

Smart Carpet: A Textile-based Large-area Sensor Network

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Abstract. Textiles are omnipresent in our daily life. Their combination with microelectronics will lead to completely new applications realizing elements of ambient intelligence. In this paper, a textile-based large-area sensor network integrated into a carpet is presented: Based on a network of simple information processing elements with integrated sensors or actuators, a self-organizing and fault-tolerant architecture is realized which detects the physical shape of the smart carpet. Routing paths are formed for data transmission, automatically circumventing defective or missing regions. Our concept allows the smart textiles to be produced in reel-to-reel processes, cut in arbitrary shapes, and implemented in systems at low installation costs. The possible applications are manifold, from alarm plants to intelligent guidance systems, occupant recognition in car seats, airconditioning control in interior lining or smart wallpaper with software-defined light switches.

1 Introduction

Many promising technologies are emerging in the area of intelligent textile materials like electrically conductive yarns or pressure sensitive fabrics [1,5]. State of the art feature sizes of integrated circuits allow for powerful and yet small and cost-efficient microelectronic devices. Many interesting applications in the field of technical textiles arise by merging micro-systems and textile fabric structures[3]: pressure sensors in floor coverings for alarm systems or motion detection (person tracking), indicator lamps in floor or wall coverings for guidance systems in public buildings, distributed

sensor networks for detection of defects in textile concrete constructions, and many more.

However, how can we exploit the functionality of all the integrated microprocessors, sensors and light emitting diodes? What happens, if the smart fabric is cut to fit as e.g. a functional floor covering of an arbitrarily shaped room? Moreover, will a single destroyed or defective module or wire lead to a complete failure of the function of the smart textile system? To cope with this problems, we invented ADNOS (algorithmic device network organization system) a self-organizing technique based on simple algorithms [2] processed by small microprocessors integrated in a regular grid and connected to conductive fibers within a smart textile.

2 Smart carpet concept

Figure 1 shows a schematic of the Smart Carpet application. Identical modules are connected to each of their four neighbors by interwoven conductive filaments used as data lines or power supply. Several defects may occur within such a wired peer-to-peer network during fabrication or operation: cuts may lead to open lines, modules may be destroyed or missing and most important, a short circuit of several lines may occur. For a high yield in a reel-to-reel production and robust functionality we require fault-tolerance to all those defects. In addition, the demand for low-cost installation requires that the smart textile can be cut into irregular shape to fit into any given room.

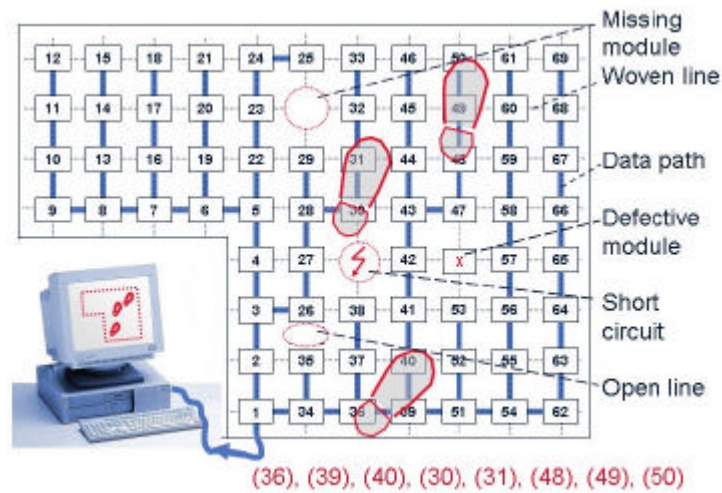


Figure 1 Schematic of the wired network within the Smart Carpet, showing the automatically numbered modules and routed data paths; the indicated possible defects can be handled by ADNOS; sensor data are sent to the PC via the portal

3 Textile integration of microelectronics

The smart textile (Fig. 2) is based on a polyester fabric with interwoven silver-coated copper wires with a line resistance of 0.40/m. The pitch of the woven pattern is 20cm in weft and warp directions, respectively. To achieve a larger sensitive area for the touch sensor, we embroider a meander-shaped wire.

