Robotics - Past, Present and Future

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The earliest glimmer of robotics occurred in mythology. The dream of creating artificial humans paralleled the dream of creating wealth through alchemy to transform lead into gold. In Greek mythology we see sculptor Pygmalion fall in love with his statue of Galatea. Venus, the goddess of love, takes pity on Pygmalion and breathes life into the cold marble.

And, in the Middle Ages in middle Europe, folks believed in the Golem, a creature created out of mud and embedded with superhuman capabilities. Then in the 1400s and 1700s ingenious designers built robots out of cams, gears, springs and music box drums to emulate human activities such as piano playing and letter writing. We have all along wanted to believe that robots could be created though human cleverness and magic.

It would be human cleverness and not magic that eventually made robotics practical. As late as the 1939 World Fair in New York, Westinghouse created a robot exhibition featuring Electro and Sparky, a robot and his pet dog. They were hits but their technology was of the 1500s, cams, gears, and so forth.

Despite the wistful dreaming, a useful robot would not become possible until after World War II. Charlie Chaplin in his incisive film, *Modern Times*, had by 1936 foretold the need for robotics by demonstrating the enervating effect of modern manufacturing upon the human psyche. Yet, it was not to be until our technical tool kit included servo technology, digital logic and solid state electronics.

Victor Hugo wrote that there is no power on earth so strong as "an idea whose time has come." The idea was rattling around with Capek's 1922 play Rossum's Universal Robots and in the 1940s' stories of Asimov that set the rules for robot morality.

The Three Laws of Robotics

1. A robot must not harm a human being, nor through inaction allow one to come to harm.
2. A robot must always obey human beings, unless that is in conflict with the first law.
3. A robot must protect itself from harm, unless that is in conflict with the first or second laws.

Armed with aerospace technology of the moment and a seminal patent by one George C. Devol, my company Consolidated Controls Corporation undertook to build an industrial robot. By 1961, that Unimate® robot went to work in a General Motors plant. It operated a die cast machine, the arch typical hot and hazardous job that human workers might best be relieved of. Unimate 001 is now in the Smithsonian Museum after working the lifetime hours of a human laborer unto retirement.

Hurrying past the origins to the present we see an international industry now running at approximately six billion dollars per year. That industry was born of U.S. innovation but has prospered largely as the result of Japanese implementation. **Figure 1** is a broad but necessarily incomplete list of jobs performed by robots for the economic as well the social benefit of industry employers and employees.

I have said that a practical industrial robot awaited technology. Emergence of the available technology set the scene for Unimation Inc. We could build a hydraulic powered robot with record playback programming to attack those heavy duty chores that demanded husky male labor using both hands. It was the automotive industry that first saw the potential. The work was hard and operations ran two shifts. Robots earned their keep.

It was in 1967 that Japan flexed its muscle. My privilege was to push the embryo industry in Tokyo. There was no time wasted, JIRA was born with 47 members! Okay, the innovation came from the USA. But Japan became the producers. By the 1990s, Japan's robot manufacturers were dominating the industrial robot industry. Japanese manufacturers had improved reliability from an initial 400 hour MTBF to an MTBF of 15,000 hours. After proving the technology in Japanese industry, Japan spread its wings to offer conservative, reliable industrial robots worldwide.

Here we are today with a six billion dollar industry dominated by Japan. Robotics, justified originally only by cost saving, can now claim advantages of quality, throughput and human safety.

What next?

Now it is time to look forward. The industrial robot scene is stable. Robots have become commodities. There are green ones, orange ones, blue ones all with similar specifications. Ho hum! Meanwhile the technology pertinent to robotics has outstripped industrial robotics. When robots can truly see, feel and understand spoken commands they can aspire to tasks in the unstructured world in which we lead our daily lives. A spectrum of such applications were proposed in my 1989 book, Robotics in Service. These applications are listed in the next two slides (**Figure 2**). A culmination comes in robotics devoted to personal service. That would be great fun for most of us and a great boon for those of us who are elderly, frail and unable to live independently.

In **Figure 3** we see a compendium of capabilities, largely sensory, that will enable robots to cope effectively with the jobs listed in Figure 2.

A "Golden Age" approaches for robotics. It will be driven by the available technology applied to the needs of an aging citizenry. Throughout the industrialized world the fastest growing population is the aged, still cognitive, but physically handicapped. Robots will serve these folks in a personal and competent fashion that can no longer be expected of their progeny. Senior citizens, living independently with robot caregivers, will enjoy help in daily living at a much lower cost than could be offered by conventional nursing home service.

As a cause celebré I reach out internationally for sponsors of the final development of a robot caregiver. How wonderful for commercial interests to enjoy remarkable profitability while adding quality to the twilight years of our seniors. Following is a short list of likely tasks for a robotic caregiver - fetch and carry, meal preparation, clean house, monitor vital signs, assist ambulation, manage the environment, communicate by voice, take emergency action - and in **Figure 4** we see jut one kindly act, "offering an arm." What excitement to be facing such a fine challenge at the turn of the century!

