Fully Integrated EKG Shirt based on Embroidered Electrical Interconnections with Conductive Yarn and Miniaturized Flexible Electronics

Torsten Linz, Christine Kallmayer, Rolf Aschenbrenner, Herbert Reichl
Fraunhofer IZM
Gustav-Meyer-Allee 25
13355 Berlin, Germany
Email: Torsten.Linz@izm.fhg.de

Abstract

A T-shirt has been developed that measures an EKG signal. This work is different to other research in the field as it focuses more on advanced interconnection and integration technologies for electronics in textiles rather than on the EKG shirt as functionality. It is the first application using an interconnection technology based on embroidery of conductive yarn that has been developed recently and published in [3].

1. Introduction

Until now, most wearable computers in the sense of real clothes exist only in laboratories. Great market success has been announced since many years. The reason for this slow start of wearable computing is the lack of real wearability of most prototypes. Yet this is essential for a broad market success. Therefore, Fraunhofer IZM has developed miniaturization and low cost integration technologies that allow textile typical treatment like draping and washing.

In earlier papers, the Fraunhofer IZM has shown different approaches to such technologies. The integration into woven structures has been presented in [1]. Temporary contacts and embroidered circuitry with conductive yarn have been introduced in [2]. Building embroidered electrical interconnection with a simple embroidery machine has been presented in [3]. Unlike earlier research [4] that concentrated on the creation of conductive embroidered circuits, this work focused on the interconnection process (click figure 1).

The usefulness of textile-integrated electronics stands out in applications where a distributed sensing, computing or energy sourcing is an indispensable part of the system. A sensing T-shirt is such an application that cannot be realized with a small device like a mobile phone. Information like EKG/EMG signals, pulse oximetry (SpO_2), body posture and temperature can only be picked up locally on different parts of the body.

The high demands on comfort in a T-shirt and the need for reliable and precise measurements, pose a challenge for the miniaturization and integration.

This paper describes the prototype development of a sensing T-shirt that measures an EKG signal and may later be enhanced by other sensors like acceleration, SpO_2, EMG, etc. The work has been shared among Fraunhofer IIS who designed the circuit and Fraunhofer IZM who layouted, miniaturized and integrated the circuit into a T-shirt using flexible substrate, flip chip technology and embroidery.

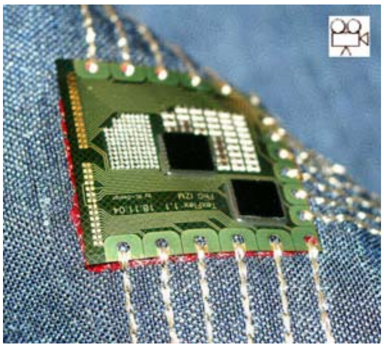

Figure 1: flexible electronic test module connected with embroidered conductive yarn [3].

2. The EKG Shirt

The EKG shirt consists of the EKG module on flexible substrate, its encapsulation, a rechargeable flat battery, three EKG body contact electrodes and embroidered "wiring" and interconnections.

Published at *IEEE BSN Internat. WS on Wearable & Implantable Body Sensor Networks*, Cambridge, MA, April 2006.

2.1 The EKG Module

The EKG module's analogue part consists of a differential signal amplifier followed by an analog second order Butterworth low pass filters ($f_g=125Hz$). It amplifies the signal between the right shoulder and the lower left rib using the left shoulder as a reference. The AD converter is tunable to overcome signal variations, which occur naturally on the body in the order of seconds duration. The flip chip microcontroller processes the data and sends it to the BlueTooth module, which transmits the data to a mobile phone or PDA. Data can be sent in continuous mode for real-time data or burst mode to save energy.

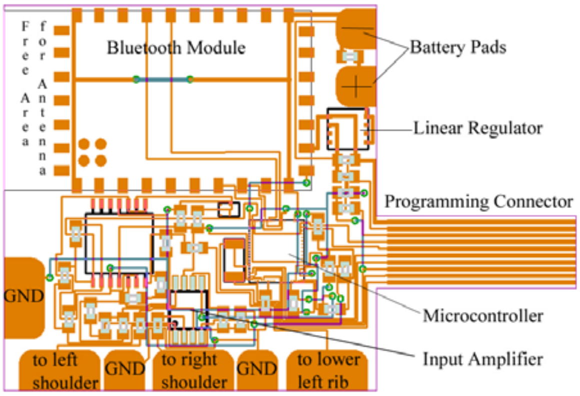

Figure 2: the largest and most energy consuming part of the EKG module is the BlueTooth unit.

All components have been chosen in the smallest available size and assembled on a 50µm thin flexible polyimide substrate. The dimensions of the module are 27x27mm (not counting the connector, which can be cut off after programming). The thickness of 2.1mm is due to the BlueTooth module, which could not be redesigned with reasonable amount of effort for this research.

