Developing Support for Sensor-Based Human-Machine Interaction

Jennifer Allanson
Computing Department, Lancaster University, Lancaster LA1 4YR
allanson@comp.lancs.ac.uk

PART I: PREVIOUS RESEARCH AND TRACK RECORD

1. LANCASTER UNIVERSITY

1.1 RELEVANT RESEARCH AT LANCASTER UNIVERSITY

The proposed research complements existing work being undertaken within the Computing Department at Lancaster University. There are 2 research groups in the Computing Department - The Co-operative Systems Engineering Group (CSEG) and The Distributed Multimedia Research Group (DMRG). The research outlined in this proposal spans the work of both CSEG and DMRG and reflects a growing area of research interest within the Computing Department at Lancaster, namely innovative models of human-computer interaction.

CSEG has for many years been leading the field of research concerned with investigating technologies that support collaborative working. The group's Computer Supported Collaborative Work (CSCW) research is internationally renowned. Members of the CSEG group are also active in the area of Virtual Reality (VR) research, exploring not only the utility of Collaborative Virtual Environments (CVE's) for supporting group working, but also investigating the potential of VR technologies for presenting a wide variety of searchable data sources.

DMRG has 17 years experience in distributed systems research and in recent years has been a leading light in both mobile and multimedia computing technology research. Projects such as GUIDE[1] for example are currently exploring issues such as contextual-awareness in mobile devices.

In recent years an increasing number of projects have begun which bring together the interests of members of both the CSEG and DMRG research groups. One key area of research within the department focuses on applications of ubiquitous computing and the Computing Department at Lancaster is lead partner in the recently commenced six-year *Equator* interdisciplinary research collaboration (IRC) in ubiquitous computing. The department has also recently received funding from the University in recognition of its emerging research activities (and resulting increase in both staff and student numbers) to be used to build an *Innovative Interactions* laboratory that will provide a focal point for research into future forms of human-machine interaction. The research proposed herein meets a need identified, both within the computing department's working context and also within the wider HCI community, for support to aid the rapid integration of emerging sensor technologies into such configurations that allow different forms of non-traditional human-machine interactivity to be explored.

1.2 KEY PERSONNEL

Dr Jennifer Allanson was appointed as a lecturer in the Computing Department at Lancaster University in November 1999. Her research interests centre on novel methods of human-machine interaction. Her PhD research, funded by an EPSRC studentship, focused on defining a new paradigm of human-machine interaction based on the detection and utilisation of human electrophysiological information. As part of this work she designed and implemented a component-based software toolkit [Allanson 1999a, Allanson 1999b] for constructing *electrophysiologically interactive computer systems (EpICS)*. Part of the evaluation of this work involved members of the University's Psychology Department, who carried out a biofeedback-based study looking at forehead muscle tension. The interactive application used for this study was constructed using the toolkit's components.

Other research that Dr Allanson has been involved in includes an investigation into the use of virtual environments to articulate requirements coming out of ethnographically-informed fieldwork studies [Pycock 1998a, Pycock 1999b]. This work was carried out in collaboration with Xerox Research Centre, Europe (XRCE) in Cambridge. Latterly Dr Allanson has been involved in the design of tangible event notification technologies for constructing awareness landscapes [Lock 2000]. She was also co-organiser of an invited session on Generative and Component-based Software Engineering which ran at the SCI2000 conference in Florida in July.

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[1] Now in its second phase

PART II: DESCRIPTION OF PROPOSED RESEARCH AND ITS CONTEXT

A. BACKGROUND

A.1 INTRODUCTION

Exciting developments in human-computer interaction are being afforded by access to a growing range of advanced sensor technologies such as eye-/motion-trackers, or devices for detecting subtle human physiology (heart, brain signals, etc). The impact of these sensor-based technologies on the relationships that exist between computer systems and their users has yet to be systematically explored. One consequence of this lack of exploration is a lack of support for interactive systems that incorporate sensors, which in turn leads to the current ad-hoc development of sensor-centric systems.

The proposed research will investigate the technologies required to support the construction of interactive systems that incorporate advanced sensing capabilities. This investigation will be used in turn to identify and analyse sensor-based interaction mechanisms with a view to developing a taxonomy of human-machine interaction based on sensing.

