FIBRE-BASED SINGLE-WIRE KEYBOARD -THE INTEGRATION OF A FLEXIBLE TACTILE SENSOR INTO E-TEXTILES

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Abstract:

A flexible textile keyboard, using carbon nanotube (CNT) filled polypropylene (PP) composite fibres, is introduced. The identification of input information is achieved by reading the effective resistance of the conductive composite fibre. By using a single wire, a complex matrix is avoided and the interface between textiles and processing electronics is reduced to a minimum. LabVIEW has been used as the output display of the keyboard indicator for testing. This keyboard is fully flexible and washable, which provides opportunities for its integration with e-textiles.

Key words:

Carbon nanotubes, conductive fiber , E-textile, single-wire keyboard, tactile sensor, wearable computer.

Introduction

The development of electrically active textiles has been an active area of research in recent years. Fibres, yarns and fabric structures with added-value functionality, such as conductivity or sensing and actuating abilities, have been developed for a range of applications. The integration of such properties into textile structures illustrates the potential for developing light-weight, flexible and conformable electronic devices on textile products. One of the most common properties used in electrically active areas is electrical conductivity. The integration of conductivity in textile structures is mainly achieved by using different kinds of conductive fibres and yarns, which are based on materials such as metals, carbon and conductive polymers. Fibres based on metallic components are the most conductive, and are used in applications where high conductivity is important in order to achieve a desired function such as data transmission or ECG measurement. There are different methods of applying metals to fibres and yarns, such as the coating of metal on a polymer filament, spinning of polymer and metal staple fibres, and the drawing of pure metals into thin wires. The drawbacks of metal based materials are their rigidity, limited tactility and the environmental issues. These drawbacks can be reduced by using polymers or nano-particle filled polymers in fibre processing. Nano-composite fibrers of carbon nanotube (CNT) filled polypropylene (PP) with low contents of CNT have been reported by several research groups [1-5], CNT filled polypropylene enhances the mechanical, electrical, and thermal properties of the fibres. Using a relatively high CNT content can improve the conductivity to the upper semi-conductive range, however achieving a fibre with good mechanical properties is a challenge [6]. Even for a fibre with good conductivity and reasonable mechanical properties, the electrical properties of the composite fibre are insufficient for utilisation as a conductor, such as a transmission wire. Nevertheless, low conductivity is a desirable feature in some applications, for example it can be used to replace ordinary resistors in a wearable computer or e-textiles applications. CNT filled PP fibres are soft, flexible and washable, compared with ordinary resistors, and furthermore they can be mass-produced with simple technologies. In this paper, we explore how to make use of the low conductivity of conductive composite fibres in a textile keyboard.

The technology of keyboard input circuits is used in sophisticated applications, such as independence typing keyboards, matrix form keyboards, keyboards using coding and decoding systems, and keyboards using A/D converters [7-9]. The independence typing keyboard is the first generation of keyboards where every single key is encoded and decoded during pressure. The matrix form keyboard uses a matrix decoding system by scanning all the rows and columns of the matrix, a key with both a row and a column activated indicates that it has been pressed. Both methods are limited in wearable computers and electronic textile applications due to the huge number of interconnections between the textiles and the controlling unit. In a single keyboard matrix the circuit is composed of a group of resistors connected in series. Each resistor is connected to ground by key pressure. The resistances through the complete electrical circuit indicate the pressed key. In this method, only two interconnections are required, however a group of ordinary resistors is necessary. A single wire keyboard was patented in the US in 1995 [10].

In the present paper we report on a single wire keyboard made of CNT filled PP composite fibres. The keyboard has only two interconnections, which reduces the manufacturing costs and overcomes the drawbacks with the textile to electronics interface. By simply encoding and decoding key input data, the keyboard can be used as a remote control keyboard, a calculator or a telephone keypad integrated into e-textiles, such as a jacket.

Background theory of single-wire keyboard

In a single keyboard matrix, the circuit is based on a composition of resistors connected in series. Each resistor is connected to ground via a manual switch. When any switch is actuated by pressure, the circuit is closed. The resistance through the complete electrical circuit indicates which switch was actuated.

Resistivity and resistance

Resistivity is a natural property of materials. All materials have resistivity; metal usually has low resistivity, while non-metal materials such as plastics have a high resistivity. The resistivity ρ can be expressed as:

$$\rho = RA / l \quad (1)$$

Conversely, the resistance as a function of resistivity becomes:

$$R = \rho l / A \quad (2)$$

The resistance of a given sample will increase with its length, but decrease with a greater cross-sectional area. Resistivity does not change with the dimensions of the materials, therefore when a wire has a uniform cross section (A), the resistance (R) is proportional to the length (l) of the wire.

