Architectural Robotics: Unpacking the Humanoid

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Abstract
In most projections of intelligent environments, the design of the physical is neglected - a bystander to progress. Researchers routinely explore, *a posteriori,* augmenting the underlying architectural morphology with suites of sensors, processors, and associated intelligence. Additionally, numerous researchers introduce intelligence into the environment via self-contained mobile robots - mostly humanoids. In this paper we offer an alternative vision in which the environmental design itself plays a more active role, assuming many of the tasks traditionally envisioned for robots ("unpacking the humanoid"). We discuss some implications of the adoption of this vision into the future, focusing on the ten-year window in the immediate future.

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Intelligent environments, architecture, robotics

ACM Classification Keywords
I.2.9 Robotics, H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. H.1.2 User/Machine Systems

Introduction

The advent of the microprocessor and its associated technologies has radically altered our world. However, fundamental change has arisen in the way we live, rather than in the (built) world in which we spend much of our lives. Our (architectural) environment, while increasingly filled with the new technologies, remains in essence “in the background”, its structure largely inflexible and unchanging.

This is not to say that Architecture has been untouched by technology. Environments are increasingly designed with emerging technologies as key elements (for example in “smart classrooms”). However, in these environments, technologies serve mostly as utilities and/or embedded appliances. In looking towards the future, a key common theme is the desire to make conventional environments (for example “smart homes”) more adaptable and intelligent.

Two general approaches to endowing (built) environments with intelligence have emerged. In the first (and most predominant) of these, a combination of sensors are attached to, or embedded within, the built environment. (In popular culture, this general strategy is dramatized in George Orwell’s *1984* [9].) The sensor readings are combined with computational elements (often also embedded in the environment) to infer characteristics of, and events within, the environment, and respond to them in an “intelligent” manner beneficial to the occupants. Examples of this general approach appear in [4] and [11].

The second general approach to making environments “intelligent” comes from the field of robotics. In this vision, the intelligence lies within self-contained robots, which are brought into the environment and which may be modified with markers or sensors to assist the robot. (The vacuum cleaner “Roomba” robot is a good example.) The robots capabilities for mobility and manipulation (i.e. to move mass) are used to supplement or complement the equivalent skills of humans occupying the same environment. This mode of independent robots entering the human environment is a staple of science fiction [1], [2]. In an interesting real world example of the strategy, a variety of robots have recently been deployed in museums [6] across the world.

In either of the above two approaches to intelligent environments, the environment itself is, literally, a background element. The goal is to introduce intelligence into a physical (built) environment, neglecting the possibility of the architectural morphology playing a key role. Additionally, the intelligence introduced is largely an “add-on” to that of the humans in the environment, rather than being integrally connected with it. The new intelligence is intended to *do things for* people rather than to work with them.

In this paper, we consider the possibility of the built environment assuming a more active role, notably in terms of incorporating significant physical adaptation (i.e. moving mass). We argue that, by carefully designing selected aspects of the environment to “morph”, the spectrum of possibilities for “intelligent (physical) spaces” is greatly expanded. The implications for both Architecture and Robotics are significant, challenging both conventional notions of what constitutes a robot, and of how the field of Architecture might evolve.

An Alternative Vision

The two approaches to future intelligent environments outlined above fall broadly within the disciplines of Ubiquitous Computing, Robotics, and Artificial Intelligence (AI). However, the innovations remain concentrated largely within those individual areas, and the field of Architecture remains scarcely impacted.

We believe that there are major gains to be made by adopting a more truly interdisciplinary approach. Specifically, we envision a new class of robotic environments wherein (carefully selected parts of) the environment are designed with programmable movement capability. The collective intelligence of the environment would be correspondingly distributed. The idea is to capture the strengths of the static sensor-based environments ("watch, perceive, and advise") and the "robot-into-environment" strategy ("investigate, fetch and carry"), while mitigating the inherent weaknesses of each.

It should be noted that the core vision outlined here is not unique to the authors. For example the notion of distributed smart elements is well-espoused by Weiser in [13]. Negroponte envisioned a similar architectural evolution in 1970 [7]. Architecture has a long and rich history of innovation in the advent of new technologies, since (and prior to) Vitruvius [12]. There have been numerous efforts promoting "adaptive Architecture", for example [8], [14]. The vision outlined in this paper, expanding the recent work of the authors [3], represents a natural extension of all these efforts.

One new innovation suggested here is the concept of "unpacking the robot" and distributing its functionality within the architectural framework. To this end, we begin with of the notion of the ultimate robotic solution - the humanoid - and dissect its perceived role in order to expose key underlying factors that might be exploited, resulting in spatially-distributed, less obvious solutions.

Humanoids are not, of course, the only possible robotic solution. The robot characters featured in the movie *Star Wars* [10], namely box-like mobile R2D2 and humanoid C3PO, while entertaining fictional creations, do represent a good rough parallel to efforts in the field. Robotics (hardware) research has followed two major thrusts: manipulation and mobility. The current practical state of the art is represented by relatively simple industrial manipulator arms and (typically, wheeled) mobile robots. However, the ultimate goal for many researchers continues to be humanoids.

The creation of humanoid robots has been a core concept in robotics since the word "robot" was coined [2]. There has been much effort and some significant progress in humanoid research in the last few years [5]. Humanoids offer the alluring prospect of combining the mobility of mobile robots, the manipulation capability of robotic arms, along with independent action, in a shape and size that is inherently compatible with spaces and tools designed for humans. In the context of this paper, humanoids promise to eliminate much of the need for environmental sensing and/or intelligence by "being," in an isolated, unified body, the eyes, ears, and brain the environment needs.