A.2 RATIONALE FOR THE PROPOSED RESEARCH

The work proposed in this project builds upon our existing knowledge and experience of supporting the development of sensor-based interactive systems [Allanson 2000]. Findings from our previous research leads us to believe that it is possible to provide support for the development of interactive systems that incorporate a variety of advanced sensing technologies. We cannot, however, identify an existing taxonomy of sensors suitable for human-machine interaction that would enable us to develop such support. This, in part, justifies our writing of the current proposal. But far more important is the issue of a complete lack of support for developing sensor-based systems. The need for such support is urgent and the investigation of suitable support is the main driving force behind the proposed project.

[McMillan 1995] suggests that a different interaction model (Figure 1) is required for sensor-based human-machine interaction to that model applied to traditional, electromechanical transducer-based human-machine interaction (Figure 2).

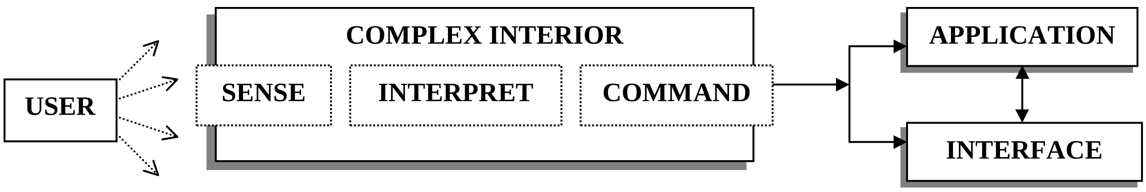

Figure 1. Sensing-based interaction model, after McMillan [McMillan 95]

Figure 2. Electromechanical transducer-based interaction model

Consideration of the electromechanical transducer-based interaction model has lead to a widespread understanding of and support for the development of systems that incorporate electromechanical interaction devices [Myers 1995]. Unfortunately, to date there has been no systematic exploration of interaction based on the sensing model. As a consequence of this, the development of all but a few specific types of interactive systems that depend on sensor-based input sources[2] must take place in an ad-hoc manner. Currently sensor-based systems development is both time-consuming and frustrating and this is a situation destined to get worse as more and varied sensor-based input technologies become available.

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2 VR is one of the few

Two key aspects of the relationship between the user and the sensing-based system are illustrated in Figure 1. Firstly, the use of sensors means that the direct mechanical linkage between the user and system is broken. This has obvious implications for the development of both mobile applications and ubiquitous computing applications, which both depend on sensors of various kinds being embedded within a user's environment (home, office, etc.). The second key aspect of sensing-based interaction is the requirement for additional processing to take place on the data collected by a given sensor. This additional processing enables the output from a sensor to be construed in a meaningful manner by an interactive application. The level of processing required will obviously vary depending on the nature of data being detected. For example, little additional processing will be required on the data stream from an infra red proximity sensor. On the other hand extensive processing will be required on an electroencephalogram (EEG) or raw brain signal. Despite these seemingly vast differences in data complexity, there should be similarities between groups of sensors that will enable generic first level of additional processing to be built into development support software. But only a sensor field-wide review such as that proposed herein will allow us to discover the complexity of the generic processing support required.

A.3 SCIENTIFIC AND TECHNOLOGICAL RELEVANCE

Recent years have seen a dramatic shift in focus for researchers investigating human-machine interaction. Increasing miniaturisation and mobility of computer systems, as well as the development of novel interfaces such as those found in VR systems are making us look again at the manner in which we engage with interactive applications. There is a growing requirement for computers to sense and make sense of both their users and their physical environment. In addition there is pressure to break the ties that bind user to machine to a given physical environment.

Sensing the Environment. Until the advent of mobile computing we rarely had cause to consider how the physical environment in which a computer system was operating effected the way it performed, the services it could offer, etc. As computers find themselves in increasingly challenging environments, they need to have ever more sophisticated sensory equipment in order to gather useful data about their physical surroundings. Mobile computing devices for example require continuous access to information about the changing context of the device (absolute physical location, proximity to service provision facilities, etc) in order to maintain connectivity across wireless networks and/or to provide specific, location-dependant services [Schilit 1994]. Analysis of context-aware mobile systems has lead to the creation of at least one system-specific development support toolkit [Salber 1999].

Sensing the User. Direct manipulation (DM) predominates as the core interaction paradigm for human-machine interaction, based as it is upon deliberate, discrete actions on the part of the user. The interactions afforded by DM technologies (almost exclusively electromechanical devices) are well understood. Furthermore these interactions are fully supported by the plethora of tools available to interactive systems developers.

