Proposition of a Modular I2C-Based Wearable Architecture

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Abstract— **In this paper we propose a novel wearable architecture based on the popular and proven I2C protocol. Our goal is to develop a modular approach towards wearable computing in a sense that users simply attach specific modules to their garments depending on their requested functionalities. The I2C bus is embedded in the clothes and magnets are used as connectors to physically attach the modules and connect them at the same time to the bus. This usable principle makes the clothes versatile as they can be entirely personalized in terms of functionality.**

I. Introduction

Thanks to recent improvements in electronics, conductive materials and energy storage capabilities, we are now able to embed small circuits into clothes. These devices are able to sense, process and communicate information between the user and his/her environment. In this paper, we present the preliminary trials and results of our ongoing research concerning the development of a modular hardware and software framework that will assist the user in his/her daily activities. The main requirement of this research is the modularity of the system, but we also seek to minimize its bulkiness and maximize its usability. Indeed, depending on the desired functionalities, the user will merely attach the required modules on his/her garment. With this in mind, we have envisioned a solution where magnets would be used as the modules' connectors. Hence, by placing the modules at the desired spot, the magnets would not only attach them to the garment, but also connect them to the embedded communication bus. Next section will present a concise state of the art, while section 3 will present our proposition and possible applications. Then, the technical details will be described in section 4 and last section will conclude with final remarks and ideas of future work.

II. Related Works

Many garments with embedded functionalities are available commercially, such as the "Know Where Jacket" with integrated GPS monitoring, or Bluetooth-enabled jacket from Burton and Motorola. We can also cite the I.O.W. jacket from Grade Zero Research and the MET5, from The North Face, both with an internal heating mechanism. More recently, O'Neill have launched in collaboration with MyWay, the NavJacket, with an interesting friend finder feature and a Bluetooth connection for displaying maps on the user's mobile phone. Also, from a more esoteric perspective, a designer from Brazil has created some GPS-enabled lingerie [6]. This non-exhaustive list shows us that electronic garments are usually made for one purpose. Thus, if users want to change functionalities, they need to change their clothes. Alternately, MIThril, a complete modular wearable platform [5], has been developed to facilitate the development of distributed real-time multimodal and context-aware applications. Used in conjunction with the WearARM [1], a wearable computing core, researchers are trying to build a high-performance wearable system that is truly wearable and unobtrusive. On a more DIY approach, Leah Buechley has developed the LilyPad [3], based on the Italian Arduino platform. The LilyPad can be sewn to the fabric and connected with various wearable sensors and actuators. Following this trend, other companies like Aniomagic have created very simple wearable components that usually don't need programming and can be sewn to the fabric. The advantage is that one can easily create custom clothes and accessories, but once sewn, the wearables cannot be changed on the fly. Similarly, Studio5050 [18] is providing a set of wearable building blocks to help rapidly develop wearable applications. Their modules communicate over a single communication line.

III. Proposition and Applications

Today, most commercial wearable products have one specific purpose (GPS jacket, led-illuminated dress, etc.). Thus, if a user wants to change functionalities during the day without changing clothes, or on the opposite, s/he might want to change clothes but not the functionality. To overcome these issues, a solution would be to establish a hardware communication standard that could be used by any clothing company in order to attach various wearable modules depending on the desired functionalities as shown on Figure 1. This plug-and-play approach not only makes our system easy to use, but it also greatly simplifies the washing of the clothes.

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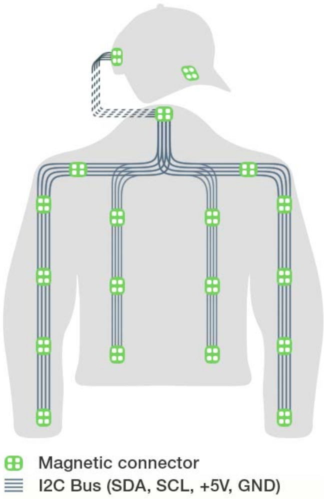

Figure 1. Architexture of our modular wearable framework

Wearable modules that could be attached to this standard bus could be classified in different categories: input, output, processing, communication, storage, and power modules. Additionally, a master module would be required in order to setup the functionalities and to manage the communication between all the other slave modules. We have opted for a wired bus instead of a wireless solution in order to reduce the overall power consumption of our system. Furthermore, only one pack of batteries is required instead of having a battery for each module, thus reducing the weight and size of each module.

The choice of developing wearables instead of an application on a mobile phone for instance is motivated by our belief that wearables give us the ability to establish a much subtle and intuitive communication between the user and the system. Indeed, using various sensors and actuators, the system could be able to detect if the user is inclined to be disturbed and could transmit information "the right way at the right time", using vibrotactile devices for instance. Moreover, by definition, wearables allow us to interact with the system hands-free, a significant advantage in many situations.