CURRENT APPLICATIONS

Die Casting	Machine Loading
Spot Welding	Stamping
Arc Welding	Plastic Molding
Glass Handling	Investment Casting
Heat Treatment	Conveyor Transfer
Forging	Palletizing
Paint Spraying	Inspection
Fettling	Order Picking
Lab Automation	Batch Assembly

Figure 1

SERVICE ROBOT APPLICATIONS

Hospital Porter	Farming
Commercial Cleaning	Gas Station Attendant
Guard Service	Hotel Bell Boy
Nuclear Power Maintenance	Space Vehicle Assembly
Underwater Maintenance	Military Combat
Parapharmacist	Companion for Infirm
Parasurgeon	or Handicapped

Figure 2

Robotics Toolchest

Electronics
- Low-cost, high-speed microprocessors
- Vast memories, negligible cost

Servos
- DC
- AC
- Stepper
- Hydraulic

Controllers
- Point-to-point
- Continuous path
- Sensor-driven

Application Software
- VAL
- KAREL
- RCCL
- and others

Position and Motion Sensors
- Encoders
- Resolvers
- Compasses
- Passive beacons
- Active beacons
- Ceiling vision
- Inertial(Gyro)
- Clinometer
- GPS

Range Scanning
- Ultrasound
- Light triangulation
- LIDAR
- Optical flow
- Capacitive
- Inductive

Vision
- Structured light
- Stereo
- Scene analysis
- Template matching
- Colorimeter
- Bar code readers

Tactility
- Wrist force sensing
- Torque sensing
- Fingertip arrays
- Limit switches
- Contact bumpers

Voice Communication
- Synthesis
- Recognition

Artificial Intelligence
- Expert systems
- Sensory fusion
- Fuzzy logic
- Semantic networks

Figure 3

Figure 4

General Design Theory and Environment

Hiroyuki Yoshikawa

1. Design

Designing is an important feature possessed by the human race. Design exists in each field of technology, such as architectural design, mechanical design, and so on; it represents the thought processes for newly creating things that did not exist prior to then. The imaginative processes outside of fields of technology have been given names like creation and production and have not been called design. When we perceive that they all share common grounds in fundamental areas, it will probably be easy to understand that design bestows upon human beings a characteristic strikingly different from those of other living creatures.

Consequently, it would seem that giving consideration to what design is is an unavoidable part of reaching an understanding of what human beings are. Moreover, it is of substantial importance to people in two senses. Factor number one is that because it is a quality not possessed by other living things, we must know about it in order to comprehend human beings. It can be referred to as an eternal theme for humankind.

The second point is that once something that has been designed and manufactured starts to exist in the real world, it will end up changing its own environment. That is directly linked to current environment problems and in some ways is an urgent issue.

Thus, it is necessary to clarify how research should be carried out concerning design as a topic of substantial importance. Since design represents various actions that reflect the distinguishing features of technology and other worlds, infinite "design theories" have come into formation with individual acts of design as their subjects. Furthermore, although architectural design theory and electric circuit design theory are both types of design, they have ended up as completely unrelated academic fields.

The sphere of research that pays attention to the parts common to all acts of design conducted by human beings and which also aims to produce theories for them is called "general design theory". General design theory first limits its questions to design in technology. Then, having done that, the task for general design theory has been to render it possible for the ideas conceived by human beings to exist physically. In other words, the subject under general design theory's consideration generally consists of the act of bringing such things to realization as man-made objects.

2. General Design Theory

Attempts to describe design in technology as a system can be found from long ago. As is aften said, it takes over ten years in any realm to become well-versed in design. In addition, many of the documents describing design have been backed by a designer's own long-time experiences. In books with titles like design theory, design methods, and so on, the designer's own experiences are directly related as if to talk about them to the reader. These in reality are highly useful books.

However, though backed by the same experiences, there have also been attempts to describe the subjects of design and the design process as systematically as possible and to establish a system for objective design. Through extracting the subjects for design as the structural relationship between functions and substance, general descriptions have carried out; a standard model has been sought as the time series for the design process; the collection of previous examples of design has been taken as the scope; and psychological methods have been used, etc.

The aforementioned all try to relate design in an as general form as possible as the foundation of actual examples of design conducted up to now. These attempts have obtained definite results and are, of course, valuable for people learning design. However, they share some common problems. That is to say, there is no way to guarantee the legitimacy of any theory of design nor to disprove mistakes. As long as those are basic experiences in design, the field will definitely be correct in some ways yet will lack the possibility of growing as a science.

