ICT Technologies, Robotic and Automation in Construction

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***Abstract*--** **We are all witnesses that the beginning of the 21st century in technological terms is dedicated to mobile communications - they are everywhere: smart phones, IPods, readers, and many other wireless devices. Once a fiction today is a reality – music on demand, video on demand, and live video conversation via IP on a tablet. What will be the next technological achievement that will have such huge impact on human living? I dare to predict that the second half of this century will by highly influenced by mobile robotics – robots will become ubiquitous décor in everyday life.**

***Index Term*--** **Technological, Mobile Communication, Human Living, Mobile Robotics**

I. INTRODUCTION

Over the past century, anthropomorphic machines have become familiar figures in popular culture through books such as Isaac Asimov's *I, Robot,* movies such as *Star Wars* and television shows such as *Star Trek.* The popularity of robots in fiction indicates that people are receptive to the idea that these machines will one day walk among us as helpers and even as companions. Nevertheless, although robots play a vital role in industries such as automobile manufacturing - where there is about one robot for every 10 workers - we have a long way to go before real robots catch up with their science fiction counterparts. One reason for this gap is that it has been much harder than expected to give robots the capabilities that humans take for granted - for example, the abilities to orient themselves with respect to the objects in a room, to respond to sounds and interpret speech, and to grasp objects of varying sizes, textures and fragility. The improvement of hardware electronics and decreasing of the components prices enabled the robot builders to add Global Positioning System chips, video cameras, array microphones (which are better than conventional microphones at distinguishing a voice from background noise), and a host of additional sensors for a reasonable expense. The resulting enhancement of capabilities, combined with expanded processing power and storage, allows today's robots to do things such as vacuum a room or help to defuse a roadside bomb - tasks that would have been impossible for commercially produced machines just a few years ago. The confidence for the robot rising is based on recent developments in electronics and software, as well as on the observations of robots, computers and even living things over the past 30 years.

In October 2005, several fully autonomous cars successfully traversed a hazard-studded 132-mile desert course, and in 2007 several successfully drove for half a day in urban traffic conditions. In other experiments within the past few years, mobile robots mapped and navigated unfamiliar office suites, and computer vision systems located textured objects and tracked and analyzed faces in real time. Meanwhile, personal computers became much more adept at recognizing text and speech. A second generation of universal robots with a 100,000 MIPS (mouse-brain) will be adaptable, as the first generation is not, and will even be trainable. Besides application programs, such robots would host a suite of software "conditioning modules" that would generate positive and negative reinforcement signals in predefined circumstances. For example, doing jobs fast and keeping its batteries charged will be positive; hitting or breaking something will be negative. There will be other ways to accomplish each stage of an application program, from the minutely specific (grasp the handle underhand or overhand) to the broadly general (work indoors or outdoors). As jobs are repeated, alternatives that result in positive reinforcement will be favored, those with negative outcomes shunned. By the end of the century, humans will meet monkeylike five million MIPS, embedded in a third generation of robots that will learn very quickly from mental rehearsals in simulations that model physical, cultural and psychological factors. Physical properties will include shape, weight, strength, texture and appearance of things, and ways to handle them. Cultural aspects will include an items's name, value, proper location and purpose. Psychological factors, applied to humans and robots alike will include goals, beliefs, feelings and preferences.As mentioned briefly in the previous sections, the construction industry has already seen the introduction of automated and semi automated means in the production of construction elements. The transition from totally manual process to nowadays semi-automated system permits to increase the productivity. Nevertheless, the advance in construction industry is not comparable to advances in other industries such as manufacturing and especially in the sectors of automobile, electronics, train, aircraft, etc. The car prices, the number of different models and variations, and the concept of mass production make the automobile industry much close to construction than the others. One of the key factors of any industry's success evaluation is its productivity.

