Micro Information Systems: A New Information Systems Research Field

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Abstract

I introduce a new field in the *Information Systems* (IS) research community in this paper: a field to be named *micro information systems* (MICRIS). To do this I have to cover several things in one paper: Show that there is a need and room for this field in the community, show that the field exists (but is not defined yet), define it, provide a research direction and a vision, and provide ideas and a working reference implementation. To define the micro information system field, I construct a neighbor field called *mobile information systems*, which hosts devices larger than *micro information systems* devices, and I make a significant discovery in defining a field to be named *nano information systems*. The latter serves to bound the *micro information system* field, by showing an also potentially interesting field with systems of small molecular sizes. In terms of a research direction, I point to traditional areas in IS, which can be re-analyzed in terms of this new field. The reference implementation presented to support research in micro information systems are based on an area from embedded systems called wireless sensor networks; it is technically oriented. In addition, I show real a mobile information system demo and a small proof of concept of a nano information system. By both defining the area, providing research directions, and showing reference implementations/demos, I believe that the field is very promising in terms of raising new research questions.

1. Introduction

In this paper we introduce a new sub-area of information systems: *micro information systems* (MICRIS). The research field of *information systems* (IS) has slowly changed: IS researchers has mainly focused on server, web, and PC-oriented applications. The reason for this focus has probably been that the power of the server and PC has followed Moore's law and therefore created many new possibilities. But in parallel and mostly unnoticed in IS, the market for embedded systems has surged. Today, about 98% of all processors are not server- and PC- central processing units (CPU), but micro control processors (MCU). These MCUs are embedded in cars, sensors, doors, watches, mobile phones, alarm systems, etc. There is already a large set of applications; the IS community need not look for new applications to understand the implications. However, there is a massive bulk of research that awaits in the new micro information system sub-field. Most of the existing work in IS can be reflected and reanalyzed in terms of micro information systems. For an alternative visualization and light-weight introduction see Figure 1.

The paper is organized such that I start with a theoretical definition of a micro information system in Section 2. Then I go on to show small but actual prototypes of mobile-, micro-, and nano-information systems. After the theory section, I show how one can use a certain platform for MICRIS experimentation. This takes place in Section 3. The hardware platforms suggested are mainly Lego Mindstorms NXT and the Sun Spot from Sun Micro Systems. The operating systems are mainly the embedded Squawk Java Virtual Machine and TinyOS. This is discussed in Section 4. In order so show that this idea about micro information systems is real, I include a section on already completed teaching experiences at a European research summer

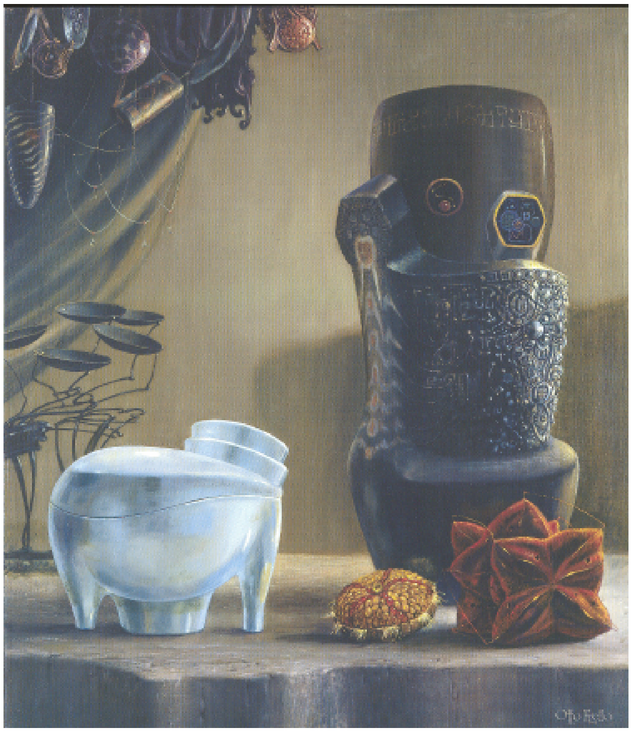


Figure 1. Notice the electronic circuits in the vase on this painting by a famous Danish artist Otto Frello (my neighbor in Copenhagen). I include two of his paintings (with written permission) in the paper to convey my message about micro information systems in a different way, but also because I am fascinated by the electronic circuits embedded in some of his paintings' motives.

school and at a business school for freshmen students; see Section 5, which also covers a requirements analysis from different user groups of MICRIS. At the end, I conclude that MICRIS is promising and points to future work.