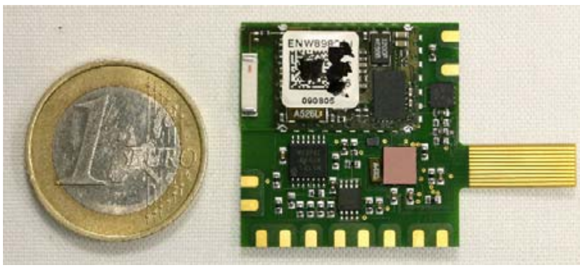

Figure 3: 27x27mm EKG module on flex substrate.

For the integration into the shirt, the EKG module has been equipped with metallized contact areas. The embroidery machine penetrates them with the needle and makes an electrical contact with a conductive thread. This process is described in detail in [3].

A 2.5mm thin battery with 550mAh and 3.7V allows a burst mode operation over 24h. The battery is attached with snap fasteners for easy replacement and recharging and easy removal before the T-shirt is washed (for details on snap fasteners see [2]).

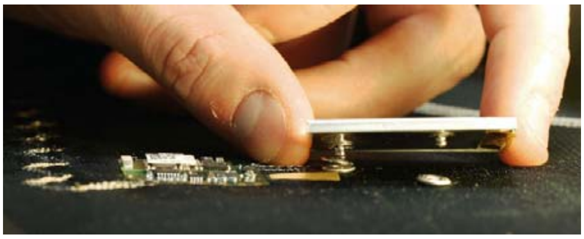

Figure 4: the flat battery can be removed for washing and charging.

2.2 Integration on the T-Shirt

A commercially available tight fitting stretch T-shirt serves as a basis for the electronics and the embroidery. The tight fit is important for the reduction of movement artifacts and good signal quality [6].

Figure 5: the shirt with electronics, snap fasteners for the battery and embroidered electrodes and conductors.

Both the conductors as well as the electrodes were embroidered with conductive yarn produced by *Shieldex*. The so-called *Statex 117/17 twine* is a silver-coated polyamide multifilament yarn. Its resistance of around 500Ohm/m is very high. Nonetheless, this is acceptable for the sensing of the EKG signal, as there is very low current anyway. For the energy transport between battery and EKG module, it was critical to keep the distance short and to embroider the distance multiple times. The choice fell on *Statex* material because it is conductive and embroiderable. (For details concerning the thread see [2, 3].)

The layout was embroidered with a semi-professional embroidery machine – Bernina artista 200 – which can be programmed with special CAD software.

With embroidery on a stretch T-shirt, it is important to ensure that the thread is not under mechanical tension when the shirt is worn. Therefore, it was necessary to stretch the T-shirt during the embroidery and during the encapsulation. A further improvement in this sense can be achieved by a zigzag layout of the long conductors to the EKG electrodes (as shown in figure 6).

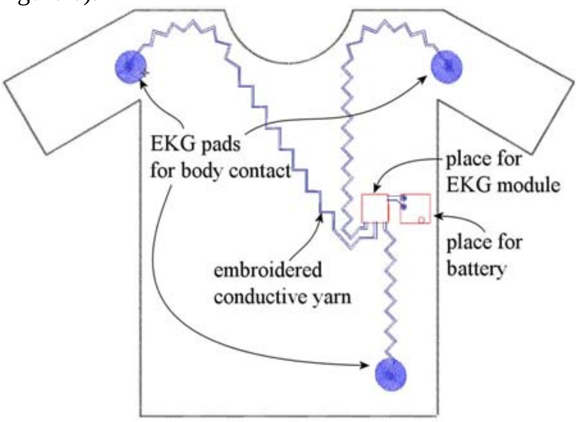

Figure 6: zigzag-embroidered conductors for maximum stretchability.

Embroidery, which is essentially similar to sewing, relies on two threads: a needle thread, in our case on the outside of the shirt and a conductive bobbin thread, in our case on the inside (body side). For this application, both these treads were chosen to be conductive which reduced the resistance. All the conductors were embroidered six times, i.e. the substrate was penetrated three times at each contact pad, as this proved to be most conductive and most reliable in earlier tests [3]. Furthermore, the conductors to the EKG electrodes were designed with double redundancy (see figures 7 and 8). Ultimately, each path between an electrode and the EKG module shows a resistance of around 13Ohm. The conductors to the snap fasteners for the battery have around 1.3Ohm each.

The interconnection technology with embroidery [3] requires that the conductive thread is conductive on the surface and is not isolated. However, this application (as most others) demands isolated conductors between the EKG module and the electrodes. Therefore, the conductors have to be isolated after the integration using flexible polymer coating, which is a common process in the textile industry.

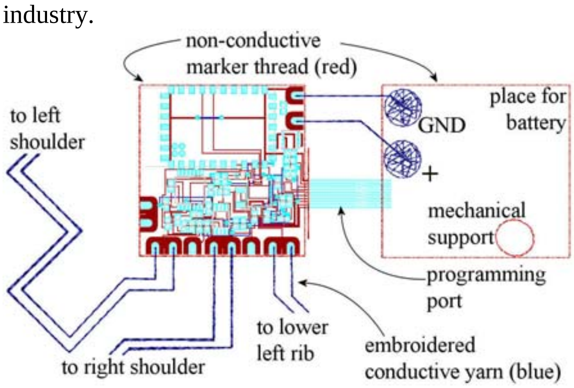

Figure 7: schematics of the EKG module with embroidery and contacts for the battery.

