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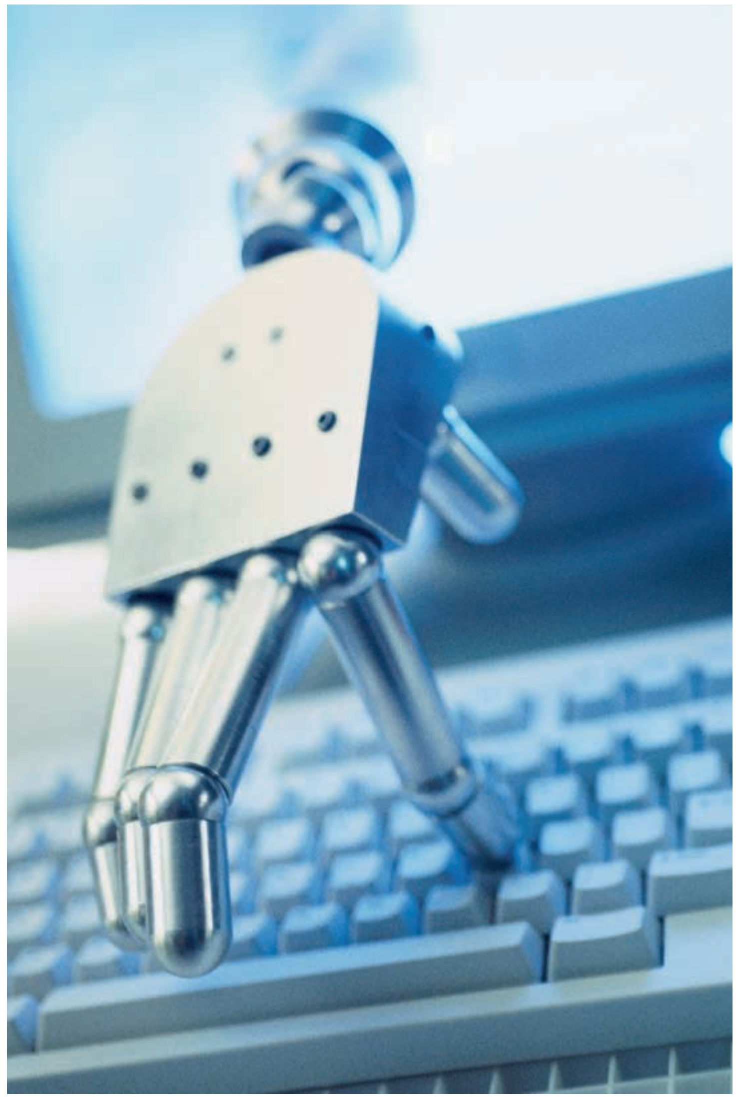
Computer-Controlled Human Operators

A new paradigm for human-computer interaction: humans guided and controlled by the computer.



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The nature of computers has changed dramatically in the last half century. Early computers were rudimentary devices that had poor language skills (assembler, FORTRAN) and impoverished interfaces and peripheral devices (typewriter, punch-tape/card reader, magnetic drum/tape memory, video display unit). Humans communicated with the computer using the computer's "baby-talk" and learned to adapt to the computer's limitations. Thus, even at this early time, humans were forced to accommodate the computer's deficiencies. However, because these early computers were so limited in their capabilities, humans controlled the interaction (Fig. 1).

Even though computers were limited, their designers' ambitions were not [1]. The goal of cybernetics, as developed in the 1950s and 1960s, was to make machines that could behave like humans by finding ways to program them with human-like intelligence [4].

One potential application of cybernetics—computer-automated design—was to develop computers that could autonomously undertake all aspects of the design process. This proved too ambitious, partly because the computers were not sufficiently powerful, but mostly because no one knew, in sufficient detail, how humans used their intelligence in the design process. Programmers were forced to downgrade their idea to our current concept of computer-aided design in which the human was given the essential role of providing intelligence to the design process.

Thus, when computers were first developed, the computer was clearly a human's servant. This "human-master/computer-slave" relationship was summarized in the well-known Isaac Asimov's Three Laws of Robotics:

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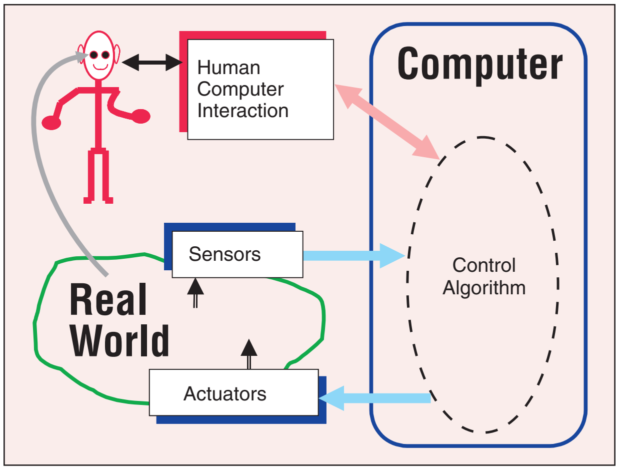

Fig. 1. Human-computer interaction.