2. Micro Information Systems Theory

I would like to start out with a definition:
Micro information systems are information systems subject to additional significant constraints related to size, form, and function.
The physical dimensions of a MICRIS system can therefore range from a few angstrom (10^{-10}m) to centimeters (10^{-2}m)! In other words, from atom size to mobile phone size, with the predominant *volume* of one MICRIS system probably being around 1 to 10 cm^3. Wireless sensor network systems will be good representations of MICRIS systems, and that is why I cover these systems so intensively later in this paper.

It is a new area, and work remains to further define how this new field can support the IS research community such as the mission of the Association for Information Systems (AIS)[1]. In addition, I have outlined the major relevant fields in Figure 2.

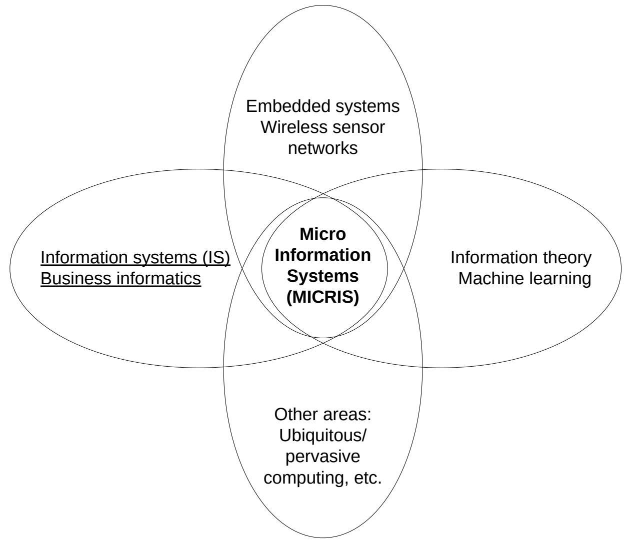


Figure 2. MICRIS systems are surrounded by other research fields, and only the dominant ones are listed above.

The different research areas in Figure 2 are included to show some main areas that MICRIS will draw on. Information systems is the main area providing most of the new research questions. A smaller field called business informatics is included as MICRIS will have a significant impact on this field as well. Then I have chosen to include some of the visions that are popular. These include wireless sensor networks, ubiquitous/pervasive computing, etc. The type if information in MICRIS is different than a traditional IS, so I include information theory and machine learning as two important areas. Finally, embedded systems provides the wireless sensor network experimental platform discussed in Section 3.1.

In order to justify the need for defining MICRIS as a new field in IS, then I have to justify why. It is new because it brings the concept of something small to the field, it explicitly adds a new kind of information, and it certainly focus on a new kind of platform, which is much smaller than what we are used to consider. It can be argued that it is similar to the pervasive/ubiquitous

[1]The mission of the Association for Information Systems is "to advance knowledge in the use of information technology to improve organizational performance and individual quality of work life."

visions, but I think they are exactly that: mainly visions, with little practical resemblance to IS. By defining the new MICRIS field to be within IS, then the research community can decide exactly how the artifacts (ie. micro systems) are analyzed and observed, which I think is the optimal approach. The *information* we examine is also different. It comes in smaller quantities and can be as small as a binary value with some inherent significance. To look at information in its most basic form is refreshing, and it is also why I have put information theory up as a relevant toolbox to take into account.