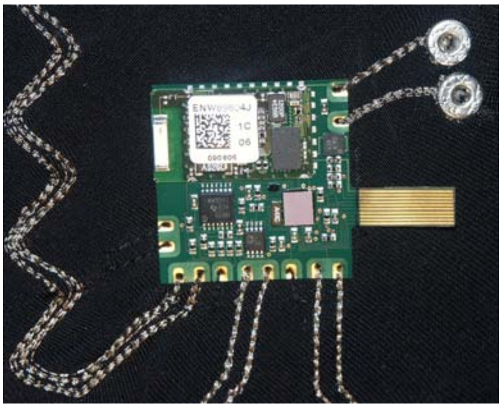

Figure 8: EKG module with programming port, conductors to electrodes and snap fasteners for the battery. (Note: as ground pads are not needed currently, they serve as mechanical fixation points and are sewn with non-conductive thread.)

2.3 Embroidered EKG Electrodes

The electrodes have been embroidered in one step together with the conductors which lead to them. This eliminates an unnecessary contact, which always comes with an additional contact resistance and contact noise.

Figure 9: embroidered circular electrode with solid gel pad for better skin contact.

On the body side, they are enhanced with a solid gel pad like in [5] to reduce movement artifacts and to improve the contact between the ionic conductor (skin) and the electronic conductor (silver-coated threads) [7]. (See figure 9.),

2.4 Encapsulation

To protect the electronic components and their interconnections as well as the embroidered interconnects encapsulation is indispensable. In [1] a glob top encapsulation has been developed for a single chip module of a textile transponder. For the much larger module in this work, molding is more promising as it offers a more defined geometry and better protection due to higher filler content of the material (see figure 10). The molding process requires that the fabric is very flat and neatly processed otherwise mold compound may be pressed outside the form. The curing temperature of typically 160°C-185°C is well below the melting point of *Statex* (PA66 melts at 260°C), however it changes the characteristics of the spandex in the shirt to some extent. The material gets less elastic around the module. As this area is quite small this may still be acceptable. Nonetheless, this issue will be addressed in further research. For this work, LOCTITE Hysol GR 9800 molding compound with a curing temperature of 165°C has been applied.

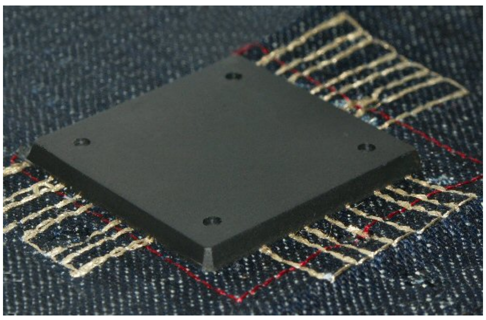

Figure 10: flexible module from figure 1 molded on jeans fabric.

This encapsulation method was first tested in [2,3] and proved reliable under lab conditions. This EKG T shirt is the first real world application of mold encapsulation of electronics on textiles.

3. Conclusions & Outlook

In this work an extremely miniaturized EKG module has been developed and integrated into a T-shirt using technologies, which make it very comfortable for the wearer. So far, the hardware has been tested in earlier state and showed good results. In a separate test, the electrodes showed similar results as standard electrodes with some movement artifacts.

In the coming weeks, the software has to be adapted to the slightly altered module that was used in the shirt and loaded onto it. Subsequently, intensive functionality tests of the T-Shirt will be carried out.

After that, the reliability of the shirt will be investigated more closely. The EKG electrodes may need improvement. Furthermore, the functionality may be enhanced with more sensors as mentioned in the introduction.

4. References

[1] C. Kallmayer et al., "New Assembly Technologies for Textile Transponder Systems", Electronic Components and Technology Conference, New Orleans, May 2003.

[2] T. Linz, C. Kallmayer et al., "New Interconnection Technologies for the Integration of Electronics on Textile Substrates", *Ambience 2005*, Tampere, September 2005.

[3] T. Linz, C. Kallmayer et al. "Embroidering Electrical Interconnects with Conductive Yarn for the Integration of Flexible Electronic Modules into Fabric", *IEEE ISWC*, 2005

[4] E.R. Post, M. Orth et al., "E-broidery: Design and fabrication of textile-based computing", *IBM Systems Journal*, IBM, 2000, Vol 39, pp. 840-860.

[5] E.P. Scilingo et al., "Performance Evaluation of Sensing Fabrics for Monitoring Physiological and Biomedical Variables", *IEEE Transactions on Information Technology in Biomedicine*, Vol. 9 No. 3 September 2005

[6] R. Wijesiriwardana et al., "Fibre-Meshed Transducers Based Real Time Wearable Physiological Information Monitoring System", *IEEE ISWC*, 2004

[7] Sverre Grimnes, Ørjan G. Martinsen, "Bioimpedance and Bioelectricity Basics", *Academic Press*, London, 2000