- First Law: A robot must not harm a human being or, through inaction, allow one to come to harm.
- Second Law: A robot must always obey human beings unless that is in conflict with the first law.
- Third Law: A robot must protect itself from harm unless that is in conflict with the first and second law.

Since computers have become more powerful, the essential nature of the relationship between humans and computers has evolved. Today, computers have become essential to our daily economic and social lives to the extent that people are now often dependent on the computer; the computer has become a more demanding partner. For example, people are dependent on access to computer-based banking, through automatic teller machines, debit cards, and authorization of credit card transactions. If these computers fail to function, the average person does not carry sufficient cash to subsist for more than a few hours. And, even with cash, the average cashier does not know how to make change without the aid of the computer-based cash register. Such dependency allows the computer to dictate to the human how the transactions will proceed to the extent that the ways that we conduct our daily business are dictated by the computing and information technologies that we use.

If we give computers this much control in our lives, we risk becoming the servants of the computer. Consider, even now, how workers on assembly lines or airline pilots have every movement determined by the needs of the computer systems that perform their operations. One of the most extreme examples is the human operator who provides telephone directory assistance to the public. These operators are little more than voice recognition devices for computers. Upon receiving the typical call, the operator's sole task is to ask for the name and type it into a computer. It is the computer's responsibility to search for the name that was typed by the operator, return the most likely match, and generate a spoken reply to the user.

It is interesting to note that this evolution of the essential nature of the relationship between humans and computers was recognized by Asimov, who in the mid-80s introduced the Zeroth Law of Robotics [3]:

- Zeroth Law: A robot may not injure humanity or, through inaction, allow humanity to come to harm.

The Zeroth Law affects accordingly the first law:

- First Law—updated: A robot must not harm a human being or, through inaction, allow one to come to harm, unless this would violate the Zeroth Law.

Human Beings as Peripheral Devices

Computers are becoming smarter and providing human interfaces that accommodate a wider range of human capabilities [5], [8]-[11]. The human computer-operator is beginning to act as a peripheral device for computers (a most intelligent and dexterous peripheral device, to be sure, but a peripheral device, nonetheless).

We should consider the characteristics of the human as a computer peripheral for two reasons. First, the human being is only valuable as computer peripheral to the degree that his or her capabilities complement the capabilities of the computer. For example, human beings are not valuable for their memory because computers can remember more and can recall it with far greater accuracy. Conversely, as in the case of the directory assistance operator, human beings are valued for their ability to recognize spoken words.

Second, this view provides designers with ideas for characteristics that may be incorporated into other peripheral devices. Consider how the characteristics of humans complement those of computers:

- Humans are intelligent, far more intelligent than any computer is likely to be for many decades to come. This intelligence means that human beings can adapt to a variety of interfaces with computers. They can act on incomplete or ambiguous instructions. They can interact directly with other humans.
- Humans are mobile. They can leave the vicinity of the computer, perform complex tasks in a variety of different environments, and then return to report on the outcome;
- Humans can recognize visual, auditory, olfactory, gustatory, and haptic stimuli. They can classify these stimuli according to abstract patterns;
- Humans are dexterous. They can precisely manipulate a wide variety of objects, regardless of variations in their shape or texture;
- Humans are emotional. They can vary the characteristics of response, depending on the global state of each individual. Depending on emotional state, the human may trade speed of response for complexity of the analysis of different options; trade accuracy for force of response; or even trade inaction for action.

There are applications such as remote sensing, environment monitoring, and telerobotics for hazardous operating environments requiring very complex monitoring and control processes, which cannot be fully automated. Human operator expertise must still carry out tasks requiring a higher level of intelligence. In such cases, human operators and intelligent sensing systems are called to work together as symbionts,

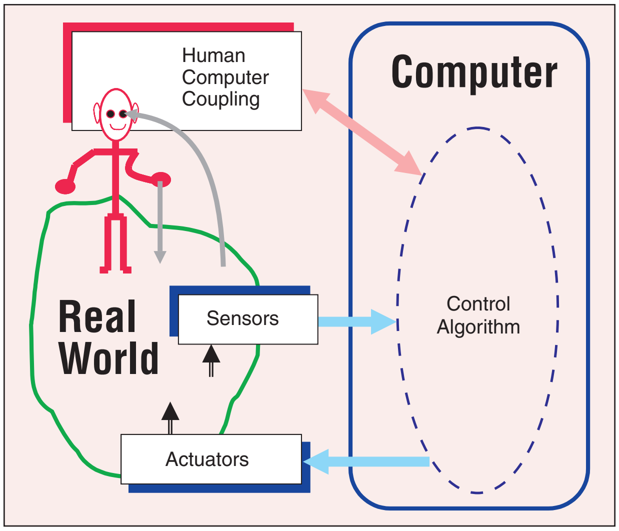

Fig. 2. An example of a human-computer interaction with a computer-controlled human operator in the physical or real world.

each contributing the best of their specific abilities [10], [11], [8]. A proper control of these operations cannot be accomplished without some telepresence capability allowing the human operator to experience the feeling that he or she is virtually immersed in the working environment.