2.1. Micro Information Systems

Defining an area called micro information systems immediately adds new things to the IS field. MICRIS systems are often based on real information such as temperature and registrations of movements while traditional information in IS systems could be database records containing some product ID or a quantity. Furthermore, it introduces a new kind of *system*; namely one that is physically designed toward its application. The novelty lies in the fact that it is not only a software-oriented, but equally a hardware-oriented design[2]. Finally, a MICRIS system can be analyzed from many different perspectives: individuals/groups/organizations, social impact, outsourcing, software/hardware development, information systems development, databases, HCI, standardization, open source, security, intelligent systems, applications such as ERP/healthcare/CRM, etc. To create an example research question (and leave it unanswered) from the information systems development (ISD) (Kautz et al., 2007) area; how does known problems in ISD map to the MICRIS field? Does the problems multiply, or simplify, or something completely different? Or what happens with business informatics (see for example (Pedersen, 1996)) in this new microscopic context? We will address it in due time.

There is a demo of a MICRIS system in Figure 3.

Figure 3. Micro Information System (MICRIS). Developed using Lego Mindstorms NXT. See the two Sourceforge projects *nxtgcc* and the *nxtsquawk* project at dev.java.net. It is developed using the Eclipse *nescdt* editor plugin for TinyOS. The text on the first line on the display is *MICRIS 1*.

The closest neighbor to MICRIS when looking at bigger systems is mobile phones. They are small specialized units that use (powerful) micro processors. They are the subject of the next section.

2.2. Mobile Information Systems

There is nothing new in seeing a mobile phone as an information system. However, there are still many traditional IS aspects that remain largely untouched on mobile phones, such as outsourcing hardware and software development. The reason that I introduce mobile information systems (MOBIS) is that it will be an important client of micro information systems. Please see Figure 4 for a demo.

2.3. Nano Information Systems

I introduce this kind of information system for two reasons: first and foremost it serves the purpose of indirectly defining micro information systems, as I define nano information systems (NANIS) as an overlapping field to MICRIS. The second reason for defining NANIS is simply because I believe that it will be highly important in the IS field, starting in a few years.

A small type of MICRIS is nano information systems: Figure 5 shows a program that allow some nano technology experimentation. To show that the idea of NANIS is not far away, I created a small project with a few atoms (the details are not important), and called the system *Nano Information System 1*, as I believe that it is the first idea to define a nano information

[2] A special processor exists that blends these two concepts and an implementation exists for Java. See `http://www.jopdesign.com`

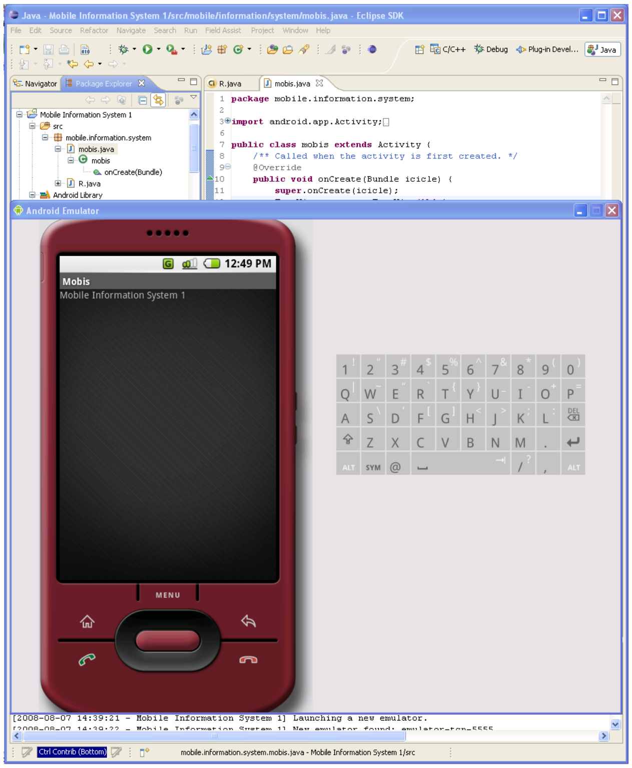


Figure 4. Mobile Information System. Developed using Google Android software development kit (SDK) and the Android Eclipse Plugin. Notice that the Google Android runs an application that displays *Mobile Information System 1* on the screen.

system in the IS field. From Figure 5 it can be seen the the weight of the system is around 10^{-24} kg, so it is small...