Equivalent circuit of keyboard

Resistance linearly increases with the increase in the length of the wire. By arranging the single wire as shown in Figure 1, a single wire keyboard is constructed. The switching on of any of the switches (S1- S16) provides an closed circuit of a complete electrical path to ground through a certain length of the conductive composite fibre, which correspondsg to the sum of the resistance preceding the switch in Figure 1.

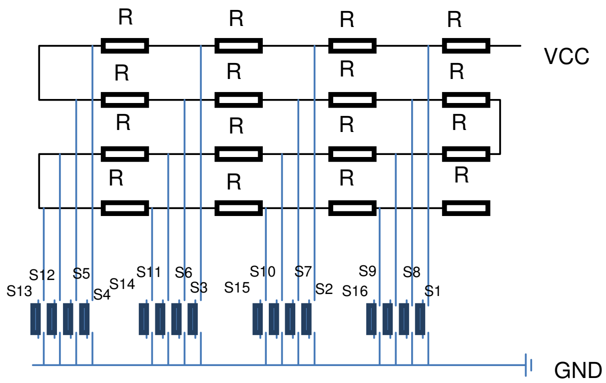

Figure 1. Keyboard equivalent circuit.

Methods

In this project, a blend of CNT (carbon nanotube) filled polypropylene was prepared. Melt spinning was employed to prepare the conductive composite fibres from the blend. The conductive composite fibre was constructed into a textile structure as a textile-based keyboard. The keyboard was formed in a multi-layer structure.

Preparation of CNT filled PP composite fibre

The CNT employed in this study was multi-walled carbon nanotubes (MWNT), Nanocyl®-7000 from Nanocyl S.A., Belgium. The MWNTs had an average diameter of 9.5 nanometers, average length of 1.5 microns and a carbon purity of 90%. The polypropylene used was a fibre grade PP, HE 445FB, obtained from Borealis, Denmark. First, the PP and MWNT powders were mixed together to prepare a 15 weight percent MWNT master batch in order to facilitate the dispersion of MWNTs throughout the polymer. Then the master batch was diluted with more PP to obtain the final PP/MWNT blend, with 6.3 weight percent of MWNT. All blending was done in a 15 ml twin-screw micro-compounder (DSM Xplore, The Netherlands), at a temperature of 200°C and screw speed of 50 rpm. The blending was repeated three times and the duration of each process was 5 minutes. The prepared PP/MWNT blend was then cut into granules and used in the same micro-compounder attached with a 0.5 mm spinneret die to make fibre filaments. The melt-spinning was run continuously at a screw speed of 10 rpm and extruder temperatures in the three zones of 190°C, 210°C and 220°C. The extruded fibre was drawn under a steady-state draw ratio of four, using two rotating rolls. The first rotating roll was heated to 80°C and the second one was kept at room temperature to cool down the fibre. Finally, the drawn fibre was collected on a bobbin roller.

Electrical property of CNT filled PP fibre

The resistance against fibre length was measured. An experimental prediction result was calculated. Figure 2 illustrates a comparison of the theoretical calculation result and the experimental data. Experimental results were measured by a multimeter.

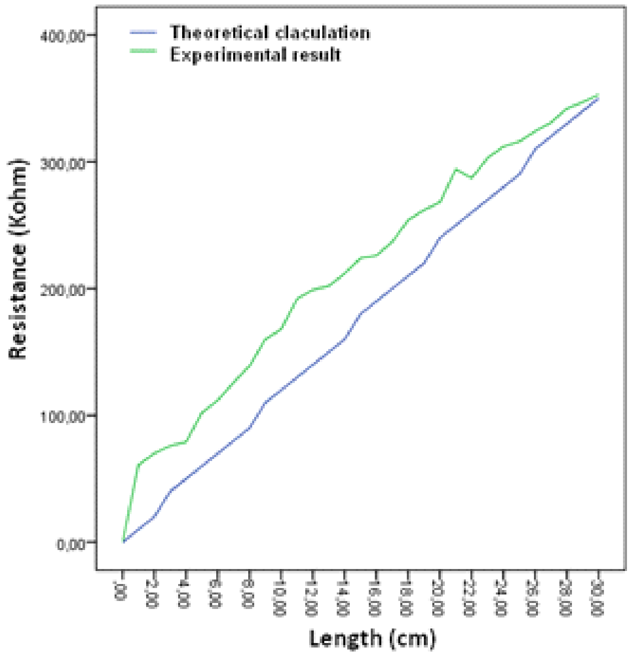

Figure 2. Resistance against length, theoretical prediction and experimental data.