The visual and auditory devices, which are currently used in human-computer interfaces are inadequate for these applications. A wide range of geometric-, force-, and touch-domain human-feedback devices will have to be developed. For efficient solutions to the complex perception tasks, these symbiont intelligent sensors will have to combine their intrinsic reactive-behavior with higher-order, world model representations of immersive virtual reality systems.

The diagram in Fig. 2 shows the human-operator acting as an intelligent, dexterous computer-peripheral that is able to carry out mechanical operations more efficiently than a robot.

Computer Interfaces to Human Beings

Given that a human being is a valuable peripheral device for a computer, the next question is: "How do we interface the human being to the computer?" Unlike other peripheral devices, there is no agreement about a standard human interface. We do not even have de facto standards.

Humans are very high-bandwidth creatures. The human visual system is capable of perceiving more than a hundred megabits of information per second. Human skin, the largest human sense organ, is capable of perceiving nearly that much, as well. The human auditory system does not have nearly as much capacity as the visual system, but does add another significant source of input.

For output, human speech is certainly capable of a wide variety of expressions; it contains information in the form of intonation and inflection as well as the actual words uttered. People communicate through body language which includes gestures, facial expressions, and eye movements. These motions are very important to communication. Humans are the only animals with a small colored iris embedded in a white sclera, making it possible for other people to detect very small changes in the direction of a person's gaze. Moreover, there is evidence that people make important judgments about other people based on "micro-expressions," fleeting movements of the facial muscles that are barely noticeable.

A specialized form of gesture is drawing and writing in which a pen (or keyboard) is moved by the gesture to form persistent images or linguistic tokens. Existing computer interfaces, even graphical user interfaces on high-resolution monitors, only make use of a small fraction of the bandwidth that is available to humans. Once again, we rely on the intelligence of the human being to learn to use non-standard interfaces and understand the ambiguous information that they present.

As computing power expands at an ever-increasing rate, it is expected that the current human-computer interaction (HCI) interfaces will evolve to more user-friendly human-computer coupling (HCC) interfaces [9].

Computer-Controlled Human Operator in a Structured Environment

Fig. 3 illustrates the human-computer interaction for a human operator carrying out complex computer-controlled mechanical operations in a structured environment. Using augmented virtual reality and an optical see-through head mounted display (HMD) device, the human operator acts as an intelligent dexterous manipulator [5]. The working environment is structured by a model-based mapping of all objects of interest using pseudo-random encoding [7].

The optical see-through HMD is preferred over the vision-based HMD because of its higher reliability (the operator can see through even in a power outage) and reduced latency while preserving the natural hand-eye coordination, which is essential for delicate manipulation operation.

Images of the working space taken by HMD video camera are used to identify the pseudo-random marked objects. To identify and locate a given object in the scene, the computer vision system must have a complete a priori knowledge of the shape parameters, which unequivocally define that object.

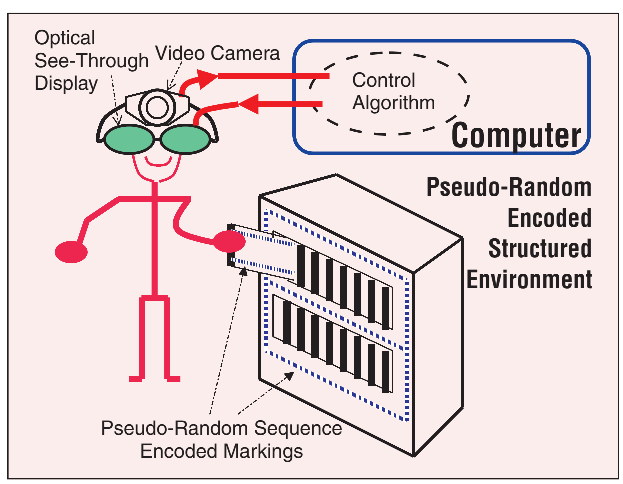

Fig. 3. A computer-controlled human operator in a structured environment using pseudorandom encoding.

This knowledge, usually the geometry and color of the object (used for object identification), is referred to as model of the object [2].

Model-based object recognition essentially consists of matching object descriptions obtained (on-line) from the input data to the (off-line produced) model description of the object. Machine vision systems for practical 3-D object recognition applications should be insensitive to the position, orientation, and scale parameters of the visualized objects. These systems should also be able to recognize partially occluded objects.

Conclusion

The new evolutionary stage of computing technology is represented by the information appliance paradigm seen as being "the natural successor to today's [computer] complexity... through the user-centered, human-centered, humane technology of appliances where the technology of the computer disappears behind the scenes into task-specific devices that maintain all the power without the difficulties" [6].

These information appliances should be able to learn and adapt their behavior to changes in their working environment including other appliances as well as human users. It's reasonable to expect that under these circumstances the information appliances will work in partnership with humans who will contribute human-specific capabilities (including innovation, complex pattern recognition, and dexterous object manipulation) that complement the capabilities of the computer. It will be a symbiotic human-computer partnership in which each partner will lead in some cases and provide assistance in other cases. The leader / assistant role of a partner will be decided on the basis of maximizing the overall efficiency of the symbiotic team.

Acknowledgments

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