Now that I have covered mobile-, micro-, and nano- information systems to some extent, I will introduce the experimental platform that can be used for MICRIS research.

3. Experimental Platform

It is valuable to be able to experiment with MICRIS systems, and therefore I suggest to define the area such that most experiments and research work consists of both a theoretical part and an experimental part. The experimental part would usually be to write an application that exemplify, clarify, validate, or falsify the theoretical part.

Here we can look to a successful research field called wireless sensor networks (see `tinyos.net`). This community demands that research work is accompanied by a demo system.

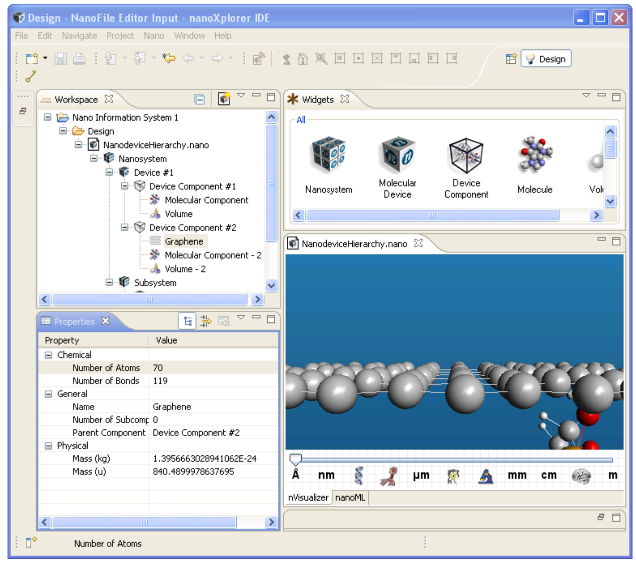


Figure 5. Nano Information System. Developed using the Eclipse Rich Client (RCP) framework-based application nanoXplorer IDE from nanoTitan. Notice that the system is labeled *Nano Information System 1*.

3.1. Micro Information Systems and Wireless Sensor Network

The recent introduction of Lego Mindstorms NXT[3] paved the way for MICRIS (see Figure 6). We will discuss how this platform can be helpful across a number of requirements in terms of teaching.

Figure 6. The Lego Mindstorms NXT educational kit.

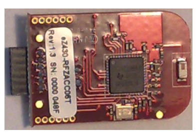
We propose Lego Mindstorms as a standard platform and we show one example of how it can be used together with wireless sensor networks. The system consists of TinyOS, Squawk and Lego Mindstorms. In earlier work (Pedersen, 2005) it was necessary to use

[3]Please see `http://mindstorms.lego.com` for a full description of NXT

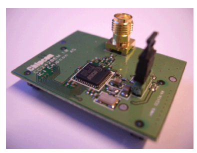
several different platforms to try embedded Java and TinyOS. With Lego Mindstorms we can use the same hardware platform all the time.

(a) Mica2 Mote

(b) Sun Spot



(c) Zigbee Radio (CCZACC06)



(d) 802.15.4 Transceiver (CC2420)

Figure 7. Mica was one of the original platforms for running TinyOS motes. Sun SPOT is the recent WSN platform from Sun Microsystems. The CCZACC06 (now CC2480) is a recent Zigbee radio from Texas Instruments. The CC2420 is widely in use today within WSN.