As shown in Figure 2, the resistance increases with length in the conductive composite fibre. The experimental data has some deviations from the theoretical calculated results; this deviation comes from the diameter variation in the composite fibres. The non-homogeneity will be improved in future work.

Construction of the keyboard

The textile tactile sensor consists of a basic three-layer structure, forming a 4×4 matrix, indicating 16 different touch areas. The sensors are covered by two layers of a non-conductive textile as protection layers, and a keyboard indicator in the top layer (see Figure 3.).

Conductive composite fibre layer

The sensing element in one layer was the CNT filled PP composite fibre. This fibre was embroidered into a plain weave cotton fabric, which is a stiff and stable material and constructed in textile, the plain weave cotton fabric secured the sensing wire in a precise location.

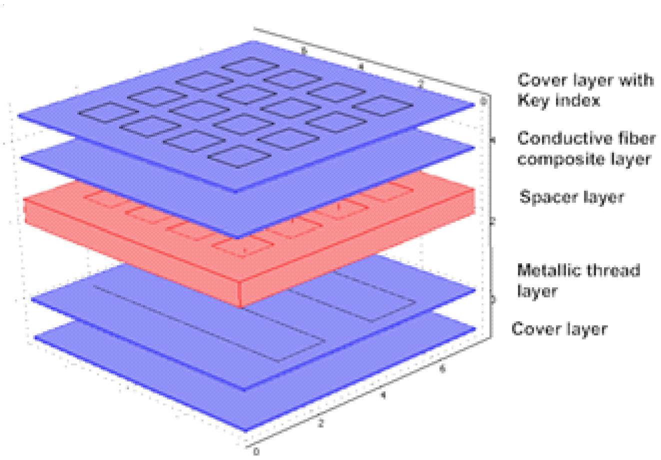

Figure 3. The construction of textile keyboard with 16 keys.

Spacer layer

The insulator between the two conductive layers was made of a spacer fabric, which was flexible enough to deform when pressed and resilient enough to recover after the pressure was released. A spacer fabric of 6 mm thickness, manufactured by Muller Textil, was chosen, see figure 4middle. The spacer was perforated in the form of a 4×4 matrix, the holes being positioned under each key.

Metallic thread integrated layer

In the metal thread layer a silver-coated polyamide yarn, Statex 235/34, produced by Shieldex, was embroidered into a plain weave cotton fabric. The resistance of the yarn is around 50 Ω/m, which can be ignored when compared with the conductive composite.

Configuration of two sensing layers

The configuration of the conductive composite fibre and metallic thread is carried out in stepwise zig-zag form, as illustrated in fig 3, with a 90 degree shift in angle between these two layers. In the conductive composite fibre layer, the length in the x and y directions was 5 units and 1 unit, respectively. In the metallic yarn layer, the length in the x and y directions was 1 unit and 5 units. The units can vary due to the size requirement of the keyboard, in our testing pattern 1 unit is equal to 2 cm.

Interconnection

The interconnection between the CNT filled PP fibre and the metallic thread and the testing setup was implemented by snap buttons (see Figure 4 right). Snap buttons are widely used in wearable computing and in the e-textile field, since they are easy to integrate and have already been used as an accessory in the garment industry for years.

Cover layers

The cover layers were used to indicate the key locations. Keys can be indicated via all kinds of textile manufacturing methods, such as printing, embroidering, and the sewing of additional materials. The materials chosen can also be varied, depending on the end application. Except for the location of the keys, the design of cover layers is not limited by any of the techniques and or layer types described here.

Figure 4. A prototype of textile keyboard used as a numeric keyboard for the laptop (left), the spacer fabric (middle) and the interface connection (right).

Program and test result

In a keyboard, the key position corresponding to the key character is converted into an electrical signal, usually a coded signal, and transmitted as a data communication code. In this project we have converted the key position by measuring the total resistance in the circuit. The method of realising the above key function in our case is the conversion of the key position from reading the total resistance of a complete circuit while pressing the key, as shown in Figure 5.

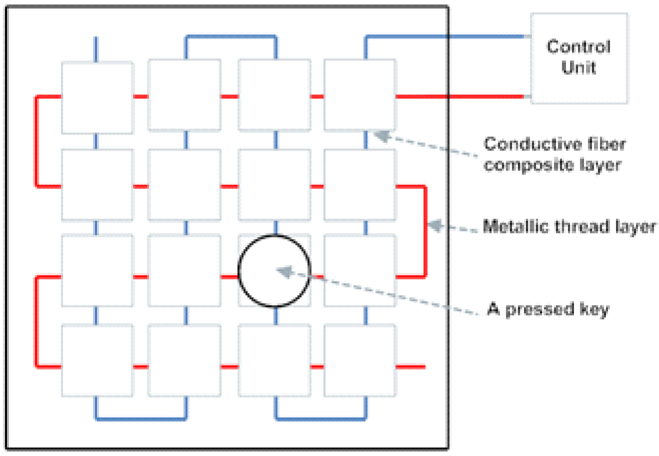

Figure 5. Top view of sensor when one key is active.

