Towards affordance based human-system interaction based on cyber-physical systems

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Abstract: Human-computer and human-system interaction has already received extensive attention from HCI research communities, yet there are a number of issues that has not been addressed so far. In this paper we propose a novel vision on future human-system interaction that is governed by the principle of affordances and facilitated by cyber physical systems. The paper reflects on current theories and practices with the goal to adapt existing results in order to apply them in living and working environments operated by cyber-physical systems. It also proposes a number of research challenges that would pave the road to realize this vision.

1 Introduction

With the expected proliferation of cyber physical systems, conventional definition of product service systems needs to be refined. While traditional product service systems offer a given set of functions to serve specific user needs, Cyber Physical Systems (CPS)s are not only capable to fulfil these traditional functions, but they are also able to adapt themselves to emerging service demands. Cyber-physical systems consist of computational (i.e., hardware and software) and physical components, seamlessly integrated and closely interacting to sense the changing state of the real world. These systems involve a high degree of complexity at numerous spatial and temporal scales and highly networked communications integrating computational and physical components. It is expected that in the future, networked, cooperating, human-interactive systems will optimize human operations through high levels of situation awareness and adaptability [Le08]. CPSs will learn as they operate to maximize performance and resiliency, creating safe, secure, and reliable systems that can function as autonomously as desired by human systems designers. While humans will interact more seamlessly with the CPS of the future utilizing their emergent system behaviour, the ethical issues surrounding the human-machine interaction will be resolved prior to determining whether the human role will be as the operators of the machines ("human-in-the-loop") or as the partners of the machines ("human-in-the-mesh").

Building and further elaborating on this vision, we propose a novel scheme for affordance based human system interaction in Figure 1. In our interpretation, affordance of a dynamically changing environment is the capability or quality of resources of the environment (e.g. technologies, products, components, artefacts, digital media) and their purposeful composition by a cyber-physical system that is recognized by end users in order to carry out a task in a given use context. This definition is partially in line with Norman's definition [No99] in the sense that it takes into account that: (1) the perceived properties of environment resources may not actually exist, (2) suggestions or clues as to how to use the properties of a resources may or may not be available, (3) perception/ recognition of an affordance can be dependent on the experience, and knowledge or culture of the end users, and (4) resource affordance can make a task performance difficult or easy. On the other hand, it goes beyond the perceptual definition, since it assumes that the actors are not only humans but also the system, and actors are not only perceiving affordances of the resources, but they also create, discover and manipulate them.

According to the technology affordance model of Gaver [Ga00], perceptible-, hidden-, false affordances and correct rejections can be distinguished based on the existence of an affordance and the available perceptual information about it. In our context, we interpret perceptible affordances as properties of individual environment resources or

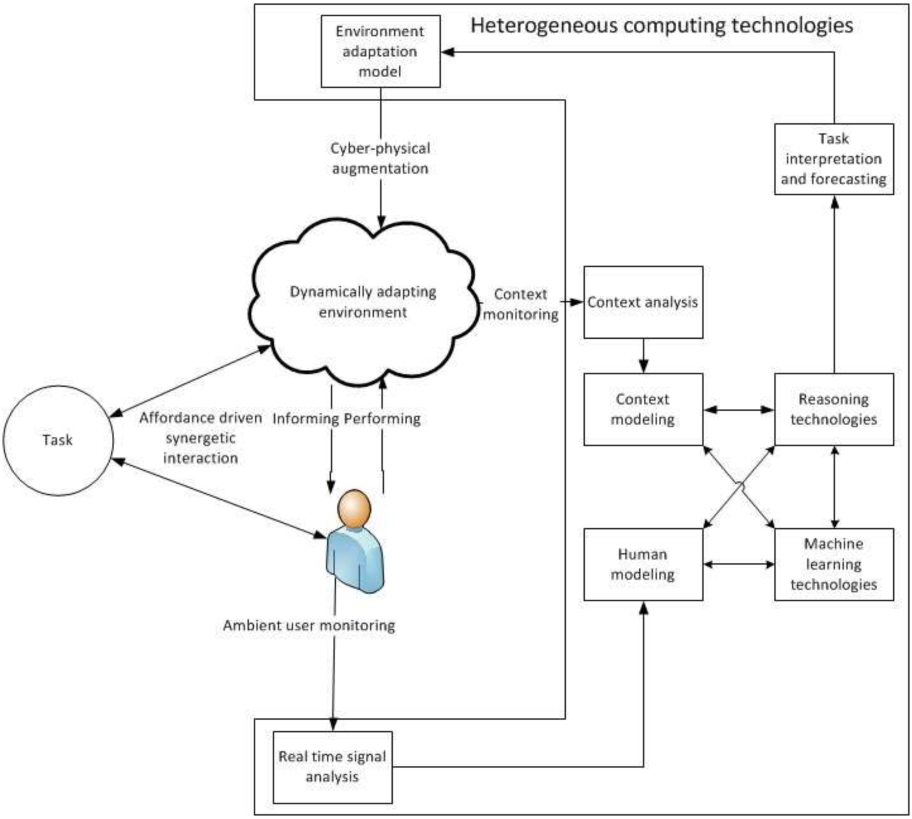

Figure 1: A model for Human System Interaction support by CPS principles

combination of them that is recognized by the actor to realize an action or quality of a product/service in a novel application context. We emphasize that the actor is not only the end user, but the cyber physical system itself that manipulates the environment resources and perceivable information to sufficiently inform actors.