TinyOS (Levis et al., 2004) is a small operating system for wireless sensor networks. We have described a port of TinyOS for educational purposes (Pedersen, 2007). It runs easily on the NXT hardware. Originally the operating system ran on motes like the Mica2, as shown in Figure 7. The operating system is small and there is plenty of room for drivers and other software on the main processor in NXT. As part of the Texas Instruments beta testing program, we are currently evaluating the CCZACC06 Radio in relation to NXT. We also have a website, `http://nxtmote.sf.net`, for the first port of TinyOS to NXT.

Squawk (Horan et al., 2007) is a research Java Virtual Machine (JVM) from Sun, which was released in the spring of 2008. It is the JVM that runs inside the recently released wireless sensor network platform *SUN SPOT* (see Figure 7).

In Section 4 we discuss the new Lego Mindstorms NXT platform in more detail, which is on its way to become a popular learning platform for educational and research purposes. With the platform description in mind, we go on to discuss the requirements for a MICRIS platform as seen from the viewpoint of IS students, teachers, industry, and researchers. This takes place in Section 5. Some of the teaching experience with the system is presented in Section 6.

4. Lego Mindstorms NXT

Established and emerging embedded operating systems can benefit from the implementation of Lego Mindstorms NXT for several reasons. The open source policy of the recently released NXT makes it easy to import new operating systems to NXT. NXT can be seen in Figure 8 and 9. The sensors can be seen in Figure 10 and 11.

Figure 8. A NXT with 4 input sensors (touch, sound, light and ultrasonic). The 3 motors are also shown.

The Mindstorms NXT system from Lego Corp. is an interesting and flexible hardware platform. The NXT PCB (the green plate in Figure 9 is equipped with an ARM MCU as well as an AVR MCU; both MCUs are from Atmel. Furthermore, these two popular MCUs are connected to input ports, output ports, an LCD, Bluetooth radio, and USB. Moreover, there is already a rich set of sensors available from both Lego and third-party vendors, which enables the use of the NXT system for prototyping in relation to almost any conceivable education (or research) project.

From an educational perspective, the number of different sensors is excellent. Many of the sensors shown in this section are very affordable and easy to obtain. This means that machine learning for educational purposes can begin to include the physical world in its experiments in a way that has never before been possible on a international scale (Lego is almost available everywhere).

In the next subsection we briefly describe the NXT software, hardware, and sensor architecture. Lego is publishing a detailed set of documentation that is available from the Mindstorms web site.

4.1. Sensors

A MICRIS platform is connected to the real physical world, so the short discussion of the sensors is well placed here. The input and output ports feature a 6-wire RJ12 connector. On the input ports there are both analog and digital lines. On the output ports

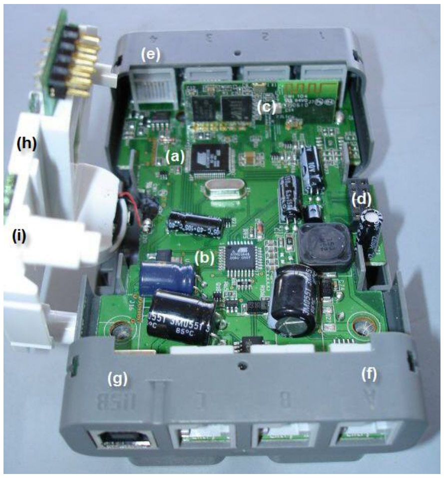
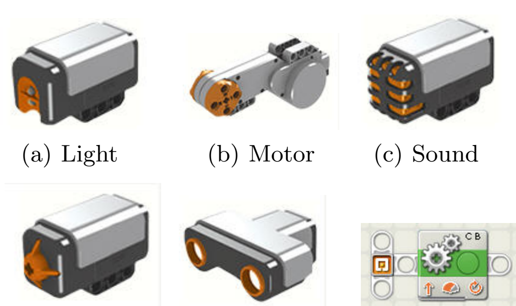


Figure 9. NXT with important hardware highlighted: (a) ARM7 MCU, (b) ATmega48 MCU, (c) CSR BlueCore4 Bluetooth radio, (d) SPI bus and touchpad signals, (e) high-speed UART behind input port 4, (f) output (generally motor) port, (g) USB port, (h) four-button touchpad, and (i) 100x64 LCD display.