By far the most significant alternative to DM currently under investigation is interaction based on the detection and recognition of natural human gestures (motion, speech and handwriting detection/recognition, etc.). Gestural interaction is itself based around advanced sensing technologies. The data that gestural interactions rely upon is continuous. Interactive systems that incorporate gestures constantly monitor their users and scrutinize the resulting data streams for recognisable actions that can be construed as instruction.

Human-machine interaction based upon recognisable gestures is commonly classified within the generic categorisation of *multimodal* interaction. Furthermore, specific sensor-based interaction technologies are often labelled as being *haptic*. However, the term haptic implies feedback from a tactile source [Webster 2000] and is therefore a misnomer for most of the technologies to which it is applied. What many of these technologies do have in common, however, is a core requirement to continually sense the system user. A clarification and reclassification of some forms of interaction based on their enabling technologies is long overdue. It will clear up many fundamental misrepresentations within (and thus simplify parts of) the increasingly complex field of human-machine interaction.

Levels of Intent. An interesting issue highlighted by focussing on the use of sensory input sources is the notion of *intent* in human-machine interaction. Sensor-based interaction does not necessarily rely on the recognition of deliberate, intentional user-generated gestures. Biometrics for example, which utilises advanced sensing capabilities, is an area of interaction difficult to categorise in terms of existing interaction models. The information required by biometrically-capable applications, namely iris patterns, finger prints, voice patterns etc, could certainly not be described as "gestural". Nor is it the case that the information source, be it the eye, the finger etc, will always be presented intentionally to a system by its user. Yet in systems that incorporate them, biometric sensing and processing capabilities play a distinct role in the dialogue that takes place between human and machine (often and initialising one).

Another example of an unintentional (in fact, largely unconscious) data source that can be made available through advanced sensing technologies and one that is being investigated as part of the human-machine relationship is *detectable human physiology* [Allanson 2000]. Physiological information such as brain signals, skin conductance and heart rate, is most likely to be used in order to provide a system with information pertaining to the changing emotional or affective condition of a user. Unsurprisingly the role that this information will play in the dialogue between user and machine is yet to be formally specified. This new information source could not take us any further from our current level of understanding of human-machine interaction based as it so often is on intentional user actions. Physiology sensors and biometric data capturing technologies are just two examples of a growing number of alternative interaction technologies that will resist being shoehorned into existing models of interaction.

Sensor-Centric Interaction. Ten years ago [Nielsen 1990] proposed that the "*fifth generation user interface paradigm [will be] centred around non-command-based dialogues*". In their Agenda for Human-Computer Interaction Research [Jacob 1993] et al acknowledged that support for the new paradigm would come in the form of new input devices, interaction techniques and software approaches. These technologies are still emerging and support for their use, as we have already argued, is patchy. Our position is that advances in sensor-centric interaction will be best served by exploring together all of the issues specific to the use of sensors as an input source. This investigation needs to be carried out in isolation from other miscellaneous input technologies alongside which sensors are often discussed.

Examples of the issues to be investigated as part of the proposed project include:

- *The types of data made available by a wide range of sensors*
- *The reliability of that data in various real-world situations*
- *Constraints upon the real time nature of the data i.e. which types of sensed information (if any) can afford to be lossy?*
- *The complexity of the data processing required on various sensor input streams.*

Other considerations for this project include identification of as wide a range of sensors as possible that could, with the right support, be employed as computer input peripherals. Some of the more esoteric sensing technologies have already found their way into the realm of human-computer interaction research [Zimmerman 1995]. Others are only just emerging from other disciplines [Fletcher 1998]. By examining these technologies together we can get a far better sense of the prospects for the rich future of human-machine interaction.

By undertaking the proposed research we can provide both the knowledge and development support required so that the designers of future interactive systems can fully exploit the wide range of intentional, semi-intentional and even unintentional interactions made possible through the use of advanced sensing technologies.

Supporting the Developer. In the first section of this proposal we highlighted the fact that human-machine interaction based on sensing relies on a different conceptual model of interaction to that employed in traditional electromechanical interaction. As McMillan's sensing model is not widely acknowledged, *sensing-based interaction is not distinguished from electromechanically-based interaction in any meaningful manner. The effect of this is that frameworks and toolkits designed to support the development of "interactive systems" only really offer support for human-machine interaction based on discrete user events generated through electromechanical transducers.* Unfortunately, these tools cannot easily be extended to accommodate other, modally disparate models of interaction, in particular those facilitated through sensory input sources.