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The CIM systems permit to balance the flexibility in the product with the manufacturing productivity. This relationship is one of the key factors of the success of the automobile industry. While the house-building construction industry continue to be very close to craft work, constructing mostly singular buildings, the automobile industry continuously seek to reduce the cost of product development. This permits also to reduce the cost of the final product. The so called platform concept of the actual automobile industry is one of the newest advances of the CIM system. It is based on the use of a number of elements in various models. The same platform design, engine, electronics, etc. are used not only in different Trends in Robotics and Automation in Construction 3 models of cars of the same company but also in the cars of other companies. This concept reduces a vehicle cost and makes the automobile companies more competitive. The high level of integration in all the production stages permits to start from the design process taking in mind the manufacturing and market aspects. The platform concept and integration lead to the high level of robotization and automation in automobile industry. In some of the EU plants the level of automation (the number of non-manually made operations respect to the total number of operations) is more than 60%. Mass production brings down the cost not only of the end product (in this case, the cars) but also the cost of manufacturing equipment (robots, machine tools, etc.). This is why during the last decade industrial robot prices in the EU have decreased and their number has increased.

Robotics in manufacturing industry is an evolution while the robotics in construction industry is the not yet finished revolution. While the number of industrial robots is counted in hundreds of thousands the number of robots in the construction industry is counted in hundreds only. Important efforts have been made to adapt the CIM concept to the construction industry created the Computer Integrated Construction (CIC) (Miyatake & Kangari, 1993) (Balaguer et al. 2002). Unfortunately, this effort has better results only in the IT related stages of the construction process (planning, suppliers' relationship, etc.) but not as good results in the production stages (pre-fabrication technology, building erection, masonry, on-site automation, etc.). Despite the recent development in RAC, the gap between the technological levels of both industries is still very high The CIM concept permits to reduce not only the cost of manufacturing but also changes the corporate culture (Kangarii, 1996).

It is easier to introduce the new technologies in automobile industry than in the construction. In general, the construction industry continues to be very conservative. In many cases when the new automatic products are not complementary to the old ones, they are hardly implemented and their use is kept to minimum. Moreover, if these products introduce inconveniences to the whole construction cycle, they are openly refused. To the contrary, in the manufacturing industry the people and the environment respond very positively to technological innovation. Researchers and end users speak the same "language" and share the same objective, which allows introducing these new technologies very quickly. According to ACEA, in 1999 the EU automobile industry investments in R&D were over 5% of the turnover while the construction industry investments in house-building technology were less than 3% (Euroconstruct, 1998). In the construction industry the big companies tend to limit their capacity to invest in "tomorrow's construction robots" from which return on investment is uncertain and too far in the future. This is also the case of the big construction machines companies, which tend to invest more in civil engineering equipments than in development of equipments dedicated for house-building.

In the field of road construction, several projects had been developed over the last decade. They were mainly focused in the development of the new generation of semi-autonomous road pavers and asphalt compactors. The EU projects CIRC (Peyret et al., 2003) and latter OSYRIS (www.osyris.org) had as the main objectives, based in the GPS and laser data, the semi-autonomous guidance of the machines and the quality control of pavers and roller processes by controlling the speed, temperature, layer thickness, travelled distance, etc. The coordination of several machines in order to improve productivity is also the objective of the project. In the field of earthwork the research is centred in the introduction of new control techniques to existing machinery like excavators, bulldozers, draglines, etc. One of the major exponents of this research area is the control by CSIRO of the 100-m tall walking crane used in surface coal mining (Corke et al., 2006). The swing cycle of the dragline accounts for about 80 percent of time taken. The automatic swing cycle improves the efficiency of the machine, taking in mind that the bucket which weighs around 40 tones when empty and up to 120 tones when full, acts as a large pendulum and requires operator skill to control well. The torque-force control during the excavation is also improving the productivity of the processes. The University of Sydney project (Ha et al., 2000) developed an automated excavator that accounts for interaction forces in analyzing the required bucket motion therefore seems promising. As the bucket comes in contact with its environment, the contact force must be regulated such that it remains within a specific range by using specific control strategy The periodic inspection and maintenance of the civil infrastructures was another important research activity. The inspection of building skeletons, complex roofs, off-shore platforms, bridges, etc. represents an extensive and valuable field of work. It is estimated that in the EU there are over 42.000 steel bridges with a replacement cost of 350 M€. The ROMA family climbing robots (Balaguer et al., 2000) able to travel in a complex 3D environment carry out several inspection sensors (laser telemeters, colour cameras) in order to transmit the field data to the "ground" system. The key issue of these robots is the grasping method (grippers, electromagnets, suction cups, etc.).

