Robotics in Civil Engineering

Dr. Tanjina Nur, Ph.D.

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Preface

This book illustrates the robotics and computer hardware and software applications in Civil Engineering. It tries to identify one or multiple problems where the use of automation, robotic technologies, or advanced management techniques can be applied to provide innovative solutions in civil engineering such as construction works, safety measures of construction site, damage inspection, building analysis etc. At beginning, we discuss the using of intelligent techniques in construction project about cost estimation and mobile imaging and computing for intelligent structural damage inspection. Then we present the nonlinear dynamic analysis of plates stiffened by parallel beams with deformable connection and numerical simulation of particle distribution in capillary membrane during backwash. Automatic method for building indoor boundary models from dense point clouds collected by laser scanners and an aerial-ground robotic system for navigation and obstacle mapping in large outdoor areas are also discussed.

In the middle part of the book, we focus on set up of an automated multi-colour system for interior wall painting and a wireless monitoring system for cracks on the surface of reactor containment buildings. Geospatial information categories mapping in a cross-lingual environment: A case study of "Surface Water" categories in Chinese and American topographic maps and passive wireless hermetic environment monitoring system for spray painting workshop are also discussed. We also try to present temporal-spatial evolution analysis of Lake size-distribution in the middle and lower Yangtze River basin using Landsat imagery data and a survey about recent advances and challenges of wall climbing robots.

The last chapters of the book describes bridge deck load testing using sensors and optical survey equipment and laser-based pedestrian tracking in outdoor environments by multiple mobile robots. We also try to find out generation mechanism and prediction model for low frequency noise induced by energy dissipating submerged jets during flood discharge from a high dam and maximum stress estimation model for multi-span Waler beams with deflections at the supports using average strains. At the end, we describe a practical monitoring system for the structural safety of mega-trusses using wireless vibrating wire strain gauges and obtaining the thermal structure of lakes from the air.

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INTRODUCTION

The word robot is usually used to refer to a mechanical agent that performs one or more tasks in which it mimics a human or animal agent either through programming or commands. Another word used synonymously is automaton. Virtual robots exist, but are most often called by the abbreviated name bots.

This term comes from the Czech word robota, which means drudgery or servitude. It was coined by Karel Capek, a Czech playwright, in his play R.U.R., which stands for "Rossum's Universal Robots." It was published in 1921, and entered English in 1923. The field of study is referred to as robotics, and people who specialize in it are called roboticists.

Robots can be classified in a number of ways. Creators may use the means of locomotion as their categories, differentiating their creations by whether they are static, on the one hand, or whether they have treads, a propeller, fins, legs, wheels, rotors, or other means of propulsion.

The National Aeronautics and Space Administration (NASA), however, classifies robots in several different ways. First, it classifies them by whether they work on Earth or in space. Second, it classifies them by the industry they work in. Third, it classifies them by the type of jobs they do.

These machines are employed in industries such as manufacturing, medicine, the military, and transportation. They are used widely in assembly operations, in which they complete a range of tasks, including the following:

- arc welding
- diecasting
- fettling machines
- gas welding
- manipulating machine tools
- placement of items into a structure that's being built
- sealant application
- spot welding
- spray painting

Robots are also used for parts inspections, making glass, cleaning, monitoring radiation, sorting, loading and unloading, fastening, forging, and sand blasting. Because they are not human, they can be used in hazardous situations such as firefighting, military warfare, and bomb detection. Surgical robots are under development and robotic hands, for example, are already used in some surgical operations, allowing the human surgeon more control in laparoscopic procedures, those done through a very small incision.

Droid is the name for a type of intelligent robot. The droid comes from a shortening of the word android, which means "an automaton that has features of a human being." Examples of droids include C-3PO and R2-D2 of Star Wars fame. George Lucas, the creator of Star Wars, has trademarked the term.

In the real world, a number of companies are working on android robots that closely resemble humans and are able to interact with real people. Much of the current work is being done in Japan and South Korea. Some South Korean companies hope to make them a household item in the future.

What is Advanced Robotics?