PWM functionality is used with the motors in the standard NXT firmware. The NXT comes with a basic set of sensors. This basic set includes an ultrasonic distance measurement sensor, a light intensity sensor, a sound sensor, a touch sensor, and motors. Moreover, there are a number of third-party sensors available such as various acceleration sensors, a compass sensor, a temperature sensor, etc. More complete listings are available at the Mindsensor and Hitecnic web-sites. The US-based Vernier also produce sensors such as pH probes or magnetic field probes, just to name a few.

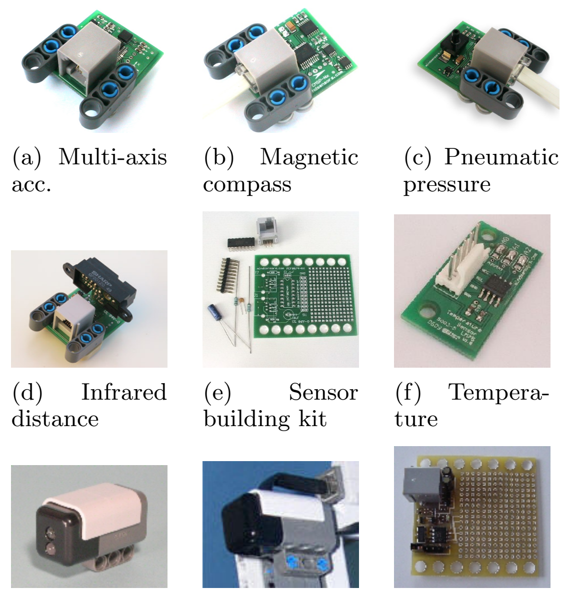


(a) Light (b) Motor (c) Sound

(d) Touch (e) Ultrasound (f) NXT-G block

Figure 10. Standard Lego Mindstorms NXT sensors and NXT-G block.

With NXT comes a set of standard sensors, as shown in Figure 10. This set of sensors can give most students enough to work with in order to create their custom motes: the light and microphone sensor are almost standard for a mote. It should not go unnoticed that there are three motors (see Figure 10b), which makes it simple to create dynamic moving and data collecting motes. For the sake of completion, there is one NXT-G block shown, which is used in the block-based programming language.



(a) Multi-axis acc. (b) Magnetic compass (c) Pneumatic pressure

(d) Infrared distance (e) Sensor building kit (f) Temperature

(g) Color (h) Gyro (i) Prototyping board

Figure 11. Selected NXT sensors from Mindsensors and Hitechnic

Mindsensors and Hitechnic are two of the main providers of sensors for NXT. Figure 11 show some additional sensors available for NXT. The motes, which can be built in the WSN classes with these sensors, resemble standard motes like MICA because we now have a temperature sensor. With the magnetic compass sensor it is possible to build a dynamic mote for outdoor navigation/orientation. Finally, with the sensor-building kit in Figure 11, there is a way to actually build a new sensor in an affordable and accessible manner. One of the advantages of multiple communities sharing the NXT hardware and sensors is that mass-production drives prices down to a level where classroom teaching becomes quite affordable.

The technical discussion above shall now be mapped to the different users of an MICRIS platform. This is the subject of the next section.

5. Requirements Analysis from Research- and Educational MICRIS Users

In this section we look at the requirements that different groups of people have in terms of using Lego Mindstorms NXT for researching and teaching MICRIS.

5.1. Students

A broad definition of a *student* is used. It stretches all the way from the first year at university or college to finishing a Ph.D. and becoming a teacher. We believe that students would like to work with Lego Mindstorms NXT because Lego is well-known to many students around the world. They immediately recognizes the appealing looks of the NXT system and the familiarity of the bricks and connectors. This means that no time has to be invested in learning a proprietary system before the first inventions can be created. Furthermore, the students recognize the value of knowing Lego Mindstorms will stretch beyond the classroom setting and on to family life and hobbies.