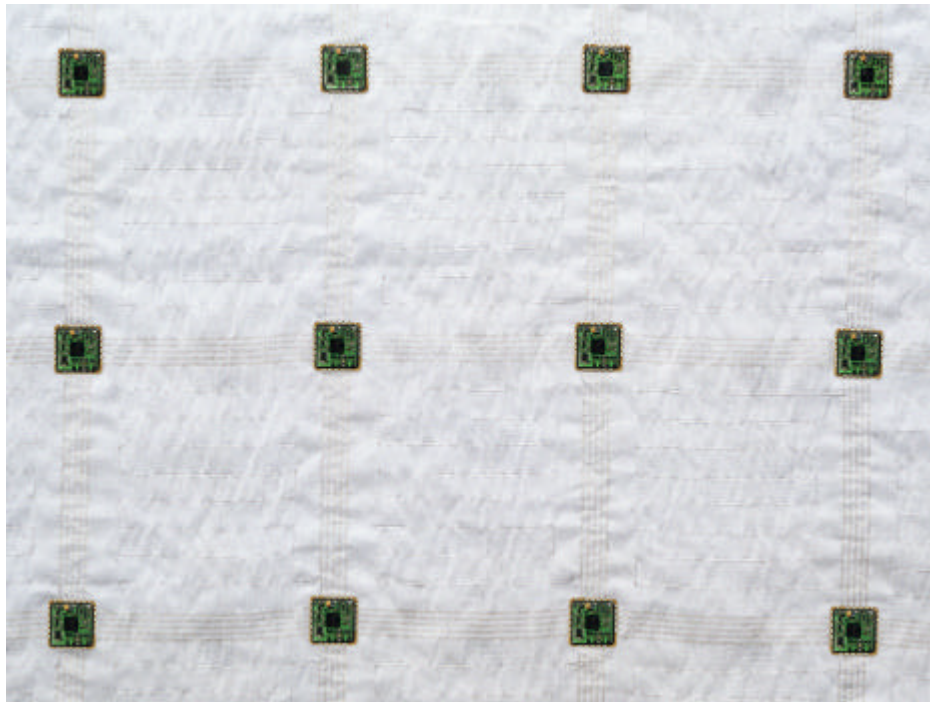


Figure 2 Microprocessor modules integrated into a fabric with interwoven silver-plated copper wires. The embroidered meander-shaped wires form the sensitive area for the capacitive sensor

The modules are connected to the crossover points of the conductive lines in a single step using anisotropic-conductive adhesive. At the crossover areas the conductive weft and warp fibers are cut to allow for the placement of the electronic modules (Figure 3a). Figure 3b shows a micrograph of the contact area on the backside of the module. To reduce mechanical stress of the devices on the PCB, the modules are encapsulated before mounting. The achieved contact resistance is below 50mO/contact. Power switches are implemented, each of which is able to switch the current for the whole network. Their resistance is below 150mO.

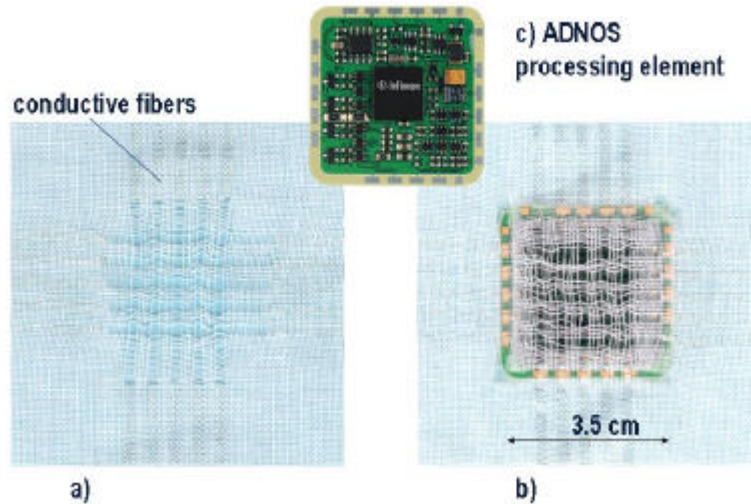


Fig. 3 Interconnection of the processor module and interwoven copper wires: a) Removal of the conductive fibers at the crossover areas by cutting b) Backside contacts of the module after the bonding process c) ADNOS module