The term "advanced robotics" first can into use in the 1980s. It is used to define any sensor-based robots that attempt to mimic human intelligence. They are used in a variety of fields ranging from manufacturing, nuclear, construction, space and underwater exploration, and health care.

Popular culture is filled with advanced robotics. The robot on the television show Lost in Space and movie robots like Star Wars' C3PO and R2D2 were some of the first seemingly intelligent robots that average people were exposed to. In 1986, movie-going audiences met Johnny 5, the little autonomous robot from the movie Short Circuit. While all of these robots appeared truly autonomous, the robots themselves were largely a combination of puppetry and acting.

By the late 20th century, the science fiction of advanced robotics and the reality of it were beginning to overlap. Advanced robots of the 21st century are considered semi-autonomous. This mean that they are able to perform their tasks with a level of independence not found in automatic machines. Those called general purpose robots are able to perform their required tasks nearly independently. Some can recognize people or objects, talk, monitor environmental quality, pick up supplies and perform other useful tasks.

Robots are able to do these tasks through the use of a sensor. A simple example of this sensor is in room cleaning robots that bump a wall and understand to turn around and try another direction. Lawn mowing robots rely on underground markers to tell them this same information. Some of the most advanced robots are able to actually "see" through the use of infrared or stereo vision.

Some of the most advanced robotics of the 21st century are humanoid robots, meaning they resemble humans in their physical appearance as well as in their actions. They are considered autonomous because they can learn and adapt to changes within their environment. Johnny is more of a reality in the 21st century than moviegoers of the 1980s could have imagined. Robots are being taught everything from how to load a dishwasher to mimicking facial expressions in response to particular types of human interactions.

One of the greatest feats of advanced robotics was seen in the rovers Opportunity and Spirit. Opportunity and Spirit landed on Mars in January of 2004 with the intention of completing an approximately 90-day mission. As of January 2009, five years later, they were still in operation. They landed on the surface with a precision unmatched in previous missions. They operate through communications with the National Aeronautics and Space Administration (NASA) and continue their missions through semi-autonomous interactions with the surface of Mars.

There were estimated to be about 3,540,000 service robots in use in 2006. At that time, there were an additional 950,000 industrial robots. In early 2009, Microsoft founder Bill Gates has predicted that every home will have a robot by 2025. Small robots like room sweepers and surprisingly complicated entertainer robots like Furby have been in homes since the 1990s. Given the advances even since those robots were introduced, the future of advanced robotics certainly seems boundless.

Application of Robotics to Building Construction

The findings of the study can be summarized as follows:

a. Construction is the largest single industry in the United States, both in terms of its output, and the labor force employed in its projects. It is also one of the least advanced, in terms of technological progress and productivity. The largest and the most homogeneous part of the construction output are the buildings which account for 70% of its total value. Any technological innovation which could increase the building construction productivity would therefore have a highly beneficial impact both on the national economy and the welfare of an individual consumer. As such it should be thoroughly examined and encouraged.

b. The robotization is gaining an increasing acceptance in the manufacturing industry. The robot population in the U.S. is growing at an exponential rate and is expected to reach, towards the beginning of the next decade, 100,000 units. This growth is accompanied by a large investment in research and development of the robotic technology. No parallel trend is evident in the construction sector. No robots are employed in construction at present and there is almost no research and development towards this end.

c. The robotization of the construction process is more difficult than that of the manufacturing production, due to dispersion of the construction activities over many sites, distinctive nature of each project, changing work location within the project and the rugged conditions on the building sites. Despite these conditions many building construction activities can be robotized at the present stage of technology with promising economic results given an appropriate design of the robotic equipment and a suitable organization of the construction tasks.

