FP6-016039

CILIA

Customized Intelligent Life-Inspired Arrays

Integrated Project

Information Society Technologies
Future & Emerging Technologies
Proactive Initiative BIO-I3

DELIVERABLE: D1.4.2 – Public

DEFINITION OF INTERFACE BETWEEN MEMS SENSORS AND CONSORTIUM HARDWARE

Actual submission date:	September 8, 2006	
Start day of project:	September 1st, 2005	**Duration:** 48 months

CILIA ("**C**ustomized **I**ntelligent **L**ife-**I**nspired **A**rrays") is a project funded by the European Union. For more information on the project, its partners and contributors please see http://www.cilia-bionics.org/ .

CONTENT

1. EXECUTIVE SUMMARY

This report describes the architectural design of the physical and logical interfacing between the various hardware components that will be integrated later into a consortium demonstrator. Choosing for wireless, BlueTooth based links, optimum flexibility will be achieved. At the same time the architecture allows for simultaneous delocalised co-design which simplifies planning, testing and integration of the future consortium demonstrator.

2. TERMINOLOGY

Abbreviations

ADC	Analog-to-Digital Converter
ARM7	Avanced RISC Machines, family-7 of 32-bit RISC microprocessor cores
API	Application Programming Interface
CPU	Central Processing Unit
DAC	Digital-to-Analog Converter
DSP	Digital Signal Processor
FPGA	Field Programmable Gate Array
MCU	MicroController Unit
MEMS	MicroElectroMechanical Systems
RS232	Recommended Standard 232, a standard serial interface
Si	Silicon
SiRN	Silicon-rich silicon nitride
SU-8	A high contrast, epoxy based photoresist

3. DEFINITION OF INTERFACE BETWEEN MEMS SENSORS AND CONSORTIUM HARDWARE

3.1. INTRODUCTION

Due to their specific design, small dimensions and operation principle, MEMS sensors can in generally not be connected directly to common signal (bus-type) interfaces but require specific front-end electronics. This document describes such an interface between the signals from the MEMS artificial hair sensor arrays and the consortium hardware that will process these signals. In Section 3.2 we will first describe the sensor arrays and their input and output signals. Next, in Section 3.3 we will briefly describe the basis of the consortium hardware, i.e. the Hemisson robot. In Section 3.4 the interface between the two units is described.

3.2. THE NEED FOR AN INTERFACING DEFINITION

There are at least three groups in the Cilia consortium (UA, UT and SDU) that will contribute to the consortium demonstrator, either in hardware or software form. The contributions of the various groups are rather heterogeneous and functionally well separated. E.g. the MEMS hair-sensors require their own front-end electronics whereas the robotics hardware has its own electronic computational and communication units. On another front an appropriate interfacing is requested as well: when hooking up MEMS hair-sensors to biological neural networks, as investigated at FZJ. To benefit from a modular design the communication between the various components of the demonstrator needs to be defined in an early stage. This will not only improve system integration but at the same time allows for delocalised co-design. In this report only the physical interfacing is addressed since this has the most intrusive effect on the hardware design whereas the logical interconnection specification has large latitude and can be still left volatile till later date.

3.3. MEMS SENSORS

Figure 1 shows the basic structure of a MEMS artificial hair sensor with electrodes for capacitive readout and electrostatic control of the spring constant. A detailed description of the fabrication process can be found in [1]. These sensors will be operated in arrays on a support resembling the cerci of a cricket as shown in Figure 2. However, since this is only one of several possible configurations, we may reconsider the exact configuration at a later stage.

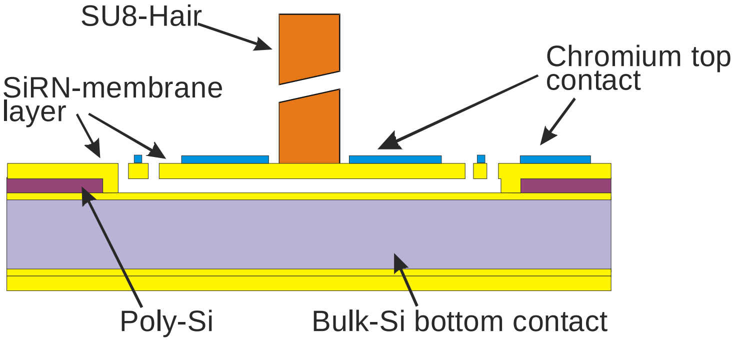

Figure 1: Cross-sectional drawing of the basic structure of a MEMS artificial hair sensor.