4 ADNOS peer-to-peer network

Each ADNOS module (Fig. 3c) is equipped with four UARTs (Universal Asynchronous Receiver and Transceiver) as ports to the connected neighbors and the input of the capacitive touch sensor. The power supply of the textile is 12V, being reduced to 3.3V by a switched power supply for decreasing the distribution losses. For the demonstrator we used a standard 16bit microcontroller. The application demands 16KB Flash and 4kB RAM. The modules are active only during data transfer. Their power consumption is approximately 10mA/module in active and 6mA/module in standby mode. The current consumption can be reduced further, using an optimized sleep mode.

Each module within the network exchanges control messages or data with its four nearest neighbors, and controls and drives a specific region. No prior knowledge about their position within the grid is used. Control data from the PC are fed into the network through a portal, which is connected to an arbitrary module.

Before operation, a set-up phase is initiated: Power switches are activated to route power to the entire network. Then short circuits within the network are detected and defective branches eliminated. Next, each module computes its position in the network using information received from neighbors and determines its distance from the portal. Then, data paths are determined (Fig. 1). The portal then numbers the modules based on established data routes. This assigns a unique address number to each module. Except for the numbers of its direct neighbors, no additional routing tables are needed

inside the network. If new defects are detected, the self-organizing routine is repeated and new routing paths are established.

The ADNOS algorithm is embedded in one of three layers of software abstraction. It establishes a peer-to-peer communication scheme, which is used to transfer data between the modules and between the network and the Smart Carpet monitor application on the portal PC, respectively. The four ports of each module have different priorities. When reception on two ports occurs simultaneously, the port with highest priority will receive data first. To avoid an unbalanced response of the network, the priority of ports is rotated at regular intervals. Below the ADNOS layer the protocol layer is responsible for communication between neighboring modules. In case of data collision, reception and transmission is performed in full duplex mode. The board layer takes care of hardware control and physical connection between neighboring modules.

The sensor data from the network is transmitted to the Smart Carpet monitor application. We use an RS232 interface at a data rate of 115200bps. The customized features are defined within the monitor application, e.g. processing and evaluation of sensed data or control of light-emitting diodes.

We have performed extensive measurements on various network configurations. The results are described in [4]. For illustrating the functionality of the ADNOS system a small network is connected to the PC. Figure 4 shows screen shots of the ADNOS user interface on the PC featuring the twelve modules. The dark blue squares are the modules, thin light blue lines are recognized connections not used as data paths. The wide lines are established data paths (Fig. 4a). In Figure 4b one module in the middle of the network has been removed. ADNOS has recognized the failure (marked red) and shows, that all modules connected to the same data paths are not longer contributing to the functionality of the network (the color changed to light blue). After initializing the reorganization a new data path is found surrounding the missing module. All remaining modules are functional again.

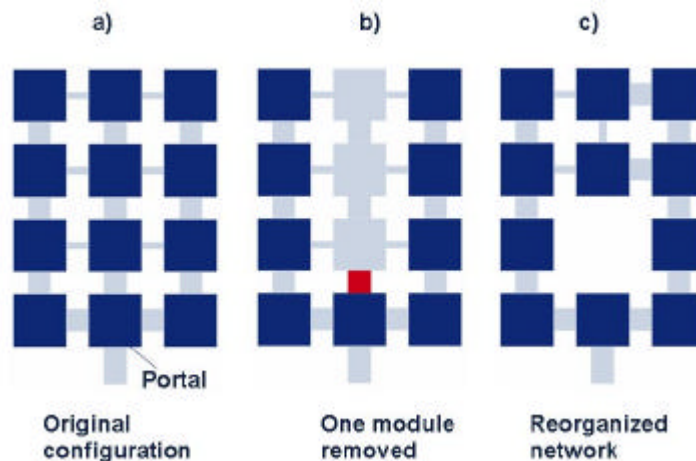


Figure 4 shows three screen shots of the ADNOS user interface on the PC featuring twelve modules (blue squares): a) original network, b) one module in the middle of the network removed, failure (marked red) recognized by ADNOS, light blue modules connected to the same

data paths are non-functional, c) After reorganization a new data path is found surrounding the missing module, remaining modules are functional again.