d. The main components of a robotic system which should be examined with reference to application in the building construction industry are the manipulator, the effector, the control unit, the sensors, and the locomotion mechanism. Almost all building activities, except for hauling of large structural members, can be performed with the existing configurations of robot manipulators, which must, however, be made sturdier considering the ruggedness of the building environment. The handling of heavy members can be performed with existing crane like manipulators. The effectors needed for building construction can be classified into two categories: grippers adapted to the nature of the objects to be handled, and specific working tools depending on the task to be performed. The robotic control of building operations has two levels. At the first level it ensures through appropriate preprogramming the performance of a required task (like painting, welding, etc.) at a static location. At a higher level it directs the movement of the robot over the entire work area with an aid of feedback from sensors and appropriate artificial intelligence algorithms. This second level requires, at the present state of technology, an additional development effort for dependable and economically feasible robot's navigation. The control of robot operations can be facilitated by human intervention , either direct, or through a teleoperator. The sensors needed for ensuring required quality of preprogrammed activity at the two control levels belong to the vision, contact and proximity classes. All these sensors require additional development for dependence, sturdiness and adaptation to building conditions for feasible application at the second level of control, and even for many operations at the first level. The mobility of robots over continuous surfaces does not pose any mechanical difficulty and depends entirely on the development of sensors and control units. Human intervention will be required when the robot is to move over discontinuous surfaces like, e.g. from one to another floor in the same building.

e. he building construction activities consist of handling of building components, connecting them to the existing structure and finishing them by application of appropriate mechanical treatment. The most amenable to robotization are the activities which require covering (with liquid or semiliquid substances) or conditioning of large continuous surfaces - vertical or horizontal, e.g. painting, spraying, plastering, trowelling, etc. These activities can be robotized without difficulty at the present stage of technology. Less amenable, but possible to robotize are activities which require moving the effector at different locations in a predetermined pattern - linear or point to point, e.g. welding, bolting, jointing, spreading of fabric rolls, etc. These activities can be robotized in building with a proper adaptation of sensory devices. The least amenable to robotization are activities requiring handling and assembly of components like structural steel members, precast elements, bricks, formwork, sheathing, etc., which require picking, orientation, precise positioning and often temporary supporting of objects.

f. A selective robotization of the building construction works can be attained with minimum development if applied to the first two groups of building activities as enumerated above. A more comprehensive robotization particularly promising under hazardous or harsh environments must, however, involve also assembling tasks. The process can be simplified when using large self-supporting prefabricated components comprising as many building works as possible, and thus minimizing the extent of assembling work on site. The finishing work on site should be limited, as much as possible, too simple, one activity, covering or conditioning tasks.

g. Four types of robots can perform all major building construction tasks. The first type used for handling of large building components may have a configuration of a building crane or a concrete pump boom. It will use grippers for picking and placing of the components, and a control unit with teleported or sensory guidance. The second type can be employed for most of interior finishing, and connecting works. It will use an anthropomorphic arm with a reach of 3-4m and tools according to the type of work to be done. It will operate from static work stations, each one encompassing a room size service area, with a preprogrammed mode of operation. The quality and precision of its work can be monitored by vision, tactile or proximity sensors. The robot may be used either directly by a working crew who will move it from one work station to the next and set it up for operation at each work station, or guided by a teleoperator, or act autonomously with movement between work stations and its setting up for operation at them monitored by sensors and an appropriate artificial intelligence algorithm. The third type employed for finishing of large horizontal surfaces will consist of a self-propelled carriage with the finishing effector mounted underneath. It can also use one of control alternatives, and associated sensory devices as described above. The fourth type will be employed for finishing of vertical exterior walls. It will employ a carriage suspenaed from the roof's parapet with the effecting tool mounted between it and the wall surface.

h. Actual robotization of the building tasks must be preceded by a detailed predevelopment design process which includes analysis of the present construction method, designing several alternatives of robot employment, selecting of conceptual design of system components for each alternative, preparation of appropriate operational procedure for each alternative, and conducting a thorough feasibility study to determine the optimal choice, which will be consequently detailed for development.

i. The development effort will focus on a manipulator with sufficient reach (for the general purpose robot), and a carriage adapted to movement between work stations. Both should be made sturdy enough to operate in rugged building environment but their weight should be reduced as much as possible so as not to impose excessive loads on the structure. The development will include also effectors with their feeding systems for performance of different construction tasks, and sensors for interaction with guiding devices fixed in the structure.