Due to the versatility of our above-proposed system, it could be used for many purposes by combining various modules together. This section will list several categories of suitable applications.

A. *Health monitoring and rehabilitation*

As demonstrated in many articles [11,14], wearables can be a perfect solution for remotely monitoring a patient's health or physical activity. Furthermore, other studies have shown a potential for enhancing rehabilitation [7,15] of a patient by using wearables. As an example, we have recently experimented with the use of an accelerometer module and a Bluetooth communication module in order to detect a potential fall of an elderly person and send an alert SMS via the user's mobile phone using simple AT commands.

B. *Smart Assistance*

Wearables can be used to help the user in many situations. For instance, the use of sonar modules in conjunction with vibrotactile devices could help visually impaired people to detect surrounding obstacles as we have shown in [4]. Furthermore, in [12], we have been experimenting with our modular wearable framework for enhancing the training of aerobatic pilots. Indeed, wearables were used to inform the user in real time during a maneuver about the corrections to apply via vibrotactile actuators and speech synthesis. Also, wearables have been proved [16] very useful to capture situational and contextual information in order to become proactive and to enhance the user interaction.

C. *Aesthetics: artistic performances and fashion*

As briefly surveyed in [2], wearables have been used for more than 10 years in performance arts, usually by transforming user movements into visual or auditory expressions. We believe that our modular wearable framework could fit in this area as the performer would be able to switch modules just like an instrument. Moreover, the modules worn by actors in theatrical representations could be easily switched between scenes.

IV. SETUP

We have chosen to use the standard I2C protocol, a simple half-duplex[1] serial 2-wire bus, to communicate between the modules. Compared to other buses such as CAN or SMB, it offers several advantages when dealing with wearables, indeed, it is cheap (many MCUs implement this protocol), easy to upgrade (addition and removal of functional modules), well known, simple (communication bus with only two wires), fast enough for all "Human Interfaces" applications (displays, switches, keyboards, …) and there is a very large number of I2C devices available.

Of course we need to address some issues raised by the limitations of the I2C bus such as the address conflicts, the bus reliability due to a failing slave module, the limited bus length and the hot swapping during data transfers. For the moment, we are using a 7bit addressing scheme as it allows us to have up to 112 different slave modules. To overcome some of these issues, we added an I2C bus extender (P82B715D) IC to every module in order to buffer the SDA and SCL lines and thus extend the possible length of the bus.

A. *Embedded I2C Bus*

For our first I2C bus implementation, we have embedded ribbons of litz[2] wire from Elektrisola [11] in a jacket. They have a very good mechanical flexibility, and are not noticeable once embedded inside the jacket with a iron-on patch. Our communication bus is made of four wires: the SDA wire for transmitting the actual data, the SCL wire for synchronizing every slave modules with the master module,

[1] transmission of information in opposite directions but not simultaneously

[2] Wire used in electronics, designed to reduce the skin effect and proximity effect losses in conductors

and two wires for powering every module with a voltage of 5V. The connectors on the jacket are made of a 0.4mm thick flexible circuit board as shown on Figure 2.

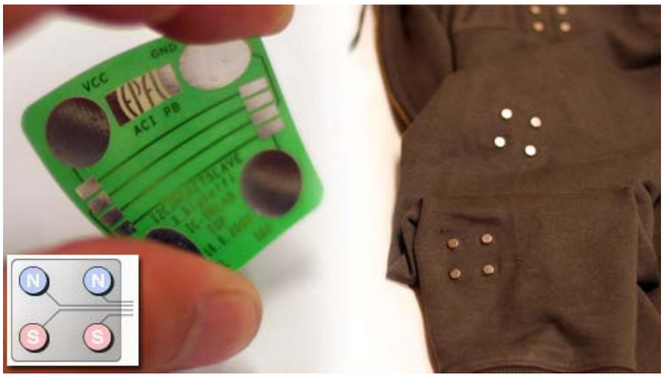

Figure 2. Connector with magnets orientation and jacket

For our second implementation of the bus, we have embedded the litz wires in jogging pants as shown in Figure 3. One central 7.4V battery is stored in a small back pocket and is connected to the five connectors are placed on the legs and around the waist. Preliminary results show that the modules are holding tightly when the user is running.