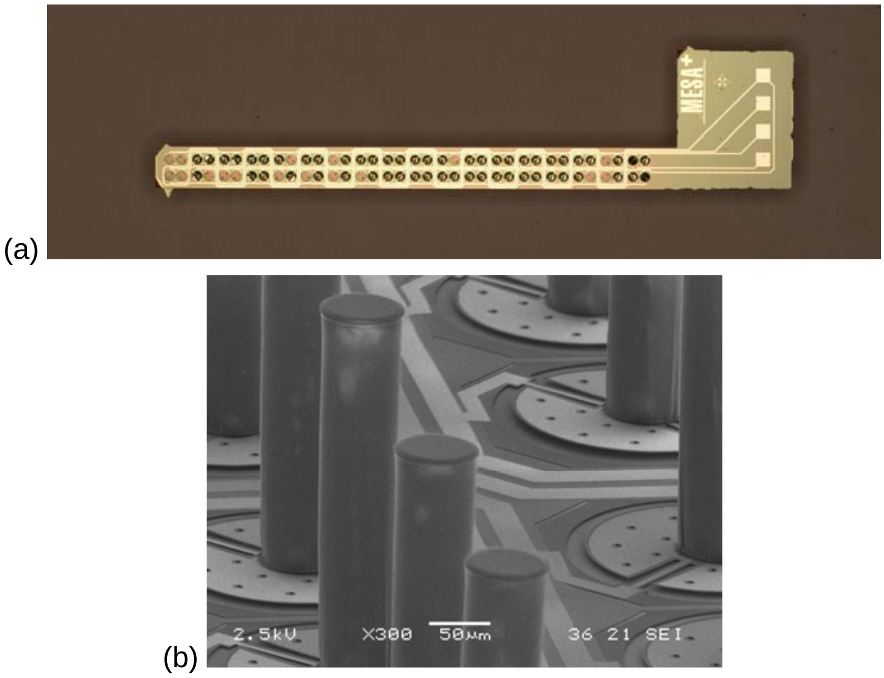

Figure 2: (a) Complete fabricated sensor array (top view), and (b) SEM photograph of individual sensor structures.

Figure 3 shows a functional schematic of the read-out electronics. Two 1 MHz signals (S1 and S2) which are exactly in counter-phase are applied to the electrodes on the suspended sensor membranes. The current flowing into the common counter-electrode (the silicon substrate) is measured using a charge amplifier followed by a multiplier for synchronous detection. The amplitudes of the 1 MHz signals are adjusted by a digital controller such that no net current is detected by the charge amplifier. The difference in amplitude between the 1MHz signals is then a measure for the tilting of the sensor membranes.

Two 16-bit, 50 MHz DA converters are used to generate the 1 MHz sine-wave signals and a 24-bit, 2.5 MHz AD converter is used to convert the output signal of the charge amplifier into a digital signal that can be processed by the synchronous detector. The controller is an ARM7 derivative (Philips LPC2129; 60 MHz). The remaining hardware, probably including the synchronous detector, will be programmed in an FPGA. As an alternative, to further improve the performance the synchronous detector may be implemented using a SHARC 21369 DSP from Analog Devices.

The output signal is a digital signal representing the torque acting on the artificial hairs.