These problems have been addressed in part by the formulation of application-specific models of interaction, such as the virtual reality model, or the previously mentioned context-awareness model for mobile computing. These interaction models enable the creation of application-specific development support. They do, however, commonly obscure important details about the physical mechanisms underlying the utility of their interactivity. Implicit in the formulation of application-specific interaction models is the idea that the developer will deal individually with specific interaction technologies, which in the case of VR interaction include gloves, wands, motion trackers, etc. Any interaction technology support these tools do provide prove to be of little help to developers wishing to incorporate VR interaction technologies, say, in non-VR applications or alternatively wishing to incorporate exciting new interaction technologies such as physiological sensors.

An alternative, application-bridging approach to interactive systems development support is to look at the affordances of different interaction mechanisms [Buxton 1998]. Interaction mechanisms such as pointers, gloves etc have inherent functionality that will impact on their utilization across a range of application domains. For example, the nature of the interactions that can take place through speech detection/ recognition technology remain the same despite that technology being applied to mobile device interaction, operations within virtual environments or control of embedded systems. What developers want is the ability to more easily integrate different interaction technologies into a given application. By identifying the affordances of interactive technologies it is possible to consider classes of virtual devices which in turn allows the development of tools independent of specific interactive technologies which support instead any of a class of *virtual* interactive devices.

The core aim of this project is to examine the affordances of different types of sensors with a view to constructing sensor-independent development tools.

B. PROGRAMME AND METHODOLOGY

B.1 AIMS AND OBJECTIVES

As described above, there are two major objectives for this project. The first is to establish a taxonomy of human-machine interaction based on sensing. This will be achieved through a thorough investigation of established and emerging sensing technologies. The sensing technologies of interest are those that can be used for gathering information about the changing state of a computer system's user and/ or its environment. More specifically, we will:

- Explore existing work on sensing-based interaction
- Analyse emerging computer peripheral sensing technologies
- Establish a range of user activities and environmental factors susceptible to monitoring
- Identify the interaction possibilities afforded by sensed, continuous data streams
- Develop a taxonomy of human-machine interaction based on sensing

The second objective of this project is to investigate the facilities required to support sensing-centric human-machine interaction. This development support will be grounded in the results of the analysis carried out on the sensing technology review. The results of the review itself, the taxonomy and the development support will be disseminated within the research community. The following section addresses the approach by which we plan to meet these main objectives.

B.2 METHODOLOGY

The period of time over which this project is to be carried out is limited by the urgent need for support of the nature proposed here. For this reason development support will be provided in the form of suitable extensions to an existing interactive systems development language (such as Java, for example). After choosing a suitable development platform, we will provide the extensions required in order for that platform to support a range of virtual sensing technologies.

B.3 PROGRAMME OF WORK

The proposed research is divided up into a number of work-packages. For each package an estimate of the required number of person months (p-m) is given. This information is also presented diagrammatically in the final section of this proposal.

Work-package 1: Investigate existing and emerging sensor technologies (3 p-m). In this first work-package we will gather information on as wide a range of sensor technologies as possible. We are particularly interested in the more unusual sensing technologies emerging out of fields of study such as medical engineering. The result of this review will be a technology reference base that will provide the basis for work to be carried out in work-package 2. We intend to make the technology reference base available via the World Wide Web.

Work-package 2: Human-machine interactions through existing and emerging sensing technologies (3 p-m). In this work package we will consider the dialogues that can be supported between user and machine in terms of different sensing technologies. This work-package will consider human activities that can be detected via sensors and meaningfully analysed by computers. This will enable us to consider potential new forms of dialogues afforded by the use of particular sensor types. In order to include user interactions with mobile devices within work-package 3, we must also consider the useful range of environmental data that is susceptible to monitoring and can consequently impact upon the user-machine dialogue. At the end of this work-package we should be in a position to talk comprehensively about different levels of interactive intent on the part of the user afforded by distinct sensing technologies. We will also consider enhancement through sensor application - where standard human-machine dialogues enabled through traditional electromechanical means are augmented or enhanced by the information that can be made available through modern sensors.