Figure 3. Running pants with embedded bus and attached modules

B. I2C Modules

As stated above, one of the advantages of using the I2C protocol is the abundance of devices that natively implement that protocol. For our experiments, we have built several modules, but have also used others out of the box. On the bottom of each circuit board we have attached four NdFeB disc magnets using conductive silver epoxy glue as magnets cannot be soldered without loosing their magnetism because of to the intense heat. The magnets have been attached in such a way (cf. Figure 2) that they would repel the module if the user tries to attach it the wrong way.

1) Master Module: First, we have designed and produced the master module, responsible for initializing all slave modules, centralizing and dispatching the data and regularly checking if all slave modules are alive. It has been built around an 8bit microcontroller from microchip (PIC18F8722) and also integrates a class 1 Bluetooth transmitter from Bluegiga. On top of the board, we have the possibility to attach an OLED touch screen from 4DSystems, thus enabling the user to interact with the system. The touch screen is connected to the master module via a simple serial connection.

2) Slave Modules: The second module that was developed is the slave storage module. It is useful for storing user preferences, GPS coordinates, addresses of nearby Bluetooth devices or interaction logs, for instance. As shown on Figure 4, the small IC supports a microSD card slot. The module is able to read and write data using the FAT16 file system architecture and understands simple commands like mkdir, append, etc. Additionally, we have developped vibrotactile modules using vibration motors commonly found in mobile phones and 3DOF accelerometer modules. The sensitivity (from 1.5g to 6g) of this latter can be changed anytime by the master module. Each slave module has its own unique address and responds to simple master methods such as setVib(address, value) or getX(address).

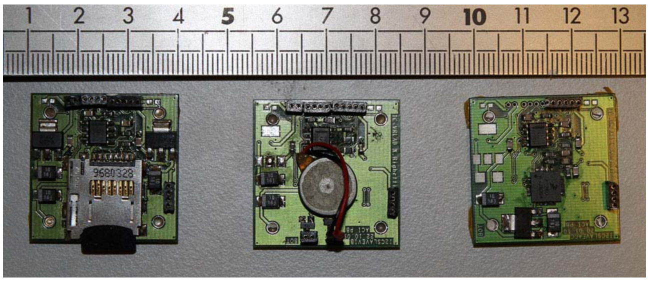

Figure 4. Slave modules (from left to right: storage module, vibrotactile module, accelerometer module)

C. Embedded Software

The software running on each module that we have developed has been compiled using the PCWH compiler from CCS, Inc., allowing us to program mostly using standard C and a few parts of Assembly for time-critical operations. Our software architecture is like an interrupt-driven state machine. External or timer-based interruptions will raise flags that will change the logical flow of the application. For the moment, the functionalities of every slave module we have been working with have been integrated as a library in the master module and are activated whenever the slave modules are connected to the embedded bus. Alternative configurations are also expressed using flags that users can switch using the optional embedded tactile display or a mobile phone.

V. RESULTS AND DISCUSSION

Our system has been demonstrated at several occasions in the framework of the European project INTERMEDIA. The scenario is as follow: a student named Chloé wears the modular jacket while following a medical course at the university. In order to connect to the classroom's access server and download the course material related to her profile, she attaches the master UI module and a storage module. She uses the master module to enter her PIN, which is then encrypted using a standard AES algorithm and transmitted to the server. The PIN is used to select the content based on the user profile located on the server and the course material is stored on the storage module using a standard FAT library. She leaves the classroom and meets with her friends at the library in order to work collaboratively on the course material. Again, Chloé uses her UI master module to connect to a projector-enabled phone, transfer the course material to the latter and control the playback with her wearable UI module. The prototypes that have been demonstrated using this modular architecture received a strong interest and raised interesting questions about the use of wearables in general.

The usability of this modular wearable approach has been proved very high; however, this scenario did not successfully prove the usefulness of using a wearable system as many comments pointed out that the same feature could have been handled by a smart phone. For our next application, we plan to focus on adding placement-sensitive sensors (accelerometers) and actuators (vibrators) in order to demonstrate the value of such wearable approach.

Additionally, some people commented that this modular architecture could also be a nice approach for testing wearable prototypes. Hence, it could be seen like a wearable breadboard that could be used to test the placement of various sensors and actuators on the body as shown recently in [17].

VI. CONCLUSION

In this paper, we have introduced our I2C-based plug-and-play approach for adding functionalities to clothes using wearable modules that physically attach themselves and communicate with other modules using magnets. We have experimented with a combination of wearable I2C modules in order to discover wireless services and interact with remote devices. Some additional I2C sensors and actuators have been tested using our software framework, but they need to be physically adapted in order to be compatible with our embedded magnet-based connectors.

In the future, we want our framework to be opened to new modules and thus we will need to implement a service discovery protocol as it is currently being studied by the Open Wearable Computing Group [13].

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