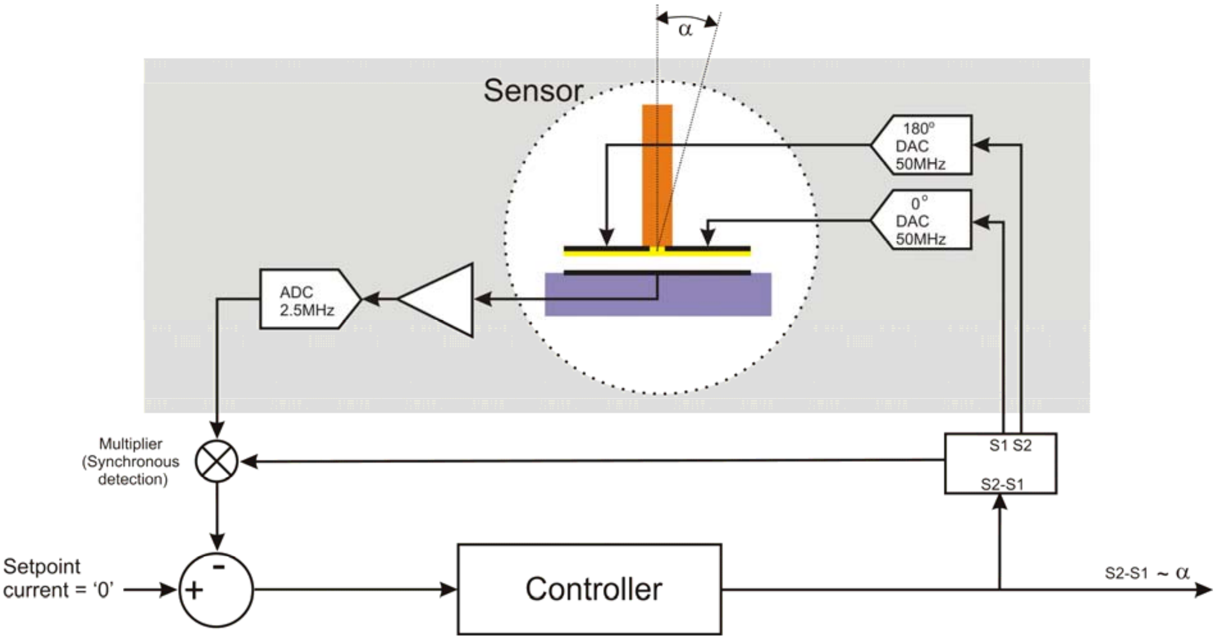

Figure 3: Structure of the hair-sensors fabricated in the CICADA project.

3.4. CONSORTIOM HARDWARE

The basis for the consortium hardware will be the Hemisson robot (see Figure 4) produced by K-TEAM Corporation [2]. The robot is equipped with several sensors (a.o. 8 ambient light sensors and 6 obstacle detection sensors) and a programmable 8bit MCU (PIC16F877, 20MHz CPU clock, 8bit, 8K words program memory). Furthermore, the robot has an extension bus system that provides an easy way to extend the robot's functionality. Several standard extension modules are available (e.g. various sensor modules like a linear camera and an ultrasonic distance sensor, a BlueTooth wireless communication module, and various other I/O modules) and all technical details are available to design a custom extension. The robot can be programmed with standard C language with a complete API and open source operating system.

Figure 4: The Hemisson robot.

3.5. INTERFACING ARCHITECTURE

For roaming robotics applications wireless data is a valuable asset. Having in mind the Hemission robot with little power provision and limited computational power it became evident that off-robot processing, e.g. by means of a PC interconnected by a limited bandwidth wireless link, would be a powerful setting. Not only does it allow to use cpu-time expensive algorithms initially, but also provides upgrade paths for future direct interfacing of MEMS hair-sensors with the robotics hardware without a PC in the loop.

3.6. BANDWIDTH REQUIREMENTS

For the consortium demonstrator we will use 4 to 8 groups of sensors (left/right cercus, longitudinal/lateral sensitivity, long/short hairs). Each sensor group requires a communication channel with a data rate of 2 – 4 ksample/s, which, with 16 bit samples, corresponds to 64 kbit/s. For a total of 8 channels the maximum required bandwidth is 512 kbit/s. The requirements on interfacing the hair-sensors to biological neuronal networks, as investigated by FZJ are largely depending on the number of nodes that can be simultaneously connected. However, considering only downstream information from hair-sensors to neural network and assuming for the time being the same configuration with 8 channels, the bandwidth should be sufficient as well since it does share the same requirements. Should we want to interface a larger number of channels, this will be possible by downscaling the sample rate. We do not expect that this will lead to important limitations since the neuronal networks will not work at pulse rates exceeding a few hundred pulses per second.