However, development of practical humanoids is an extremely difficult challenge. The self-contained practical humanoid must "do it all". To reach the point where humanoid robots could be safely deployed among humans, it will necessary to solve many – in fact, almost all – the major problems currently engaging the field of robotics. This includes legged locomotion, dexterous manipulation of general objects, real-time environmental sensing and cognition of unstructured and dynamic environments, and practical robot intelligence. We question the likelihood of these difficult problems all being solved in the near or medium term. This strong element of doubt remains for any non-humanoid system expected to be entered into an environment as a self-contained quantity.

Correspondingly, we question the extent to which static environments, however sensor-rich and compute-rich, will satisfy the general needs of motion-hungry humans. While there are certainly applications where pure environmental monitoring (with or without human intervention subsequent to events detected) is appropriate, motion is the key to most human environments. People move mass (themselves and other things) which inevitably obscures the view of sensors and changes the state of the environment in unpredictable ways. People also want or need to have things moved for them. In an environment judged intelligent by human occupants, the environment will, we argue, provide some motion capability.

A natural question therefore arises: which mass-moving capabilities should be “unpacked” from robotics into the environment? We believe that the solution lies in the way people are likely to want to interact with intelligent environments. We argue that, contrary to most philosophies underlying intelligent environments, in the wider view the intelligence should not *do things for* the occupants, but instead *help them do things*. We believe that an underutilized resource in most prior research in intelligent environments is the human occupant.

Humans tend to bring both intelligence and mobility into an environment. Humanoids are intended to replicate both capabilities. Intelligent environments which are static are usually coupled to some level of intelligence, but that intelligence usually is decoupled from that of the human occupants. We argue that by considering the human faculty, and exploiting some of its core sensing, manipulation, and intelligence capabilities, many problems which currently appear daunting can be greatly simplified, with their solution transformed into the realm of near-term feasibility.

For example, a nursing home might feature a robotic organizer/storage retrieval system. This organizer, storing and shuffling modular “drawers” containing occupant effects, would be integrated with its physical surroundings. A robot “tongue” would emerge from the wall to deliver and retrieve selected modules on demand. A bed-ridden human would provide the complex and higher-level actions, organizing, identifying, and manipulating the objects in the modules. And the physical environment itself would provide the complementary low-level logistics. All of these components could work more or less harmoniously and semi-autonomously as required of the activity. What has been “unpacked” is local mobility and materials transfer. The scenario is quite feasible with current technology.

Thus, our high-level vision of future intelligent environments is one in which the physical environment plays a more active role, adapting parts of its morphology in close partnership with the actions of the humans in the environment. We envision the human-environment relationship to be highly symbiotic. Not only will the capabilities of the environment reduce the demands on the human occupants, but also – critically from the design point of view - vice versa: the human inhabitants of such an environment will reduce the demands on technology.

Future Possibilities: 2019 and Beyond

What form might future intelligent environments take if the vision in the previous section were adopted? We envision an ensemble of simple programmable moving elements integrated into the overall environment, each with a specific function, each working as integral components of an ensemble. For example, an aging in place application might feature a robotic organizer/storage element as discussed above, along with a programmable side table, a travelling post (to provide physical support when necessary along commonly traveled pathways), morphing ribbon displays/sensors and flexible touch screens. Each element would have "just enough" intelligence and/or mobility to perform its designated function, autonomously and as a networked system. A collective higher intelligence for the environment may or may not be necessary, depending on the application.

Innumerable variations on the theme suggest themselves. For example, a "saved" configuration of the ensemble in one space might simply reform in another (from the resources in the new environment), as a person moves during the day. In an alternative approach to sensing, the environment could feature subtly moving and adjusting sensors (to achieve greater coverage with few sensors, for example). This could be achieved using conventional hinge joints, or using continuum stalks and tentacles.

How evolved might general intelligent environments be in 2019? It is likely that the amount of progress that an observer viewing current research would expect in the near-to-mid term will depend strongly on the degree of belief, on the part of the observer, of the probability of major breakthroughs in computational intelligence and autonomous robots. AI and autonomous intelligent robots are the key elements in most current efforts; they also have traditionally been, and remain, the two major "holy grail" problems in robotics. The authors doubt the likelihood of sufficiently significant breakthroughs in either area to cause a paradigm shift in practical intelligent environments by 2019.

We do, however, believe that breakthrough near-to mid-term advances are quite likely following the approach outlined in this paper. Consider the following fundamental questions: Does a physical machine have to be a humanoid (or an autonomous robot at all) to robotically augment humans? Do people want such machine servants? Does a system have to possess machine intelligence to exhibit intelligent behavior when acting in concert with humans? We believe that the answer to these questions is "no" and that exploiting the reasons for this response provides a new way to think about the design of intelligent environments.

In summary, the direction for future intelligent environments suggested in this paper involves not the insertion of technology into architecture, but in many aspects the reverse. Our vision involves the architectural element in a more central and dynamic manner, creating and exploiting a novel human-environment-machine symbiosis. The resulting sub-discipline would not reside within Architecture or Robotics, but form a new hybrid of the two. The "future" outlined here presents significant challenges for both disciplines (and those allied with them) as well as many exciting and promising possibilities. For more information, see www.cT-project.org.

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