5.2. Teacher

From a teacher standpoint the system should be useful across many subjects. In addition, the systems used would ideally be portable to other institutions to make time investments worthwhile. Due to the ubiquitous use of Lego Mindstorms (at least compared to other educational systems) the teacher would immediately become part of a well-functioning community.

5.3. Industry

It is best for industry if the student learns using a system that prepares them for real applications. It is equally important for industry to have a system that is able to upgrade the skillset of existing employees. The field of embedded machine learning is just developing and anyone not in school or able to attend conferences will miss the chance to catch on to this rewarding area. Lego Mindstorms NXT is available on many websites and the employee or the employer can choose to invest in a few sets to get started. In terms of wireless sensor networks it is even more interesting if the software used for embedded machine learning represents a viable source of revenue. There are already companies that use TinyOS (like ArchRock) and the recent introduction of the Squawk JVM should result in a dual license schemes that will be commercially attractive.

5.4. Researchers

The research role is often associated with a corresponding teaching obligation. If that is the case then the researcher would be looking for ways to combine teaching efforts with research efforts. With Lego Mindstorms NXT this is possible. Many schools are able to acquire a number of NXT sets, and due to the open hardware/software source nature of Lego Mindstorms the researcher can use the same hardware in the laboratory as in the classroom.

6. Experiences with Teaching Embedded Machine Learning Education using Lego Mindstorms NXT

We have tried the TinyOS and Lego Mindstorms NXT combination with different groups. The youngest group was a second-semester business/computer science profile. It was possible in 5 hours total during a theme week with Lego Mindstorms to get radio connection between two units and manipulate the display. The students were very excited, even though we initially thought that TinyOS would be much too hard for such a young group. No actual programming was conducted in that short period.

The second group we have been able to expose the system to was 30-40 masters/Ph.D. students at a large EU project on ubiquitous knowledge discovery (see Figure 12). The teaching part of introducing TinyOS, the associated programming language nesC, the software, and hardware parts of Lego Mindstorms NXT took 2 hours. Then 4 hours of laboratory work followed where each group had two sets of Lego Mindstorms NXTs. The task was to use an algorithm on one NXT and send the results to another NXT via Bluetooth.

The original firmware (software) is open source and we have also had a team of master students who worked with the ultrasonic sensor to get a robot to follow a sequence of commands. This group did well using a modified version of the original firmware (using the `http://nxtgcc.sf.net` project) and it was another example of how Lego Mindstorms can also be used.

6.1. Outline for a Potential Future www.micro-is.net Website

To introduce and capture the subsequent activity around MICRIS in the IS community, it would be an idea to consider a website where knowledge can be captured and shared. It can be a website with blogs, wikis, filesharing area, user forums etc. Often when

(a) 18 NXT in one bag

(b) KDubiq Summer School in Porto

(c) Teaching

(d) Exercises

Figure 12. Teaching TinyOS on Lego Mindstorms at the KDubiq Summer School for about 2 hours plus 4 hours of labs.

giving a tutorial at a conference it is hard for the audience to find possibilities for collaboration afterwards, but a common website could be one way to ensure this possibility.

7. Conclusion

Micro Information Systems (and its yet unborn sibling nano information systems) will play a role in the IS community for years to come. The work ahead of us is so vast that it will be (and perhaps should be at this point) difficult to predict where we will end up.

In this paper we have observed that Lego Mindstorms NXT is an exciting platform for MICRIS learning and research. Several examples of early use of this system has been provided ranging from first year students to master students and Ph.D. students.

Future work include making the platform easier to use for non-computer science majors. Eclipse (the open source application framework) will play an important role to reach this goal.

We hope this can serve as starting point for many exciting and rewarding hours of teaching and research within the IS research community, and now leave you with the inspirational picture in Figure 13.

Figure 13. Embedded electronics coming out of the bench, which is easier to see on the real painting. Painting by Danish artist Otto Frello (see `http://www.ottofrello.dk/`.)

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