Table 1 summarizes the data rates provided by BlueTooth. In asymmetric data mode there is sufficient upstream capacity for 8 sensor channels while the download capacity can be used to control the robotics and interface hardware. For 4 channels the bandwidth is clearly large enough to even have bidirectional real-time interfacing. The limited bandwidth requirements of the sensory system fit well in the capabilities of BlueTooth devices.

Table 1: BlueTooth maximum data rates.

Configuration	Max. Data Rate Upstream	Max. Data Rate Downstream
3 Simultaneous Voice Channels	64 kb/sec X 3 channels	64 kb/sec X 3 channels
Symmetric Data	433.9 kb/sec	433.9 kb/sec
Asymmetric Data	723.2 kb/sec or 57.6 kb/sec	57.6 kb/sec or 723.2 kb/sec

3.7. INTERFACE

Standard BlueTooth modules will be used for the interface between the MEMS sensors, the Hemisson robot, and a PC, as indicated in Figure 5. Two BlueTooth modules were selected for use with the CILIA hardware: a class 1 and a class 2 device, both from DataSoft Systems AB [3]. The main difference between the modules is in the range: the class 1 device has a range of 100 m and the class 2 device has a range of 20 m. Of course, the higher range and transmit power of the class 1 device also results in a higher power consumption.

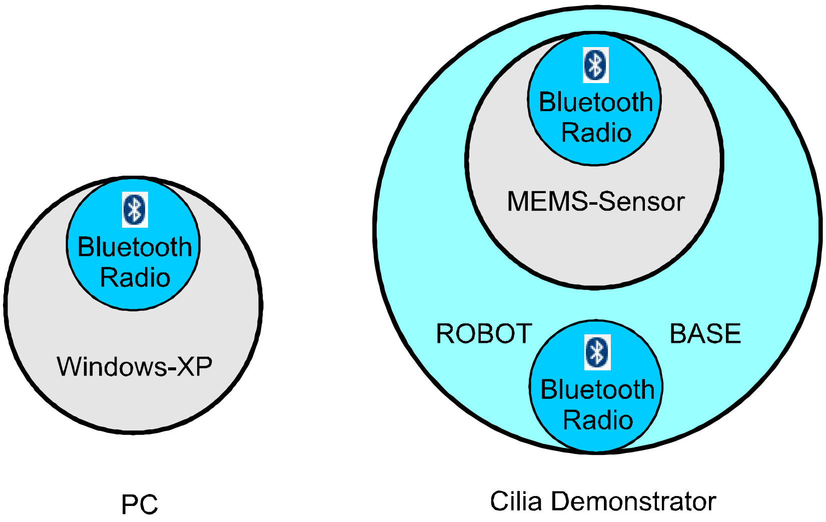

Figure 5: Schematic illustration of the interface with three BlueTooth devices: one in the PC, one connected to the MEMS sensors, and one connected to the robot.

The BlueTooth devices will be used to establish standard RS232 serial links between the MEMS sensors, the robot, and a PC. In fact, at the University of Twente an RS232 serial link is already used for communication between MEMS devices and a PC so that the transition to a BlueTooth interface should not be a problem.

Figure 6 illustrates the 4 basic modes in which the system will be able to operate. There will be bi-directional links between the PC and robot (a) and between the PC and the MEMS sensors (b). This is the basic situation, in which all data processing can take place in the PC.

Of course, the final aim is that all data processing is done locally in the MEMS sensors and the robot, so that the PC is no longer necessary. Therefore, two more modes will be used. One in which the PC will be nothing more than a data logger, storing received data from the MEMS sensors and sending the data to the robot (c), and another, in which the PC is not used and a direct communication is setup between the sensors and the robot (d). In fact, in mode (d) a wireless connection is not needed and the BlueTooth devices could be replaced by direct RS232 connections.