Work-package 3: Develop Taxonomy of Human-machine Interaction based on Sensing (4 p-m). In this work-package we will gather information on as wide a range of sensor technologies as possible. We are particularly interested in the more unusual sensing technologies emerging out of fields of study such as medical engineering. The result of this review will be a technology reference base that will provide a basis for the taxonomy. At this point will we be in a position to formally classify sensing technologies in terms of the types of data they detect, the data processing requirements for the data steams they make available, the nature of human-machine interactions afforded, etc. As the groundwork for the taxonomy will have already been carried out in previous work-packages this work-package is concerned with formalising and documenting the human-machine interactions facilitated by advanced sensing technologies.

Work-package 4: Develop sensor-specific extensions to existing interactive systems development tool (8 p-m). Drawing on the knowledge gained from the reviews, analyses and formalisations carried out in work-packages 1 to 5 this work-package will focus on the creation of development tools in support of systems which incorporating sensors. This development support will take the form of extensions to an existing interactive systems development platform (to be identified).

B.4 NOVELTY, TIMELINESS AND IMPACT OF THE RESEARCH

The novel aspect of this work is that human-computer interaction based on sensing is, for the first time considered as a distinct mode of interaction, requiring its own high-level conceptual model and system support strategy.

The timeliness of this investigation is reflected in contemporary attempts to redefine human-machine interaction. Supporting the notion of ubiquity in computing requires systems to be aware of both their users and their surroundings. This so-called contextual awareness relies on computer systems continually gathering environmental data most often using different kinds of sensors. The same is true of new paradigms of computing - perceptual computing [Turk 2000], affective computing [Picard 1997], brain-computer interaction and other forms of assistive computing (computing for the disabled).

We consider the impact of this research will be twofold. Firstly, sensing-based interaction challenges conventional wisdom that successful human-machine interaction outcomes depend upon the transformation of *deliberate, intentional actions* into commands or changes in the computer's state. By formulating a taxonomy of interaction based on sensing the range of potential interactions and the associated levels of user intention can be explicated. This in turn will enable us to use computers within an environment in a way that enhances the interactions (both human-to-human and human-to-computer) that take place within that environment.

We envisage the second consequence of this work to be the speeding up of advances in the field of sensor-based interaction. This is due to the provision of an overview of current sensor technology as well as formal models of the interactions that these technologies can afford.

C. RELEVANCE TO BENEFICIARIES

The work described in this proposal is relevant to researchers concerned with both human-machine interaction and context awareness in mobile systems. Any researcher concerned with enhancing the relationship between user and machine should be aware of *all* of the possibilities for collecting user-related data and making it available to the system. Any research concerned with context-awareness in general should consider the wider range of contextual data that may effect how a system interacts with both its user and the environment. With the knowledge accumulated and analysed by this project an interactive systems designer can make an informed judgement about which subset of the available information is useful for a particular interactive application and how best to integrate that information into a given application.

D. DISSEMINATION AND EXPLOITATION

The Computing Department at Lancaster has an excellent publication record and has a tradition of international dissemination of research results through both journal and conference publications. As the first point of research for many computing researchers in now the World Wide Web it is envisaged that all of the results of this work will eventually be presented in this format.

E. MANAGEMENT AND RESOURCES

E.1 MANAGEMENT PLAN

The Computing Department at Lancaster University has considerable experience of managing research grants. This project will be managed within that context by fortnightly meetings between the principal investigator and the researcher employed to work on this project. In addition we propose to make use of the Department's newly founded Ubiquitous Computing Special Interest Group (UbiComp SIG) as a forum for discussion of our research and evolving models. As well as weekly UbiComp SIG meetings and technical forums run by the DMRG group we intend to liase with our many associates at other academic institutions and within industry both in the UK and the US. This will be done formally through conference workshops and informally through mailing lists and online discussion forums.

E.2 RESOURCES REQUIRED

The resources required for the project are justified below. Further details can be found in the associated EPS(eRP) form.

Personnel. The project requires one full-time research assistant for a period of 18 months. We have been in contact with a graduate student from Georgia Institute of Technology who has expressed an interest in working on this project if it is funded.

Equipment. The equipment costings are based on the purchase of a PC, a portable notebook PC and a range of sensing peripherals. The first PC will be used for collecting and assimilating information as well as for developing the toolkit support. The mobile PC will be used, along with the sensing peripherals, to assess the usability of the toolkit extensions in support of peripheral sensors in a variety of real-world situations.

Other consumables: Money to organise a workshop in order to establish a community of researchers interesting in the issues central to sensing-based interaction.

Travel. The travel support requested will be necessary in order to facilitate the presentation of early work at various international workshops, as well as to maintain Lancaster's existing track record of presenting work at key conferences.

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