5 Smart carpet prototype

Using the technology described above a smart carpet prototype was fabricated with 120 integrated microprocessor modules. The smart textile was cold-laminated between to layers of textile to reduce the mechanical stress and equalize the height of the modules (2 mm). The top layer is a tufted carpet combined with a 1000 gram fleece as back-side. All modules and sensors are fully functional. The size of the carpet is 240 cm x 200 cm. The power consumption of this network is 8.4 Watts. After initiating the self-organization the PC user interface shows all 120 modules (Figure 5). If sensors are activated red dots appear on the screen indicating their location. Figure 5 shows the sensor signals a person generated while moving across the smart carpet from lower left to the upper right corner.

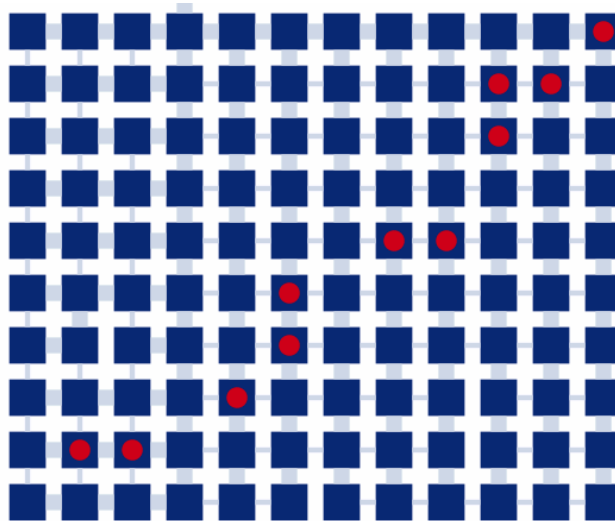


Figure 5 Sensor signals on the PC user interface generated by a person moving from the lower left to the upper right corner. The smart carpet area is 240 cm x 200 cm.

6 Smart carpet applications

The PC application software can be adapted to the specific functions the smart textile should support. The customized features are defined within this application, e.g. how the sensed data are processed and evaluated, or how light-emitting diodes are con-

trolled. A wide range of new applications is opened by the smart textiles that feature the self-organizing and fault-tolerant integration technique.

Convincing examples for applications are smart carpets working as alarm systems, air conditioning control or intelligent guidance systems.

Using data mining on the sensed data, different function can be triggered: The light will be switched on automatically if a person enters the room. Foot steps beginning at the window will trigger a burglar alarm. If a person falls down on the carpet and doesn't move afterwards an emergency call will be activated. Figure 6a shows the sensor signals derived from the smart carpet with a person, lying on the floor as depicted in Fig. 6b. Or, if the person didn't leave the bed for a certain time, a nurse is called to look for her. Such a functionality would give elderly or handicapped persons a chance to live a self-determined life, without feeling abandoned.



Figure 6 Sensor signals (left) derived from a person that lies on the smart carpet prototype like depicted in the right picture

In future, the functionality of the ADNOS module can be integrated in a single silicon chip with an estimated chip size of approximately 7mm^2 using a 180 nm CMOS process. The range of suitable and available sensors and actuators is wide spread: sensors are available for various parameters such as pressure, temperature, humidity, smoke, gas, and sound. The applications for the ADNOS network are nearly as manifold as the applications for textiles itself, spreading from alarm systems for truck tarps, occupant recognition in car seats, temperature and humidity control in interior lining, to smart wallpaper with software-defined light switches.

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