The keyboard was tested using a LabVIEW program. The algorithm of the flow chart is given in Figure 6.

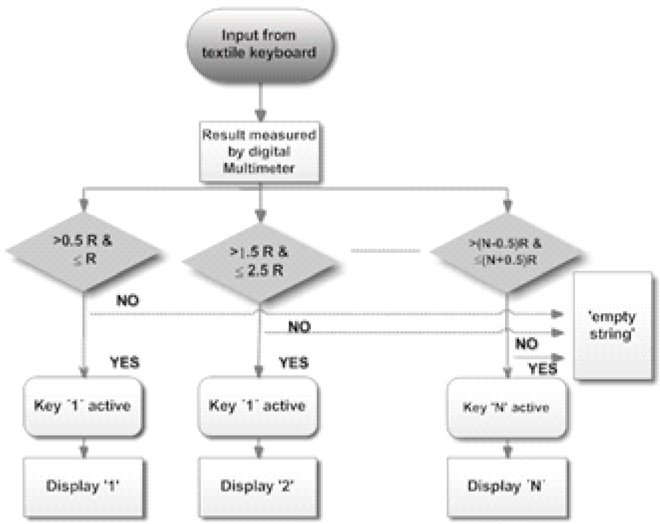

Figure 6. Flow chart of confirmation key press and display function.

Key identification and display

According to application requirements, this keyboard can be assigned a number of keys; for the purposes of testing a keyboard with 16 keys was produced. A closed circuit is formed by pressing any of the keys. A unit of resistance (R) was pre-determined by measuring the overall resistance of the whole fibre and dividing by the total number of keys in the keyboard. Each key was encoded by a unique resistance range. In theory, the measured resistance is N times (N denotes the location of the pressed key) of the unit resistance (R). However, in real situations there is always a deviation; the encoded resistance range compensates for this deviation. For example, when key '10' is pressed, the measured resistance would be around 10R, which is within the value range [9.5R, 10.5R] representing key '10'. The number '10' will then be displayed on the screen of the computer. The rest of the keys will be displayed as empty strings. The displayed keys are saved by the shift register in the LabVIEW program and shown in sequence until key 'C' is pressed. For testing, a digital multi-meter measured the total resistance of the circuit and compared it with the pre-determined range. In the real case, the measurement can be done by a microprocessor.

Test setup and result

The textile keyboard was connected via snap buttons to the electrical wires of the multimeter to measure the resistance, the resistance was sent to a LabVIEW program. The test setup is shown in Figure 7, and the result, in a display created in the LabVIEW environment, is shown in Figure. 8.

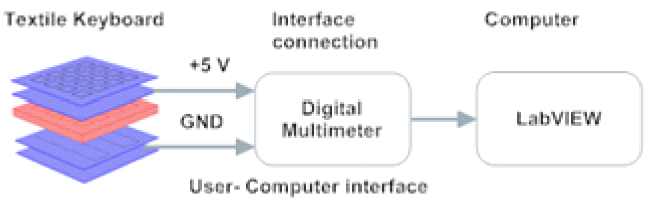

Figure 7. Overview of the keyboard testing system. There are only two interconnections between the textile keyboard and the test setup, the VCC power in and ground.

Figure 8. Textile keyboard interface in LabVIEW.

Conclusions and future work

In our project, we have used low conductivity properties to create sensors which can bring new applications for conductive composite fibres. We have produced a CNT filled PP fibre and integrated it into a single-wire keyboard. Using its low conductivity, we have been able to use the fibre as a set of series-connected resistors and integrate these into a single-wire keyboard.

This project should be seen as an early experiment to demonstrate the potential of using conductive polymer materials in interactive textile structures. Future work should be focused on the fibre and keyboard construction.

Concerning the fibre, the indication range of [nR-0.5, nR+0.5] implies some inaccuracy and changes in resistivity caused by changes in temperature and humidity. Future work would preferably be targeted at the improvement of the mechanical properties of the CNT filled PP fibre. A fibre with a more uniform diameter can achieve a higher accuracy and, consequently, reduce the size of the keyboard. It should also be of interest to reduce the CNT part of the fibre to achieve better processing properties. Such improvements enable the possibility of integrating the fibre in, for example, the weaving process. The use of new textile techniques such as 3D weaving affords the possibility of manufacturing sensing layers with the spacer in one process, which reduces the costs and time consumption.

Acknowledgements

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