From Sensing to Acting—Can Pervasive Computing Change the World?

Summary based on:
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Further resources can be found in chapter 5 (References).

1. Introduction

Pervasive computing, also known as "ubiquitous computing," involves integrating computing into the daily lives of individuals and the physical world. This field has made significant progress in the "sense" and "think" aspects of the Sense-Think-Act model but has not made as much progress in the "act" aspect. Thus, the next step for pervasive computing is to focus on the "act" aspect, in which computers are able to actively adapt and react to changes in their environment. The healthcare industry is suggested as an area where this could be particularly useful. Another field with high potential is machine learning and artificial intelligence. It is suggested that AI & ML will play a crucial role in enabling computers to take action based on the data they collect.

2. From Sensing to Acting

2.1 Actuator Hardware and Technology

Pervasive computing research has advanced significantly in the development of sensors, but there is still a need to research and develop novel actuator technology that can influence and act on the physical world. Examples of actuator technology include loudspeakers, motors, and thermostats. This technology is already being developed in specific domains, such as home automation and the automotive industry. In healthcare, there are also emerging examples of "actuation" technology, such as the Implantable Cardioverter Defibrillator (ICD) and closed-loop systems for the management of diabetes [1]. To continue making progress in the field of pervasive computing, it is important to be creative in finding ways to utilize existing actuator technology.

2.2 Operating Systems and Programming Frameworks

Pervasive computing research has made progress in the development of sensor technology and programming abstractions to handle and manage the data collected from these sensors.

However, there is a need for programming models that can link sensing, analysis, and acting together in order to effectively utilize actuator technology and allow computers to take action based on the insights gained from sensing and analysis. To achieve this, programming abstractions such as concepts, design patterns, software frameworks, and APIs are needed to bridge sensing with acting and effectively utilize advanced sensing and analytical technologies merged with actuator technology.

2.3 AI and ML Models

Artificial intelligence and machine learning methods have been widely used in pervasive computing for analyzing and understanding data collected from sensors and other sources. However, less attention has been given to using these methods to take action based on the insights gained. Researchers have explored the use of recommendation technology, applying AI and ML methods in the field of mental health to predict the potential impact of certain activities on a person's mood. This technology has the potential to improve mental health and well-being by suggesting activities that are likely to have a positive effect on the user [2,3]. Using AI and ML for recommendation technology may be a promising approach in the broader field of pervasive computing.

Emerging foundational AI models may accelerate this development. Recently published Large Language Models (LLMs) like OpenAI’s ChatGPT [5] can not only conduct human-like conversations, but learn almost anything based on language, e.g. writing code, controlling robots, generate creative content and many more. Groundbreaking innovations like these will bring disruptive and yet unpredictable economic changes as the model’s capabilities are growing exponentially [4].

2.4 User Interfaces and User Experience

Pervasive computing should go beyond just collecting data and analyzing it and instead actively assist and help humans. To do this, computers need to be able to sense, think, and act in the world. Much research has been done on the sensing and thinking aspects but not as much on the acting aspect. In order to move towards acting, there are several key research topics to address, including the development of novel actuator technologies, understanding and designing for autonomy and safety, and developing new user interface technologies. These challenges will require interdisciplinary research, drawing on fields such as robotics and autonomic systems.

3. Topics and Challenges

3.1 Innovative Actuator Technology

One key research challenge in the field of pervasive computing is to investigate the technology behind actuators or the components that allow computers to take action. This includes hardware, software, operating systems, programming languages and frameworks, artificial intelligence and machine learning methods, and user interface technology. Some of these technologies will be specific to certain applications, such as home automation or medical devices, while others may be more general purpose. All of these technologies will involve a combination of sensing, thinking, and acting components that integrate technologies from across the entire technology stack. Pervasive computing research has always been interdisciplinary, and this will continue to be the case as the field moves towards a more active focus. Disciplines such as robotics and autonomous systems will become increasingly relevant in this context.

3.2 Safety

One of the major challenges in transitioning from data collection to taking action is ensuring human safety. This will be a significant ethical issue in a more active pervasive computing research agenda, similar to how privacy has been a major issue in data collection. Safety is particularly important in the medical field, where automated technology such as insulin pumps must be thoroughly tested for performance and accuracy. However, safety is also an issue in other areas, such as home automation and energy usage, where incorrect actions could lead to flooding or excessive energy use. It will be important to establish a scientific vocabulary with concepts, methods, and theories on how to deal with safety in pervasive computing, including methods for formally verifying the safety of safety-critical systems. This may involve regulatory certification, similar to what is required for medical devices, and a greater emphasis on reproducibility and verifiability in research. Formal methods for assessing, analyzing, and verifying the behavior and safety of pervasive computing systems will likely become a key part of this field. Another safety issue may be biased AI that has been trained on a certain set of data, which iis gaining relevance in research too.

3.3 Levels of Autonomy

Autonomy, or the degree to which a computer acts independently and the degree to which a human is involved, is an important research topic and challenge in the field of pervasive computing. Pervasive computing systems can be completely autonomous, operating without

human intervention or supervision. However, as computers become more autonomous, it becomes important to understand the role and involvement of the user. This includes how to communicate with the user, how to interrupt the user, and how the user can understand and interact with the actions of the computer. These issues are particularly relevant in the field of human-computer interaction within pervasive computing.

4. Outlook

The progress that has been made in pervasive computing, which involves integrating computing into the daily lives of individuals and the physical world is discussed in the article. While significant progress has been made in terms of collecting and analyzing data, there has not been as much progress in terms of taking action based on that data. In order to truly be useful and helpful to humans, computers need to be able to act on the information they collect. This will require the development of new actuator technologies and a focus on understanding and designing for safety and autonomy. The article suggests looking back at earlier writings on pervasive computing and related fields, such as artificial intelligence, in order to further develop and refine the research and development agenda in this area. Additionally to the aspects discussed in the paper, we suggest to take in to account the most recent and considerable advances in the development of foundational AI models, as their impact might be disruptive to many fields [4].

5. References

[1] Walsh, F. (2022). Artificial pancreas to revolutionise diabetes care in England. Accessed on January 4th from: https://www.bbc.com/news/health-60133358

[2] D. A. Rohani, et al. (2021). “Recommending activities for mental health and well-being: Insights from two user studies,”IEEE Trans. Emerg. Topics Comput., vol. 9, no. 3, pp. 1183–1193.

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[4] The Economist (2022). Huge “foundation models” are turbo-charging AI progress. Accessed on January 2nd from: https://www.economist.com/interactive/briefing/2022/06/11/huge-foundation-models-are-turbo-charging-ai-progress

[5]: OpenAI (2023). DALL-E 2 text to image generator, from: https://labs.openai.com/e/p2LfiFr48AKJ5MRUo7OvO73E