That is where attempts have arisen to formulate a plan to describe design systematically all the while fulfilling the conditions of a science. If that is possible, it will be a plan in which design theory as its result will advance into a minute system through theoretical research into the field. Moreover, as a result, the act of designing as its practical application will promise a harmonious development offering a richer artifactual environment.

General design theory has been proposed as one possible method going in accordance with the line of such a plan. That takes as the axiom a simple model related to the human conceptual system, and it attempts to describe all the acts of design as the theorem. If it is verified that all the theorems obtained can explain without exception the acts of design in the current world, then that will bear a structure in which the axiomatic system-namely, the legitimacy of the theoretical system deduced from that-will be strengthened.

3. Verification

General design theory, which was proposed in the 1970s, has only three axioms; it is a very abstract thing. Speaking from the premise that applicable design theory exists in the design of all spheres, such abstractness is inevitable. But a problem is presented in that the theorem obtained will be abstract, too. Moreover, when it comes to verifying the theorem, that will not be abstract since the means of verification consists of observing the designs of actual designers. Here arises the characteristic thorny problem of the disparity between the abstractness of the experiments for identification and the theoretical results obtained; it is a problem that does not appear in the so-called exact sciences such as physics.

Similar problems exist in other intellectual research as well. Nevertheless, perhaps we ought to conclude that, on account of this, design research ultimately can not enter the scope of empirical science as a method in common with the natural sciences, which conduct verfication through experiments and the presentation of hypotheses in the theory.

At present, the outlook is that there will be limitations to general design theory's ability to improve its precision through empirical science methods. That is because a task within general design theory is for the people who are designers through and through to construct theories concerning the act of design within their own perceptions and controllable thoughts. And these thoughts have limitations to the accuracy of their observations. Expressed another way, they are believed to differ in nature from natural phenomena, which are the subjects for observation in the exact sciences like physics.

4. Validity

Something replacing observation and measurement in empirical science or else something supplementing that is needed to solve this problem. The method known as utility has been proposed in general design theory. That means to develop a system that can undergo practical application in reality based on knowledge obtained from general design theory and to use it in actuality. Namely, this is to put it to use and judge its value. If it is useful, the design theory proposed as a hypothesis can be regarded as standing up to verification. However, if it is not useful, it will be disproved. Here a system that can undergo practical application means anything from primers on design, to anthologies of actual examples of design, calculator systems, and so on. In any case, it must reflect the design theory.

In reality, to create these systems or else judge their value is the venue for actual design. At times that will be in the laboratories for design research, but the design section of a manufacturing industry where actual design activities are conducted may suffice just as well. In that case, the survival or the system in the market is linked to verification of the theory. Consequently, the fundamental set of proposals for hypothetical theories in empirical science and verification through experiments comes to be replaced here by the set known as proposals for hypothetical theories and judgment of their legitimacy through utility.

In this way, considering that general design theory is something crisscrossing various fields of engineering, engineering can be suggested as an independent field of scholarship with a structure different from that of empirical science. In addition, utility means reality, or to make an existing thing. Therefore, a connection can be anticipated as well with historical science, which is related to things that have existed. A task for the future is to have "practical science" become possible, which will verify theories through utility as a way to provide structural connections between empirical science and historical science.

5. Utility

In this way, general design theory does not stop at mere contemplation in research laboratories; it needs not to be practial application but must be connected with the real world even in its theoretical structure. With this background, general design theory has shown a number of developments up to now.

The second meaning of design research, which was touched upon at the outset--namely, the view that what people have made has ended up producing a unique environment for human beings--becomes the weightiest topic in the sense of the previously mentioned utility. In this case, it goes beyond the question of how human beings have designed, for it means to research the artificial environment itself. What is called an artificial environment in general does not exit. There only exists one real environment that surrounds humankind; the research treating it as its subject is artifactual engineering.

On the one hand, planning practical usage as a substitute for experiments and historical investigations is importants as well. For example, industry-university cooperation is one venue for utility, but at the present juncture that tends to be excessively induced by myopic material gain.

If utility is to be viewed as everything that creates history, in this case technological design as something producing an artificial environment should be injected compositely as much as possible into human intelligence. Only once that becomes possible will it also be effective as a venue for verifying design hypothesis. The "Intelligent Manufacturing System (IMS) International Cooperative Research Program" has been proposed from that perspective, and it is corrently being advanced.

6. Closing

Research concerning design is something I stepped into, led by simple doubts as to whether engineering is an academic field. There have been various developments thereafter. The aforementioned artifactual engineering and IMS Program have facets that are not necessarily connected at all with general design theory, rather they have been born out of the demands of a particular era. Yet that makes possible the interpretation that reseach into design theory has developed in a way not unconnected to the changes in the times.

My conclusion currently is that engineering itself is a unique academic realm. However, its development ought to be joint with the technological actions of human beings. Therefore, I have expectations about the day when engineering, in link with an expansion of technology, will be positioned as a more general and basic field of scholarship.