j. The robotization of building construction may be easier within the framework of closed systems using large selections of predesigned components to be prefabricated in plant, and assembled on site. Such systems may employ CAD/CAM programs and procedures for design, managerial planning and robotization - on site and in prefabrication plant, of building projects, for optimal utilization of human, robotic and material resources. An extension of such systems will allow for automated adaptation of existing designs to particular requests of users. It will also allow for automatic adaptation of production resources in the prefabrication factory to the changes in the basic design.

k. A preliminary economic analysis indicates that a value of a construction robot to its user may be, under normal working conditions, approximately $250,000, based on 1983 prices. The value was calculated as the present worth of savings in labor from robot's employment less the associated operation and maintenance costs. It is expected, based on the current cost of manufacturing robots, that this value will exceed the cost of purchasing and installation of a construction robot after its development. This expectation assumes rational utilization of the robots in suitable building projects. Should the robots be used at a rate much lower than the indicated above, or in building projects very ill structured for robotization, they will have difficulty competing economically with the conventional building methods.

l. The value of robots in building construction increases under conditions which impair the performance (and decrease the productivity) of human labor. Such conditions arise when the building is performed under harsh weather (very hot or very cold), in high altitudes, or in extended periods of overtime work. . The economic analysis indicates that the value of robots under such, conditions may be higher to the user by 50% and more than under normal conditions, as discussed before. The value of robots is particularly high when their use can limit human participation in hazardous tasks with a high fatality or injury incidence to workers.

m. Another important benefit expected from robots application is the improved quality of the product due to a higher accuracy and a better control of robot operations. The benefits include savings in materials, in repair work during the construction, in maintenance thereafter, and a higher satisfaction of the user. These benefits are difficult to quantify, however their value is considered by users as important as productivity gains attained with robotization.

n. The economic success of robotization in building will ultimately depend upon the extent of replacement of the human labor. It may also change the contents of many existing tasks. Such changes may be resisted by the workers on site and their unions. The robotization will certainly require changes in the contents of managerial tasks on and off the building site, and the training necessary for their performance. It may also be resisted by the management, especially at the lower levels, in the construction companies. The resistance of labor and management may be avoided or at least mitigated if the implementation will be preceded by a planned effort to secure the cooperation of all parties.

What Does a Robotics Technician Do?

The job of a robotics technician is to design and maintain automated robotic systems. These technicians must be knowledgeable in a variety of areas, such as mechanical repair, electric circuit design, and computer programming. A two year associate's degree is usually required for individuals in this career.

Robotics technicians work in many different locations. Some are employed by factories and automation facilities. Industrial robots in these places usually have a specific job, such as welding or painting. Any time that a robot breaks or malfunctions, a robotics expert is responsible for diagnosing and repairing the problem. Robot techs must be able to work under pressure in order to minimize factory downtime and fix problems quickly.

Malfunctions in robotic systems are not always caused by physical problems, but can also be created by computer errors. A robotics technician must understand the programming code used to control a device. Technicians often must search through many lines of programming code in order to discover a mistake, and then re-program a robot to function properly. The ability to work methodically and patiently is a vital skill for workers in this profession.

Robotics technicians use a variety of diagnostic and repair tools. These include oscilloscopes and multimeters, which are used to measure electrical signals. Technicians must also be familiar with programmable logic controllers and electronics schematics, in order to determine the source of a malfunction.

Training for robot techs begins at the high school level. Individuals who are interested in this career typically take classes in science and mathematics. Many workers also attend a technical college or trade school to obtain an associate's degree in robotics technology. Over a period of two years, robotics students typically learn about microprocessors, hydraulics, electronics, and other technologies used to create robots.

The education of a robotics technician does not always stop at the college level. Many workers receive specialized training from an employer. Companies that use robots often train workers in the detailed specifics of a particular robotic device or model. Technicians gain valuable experience by working hands-on with robots in actual factory locations.

Some technicians become supervisors or trainers, and provide education about robotic systems to other workers. Robotics trainers work for technical companies, trade schools, and colleges, and demonstrate the proper way to use and repair robots. Technicians with high levels of experience can be hired by robot manufacturers, and provide advice on ways to improve new robotic systems.