologies to be used for such a network to optimize area coverage while using as few nodes as possible and keeping network integrity at a high level[3, 28].

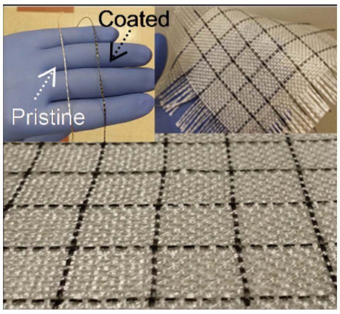
Similar work

Wu et al.[31] construct a stretchable strain sensor from a laser-cut and partially electroplated carbon fiber reinforced polymer. With these sensors, they build a smart fabric consisting of 5 sensors and a compute node in the form of a glove, shown in Fig.2.3a. The compute node reads all the strain sensors, interprets the values of the finger sensors, translates them into words, emits the translation through text-to-speech (TTS) synthesis, and transmits the translation wirelessly over Bluetooth to another computer for human confirmation. Their work involves the reading of multiple sensors by a compute node located on the fabric, transmitting results to a computer for further processing. However, it lacks intra-fabric networking and scalability, though scalability beyond 2 gloves would most likely not be necessary.

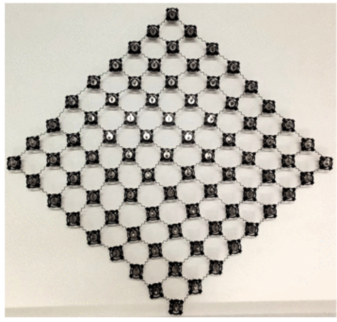
Luo et al.[15] developed an easily scalable and highly adaptable sensor array using fiberglass roving coated with multi-walled carbon nanotubes, which was further processed. The resulting fiber can be woven into fabrics and acts as a single sensor. This makes



(a) A glove equipped with five strain sensors for sign language translation, by Wu et al[31]



(b) CNT based woven strain sensor to sense strain in a 2D grid, by Luo et al[15]



(c) A smart fabric consisting of small robots, connected by springs, by Obilikpa et al[19]

it very easy to weave multiple fibers vertically and horizontally into a fabric with easily adaptable sensing precision by adjusting the relation of sensing and regular fibers. The end result is a fabric that can sense strain in a 2D grid. Luo et al. focus on the sensor array aspect in this work, but do not present a scalable approach to reading these sensors in a way that is as scalable as the fibers themselves are.

Obilikpa et al.[19] proposed a robotic fabric consisting of multiple battery-powered robots, connected by rigid or flexible links. They estimate their position in relation to their neighbors by broadcasting infrared (IR) messages. The robots can move individually, but their movement is inaccurate. Utilizing Motion Control Algorithms (MCA)[20], the movement error for each robot can be overcome in the fabric, and the fabric can move coherently. This concept lacks the information about the articulation of the complete fabric in any single location. This is mostly overcome by the chosen MCAs. The communication over IR is dependent on the surface the robots are walking on and can be manipulated by a change in the reflectiveness of the surface the fabric is moving over.

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