In our vision, the cyber part of a CPS is represented by heterogeneous computing technologies, and the physical part of the system is envisioned as products and artefacts of natural and artificial environment that are together forming a service oriented cyber-physical system. In this scheme, it is envisioned that services are offered to the user through task oriented interaction, which is achieved based on available resources of the environment that are purposefully manipulated by heterogeneous computing technologies. Through this manipulation, the environment resources are presented to users considering users‘ capabilities and preferences, affordances of the environment and possible workflows for completing task(s) at hand. Task oriented purposeful manipulation of a dynamically adaptive environment, however, requires novel approaches capable to (i) monitor user characteristics and activities, (ii) inventorization and monitoring of artefact and products (iii) intelligent computing mechanisms to form models of the users, context and tasks, and (iv) synthesis and forecasting methods capable to model and simulate possible scenarios and expected outcomes. The paper presents a number of research challenges summarizing the essential issues of our concept.

2 Research Challenges

2.1 Ambient user monitoring and modelling

Ambient user monitoring and modelling enables cyber physical systems to characterize and profile users and to personalize services. Recently developed monitoring technologies are able to detect and interpret user activities, health and well-being, interest and preferences of users in given contexts, however, reliable monitoring of other characteristics among others emotions, motivation, engagement still require novel technological solutions [SS14]. When combined with advanced signal and pattern analysis technologies and machine learning techniques profiling of users and personalization of services can be achieved. To this end a number of research challenges should be addressed in the near future.

Research challenge 1: Systematic exploration of relationship among low level measurable indicators and high level user characteristics. For instance, while electromyography is primarily intended to measure muscle activities, the measured signal may also contain meaningful cues on the engagement level of a person. These secondary meanings of signals may be used to characterize user’s engagement in motor rehabilitation.

Research challenge 2: Developing human modelling architecture that enables personalization and human characterization by compiling the distributed human information from separate sources.

2.2. Context awareness

Context information is important for applications that need to adapt to situations in which the user′s context is rapidly changing. It is gathered from the environment surrounding the system to be utilized for enabling better adaptability of the applications. Dey and Abowd have introduced a general definition of context awareness of system [DA00]: *"A system is context-aware if it uses context to provide relevant information and/or service to the user, where relevancy depends on the user′s task."* The problem is to find a solution for dynamic acquisition and representation of distributed context information and its efficient provisioning for the applications in order to enhance their adaptability and context-awareness.

Research challenge 3: Development of monitoring technologies for every day object usage and physical environment and interpreting their (potential) role in the actual context. Context awareness of a system highly depends on systems' capability to capture and interpret relevant information about resources and resource usage in the environment.

Research challenge 4: Development of new principles for virtualization, modelling and representation of a complex, heterogeneous physical world.

2.3 Reasoning

Machine and system intelligence is still limited to few links and rules in representing and interpreting information and knowledge over the physical space, physiological space, psychological space, socio space and mental space [HPS01]. As a result, these systems and machines are not capable to autonomously discover laws and solve emerging problems in these spaces. They are merely able to process pre-designed algorithms and data structures in the cyber space with a limited ability to go beyond the cyber space, to learn linking rules, to know the effect of linking, and to explain computing results according to physical, physiological, psychological and social laws [Zh11].

Research challenge 5: Interpretation of physical, physiological, psychological, social, and mental processes requires development of new theories, approaches and algorithms capable to establish new models of humans, tasks and context.

Research challenge 6: Overarching reasoning approach to establish relations between task, human and environment models.

2.3. Cyber-physical augmentation

Cyber-physical augmentation entails the concept that existing systems and environments may be dynamically extended with new functions by purposeful composition of elements and cyber augmentation of existing artefacts governed by user needs and task performance [HG13]. Synthesis of new composition, however, is not a straightforward process. It may be governed by examples and solutions from the past, analogies to similar context and workflows as well as by modelling and simulation of possible outcomes in the cyberspace. Cyber physical augmentation holds among others the following research challenges for my interaction scheme:

Research challenge 7: Exploration of principles for composition of dynamic service provisioning based on existing environment resources, personalized user needs and requirements for task completion.

Research challenge 8: Modelling and forecasting the influence of cyber-physical augmentation on usability of the environment.

2.5 Informing

Informing aims to offer the user means to perceive and to comprehend the necessary information about a dynamically changing environment. Dynamic adaptation of the environment to user's awareness and task execution process is of importance not only to avoid information overload, but also to provide essential clues according to the capabilities and knowledge of the user. In addition, it is also important that the physical and cyber cues offered to the user are timely synchronized and do not provide contradictory information.

Research challenge 9: Development of methods cyber-physical augmentation with the goal to inform users on semantic, pragmatic, and apobetic levels of communication [Gi06].

Research challenge 10: Synergistic presentation of environment affordances with consideration to physical, mental and emotional states of the user and task completion steps.

2.6 Performing

Performing covers activities aiming at completing tasks in a dynamically changing environment. Execution of these activities can be supported by implementing automatism, surrogating and complementing user actions as well as by assisting users in task execution. Highly adaptive and assistive systems are capable to adapt themselves to the level of assistance required from the user [MH14].

Research challenge 11: Development of principles and methods for dynamical adaptation of environment to user needs and task performance.

Research challenge 12: Development of artificial learning mechanism for real time assistance of users.

3 Conclusions

The paper presented a novel view on human-system interaction considering affordances of a dynamically changing environment, which are purposefully manipulated by cyber physical systems. The goal of this paper is to provide a position statement and to initiate a discussion in the scientific community of human computer interaction and cyber physical system developers. It identified a twelve research challenges that are needed to be addressed in order to realize affordance based human-system interaction. The authors strongly believe that these research challenges are addressing the most urgent issues related to human-system interaction as well as they are creating a roadmap for implementing a human-in-the-mesh concept.

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