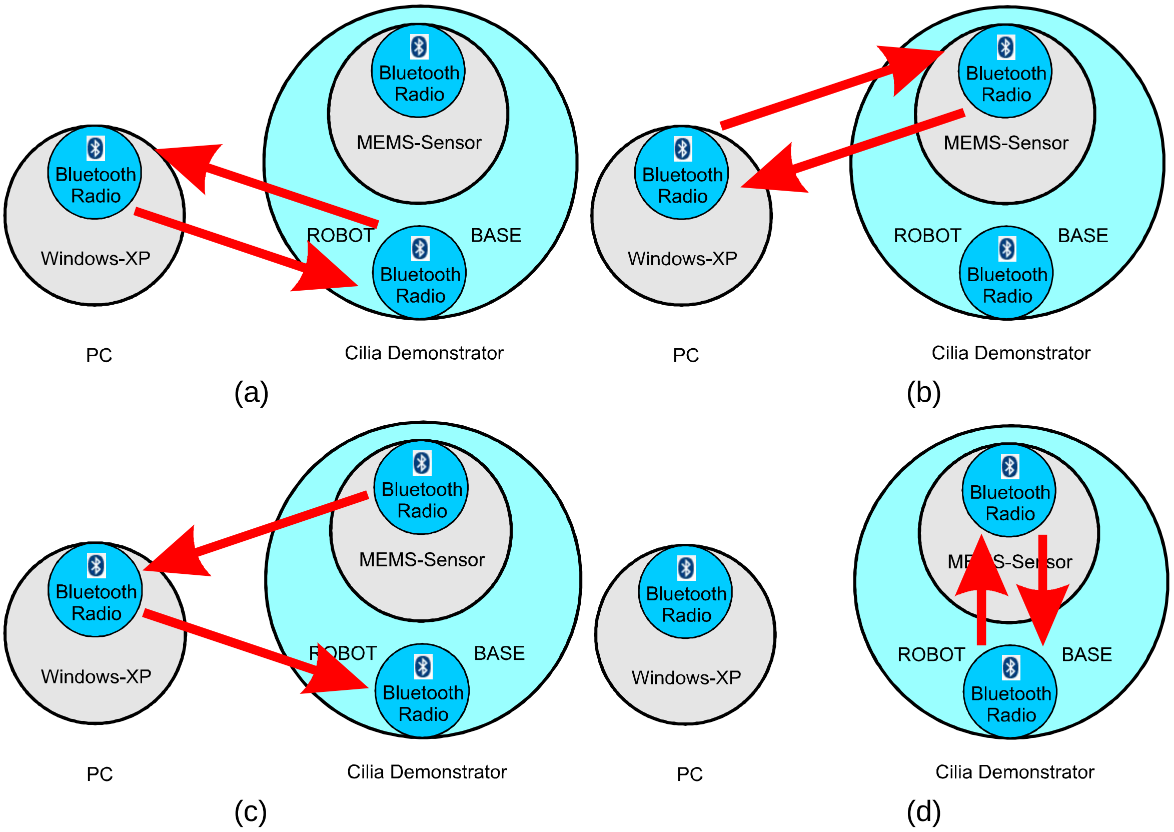

Figure 6: Four modes of operation: (a) serial link between PC and robot, (b) serial link between PC and MEMS sensors, (c) PC used for relayed communication between MEMS sensors and robot, and (d) direct serial link between MEMS sensors and robot.

3.8. CONCLUSION

Using fairly modest means, commercial robots equipped with BlueTooth communication modules allow for a straightforward interfacing of MEMS-hairs using tailored front-end signal processing and pseudo standard digital interfacing (RS232). The chosen hardware allows for a variety of connection alternatives including the use of a PC in the loop and direct interfacing of the MEMS-hairs to the robotics vehicle. This flexibility safeguards both a flexible use of the (parts of) the demonstrator as well as de-localised development of the various parts of the demonstrator (e.g. proper interfacing of the MEMS sensory hairs can be accomplished independently from other developments).

4. REFERENCES

Dijkstra MA et al (2005) Artificial sensory hairs based on the flow sensitive receptor hairs of crickets. J Micromech and Microeng 15 7 S132-S138

K-TEAM Corporation, Y-Parc - rue Galile 9, Yverdon-les-bains 1400, Switzerland, http://www.k-team.com

DataSoft Systems AB, Petersviksgatan 26, 856 34 SUNDSVALL, Sweden, http://www.datasoft.se