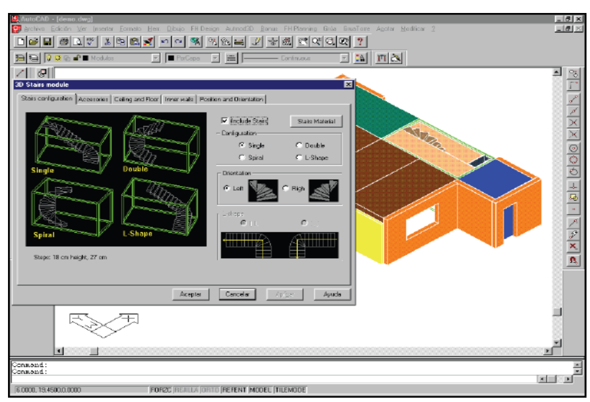
Interior-finishing operations in the building are very time consuming and requires high degree of accuracy. There are several mobile manipulators able to perform variety of operations like extend, compact and control the thickness of the floor concrete, painting and steel column fire protection spraying, assembly of interior walls and ceilings, etc. Most of these robots are teleported and perform only simple operations. The most representatives ‘robots of this type are Japanese ones. Three examples are presented: the "Mighty Hand" robot from Kajima (www.kajima.co.jp), which lifts heavy elements in construction as concrete walls, etc., and the SurfRobo from Takenaka (www.takenaka.co.jp), which automatically compact the concrete floor by using two sets of rotary floats. The right hand side of the figure shows Kajima´s concrete floor surface finishing robots. These robots are already used in several building construction sites where they succeeded in releasing workers from thousands of operations (Hasegawa, 2006). The last decade has witnessed the development of several robots for automatic assembly of buildings. An effort had been done in the brick laying masonry and the development of robotic prefabrication of façade and wall elements. The EU project ROCCO developed a large-range (10 m reach) and high payload (up to 500 kg) hydraulic 6 DOF robots for brick assembly (Gambao et al., 1997). The robot is equipped with auto-tracking laser telemeter in the tip in order to perform prices (up to 5 cm) brick assembly. In this way the control system avoid important arm flexion. The robot performs the assembly sequence obtained by the planning software and needs an initialization process in order to know the bricks pallet position. During the last few years a tendency to develop wearable robots for different applications immerged. First this type of robot were thought of from a military point of view, and that is to provide soldiers with powered exoskeletons to allow them handle heavy loads and resist longer periods without being exhausted. The main limitation of these robots is their power supply, but in the construction site this should not be a serious problem, since the robot can be iambically connected to a power source while being wearied by an operator. A wearable/exoskeletons robot is able to endow the operator with more strength beyond his natural limits and allow him/her to handle heavy objects during their construction activities such as carpentry or fitting ceiling boards as they require large muscular power. The prototype developed in (Naito et al., 2007) is an example of such application. The assembly of steel-based buildings is performing by welding, such as column-to-column and column-to-beam joints. The Japanese WR mobile robot performs a variety of column-tocolumn welding. The steel columns of up to 100 mm thickness can be round-, square-, or H-shaped, as well as box-sectional members. For column-to-beam welding, there is a combination of welder/transport type which can run on decks and a type which can weld lower flanges from below. Automation and robotization of the complete building erection is the most exciting experience. Applying to the high-rise building there were several Japanese projects. The most significant is the SMAT system developed by Shimizu (Miyatake, 1993). It was used for construction of more than 30 stories office building. It consists of all-wheatear, full-robotic factory on the top of the building. The lift-up mechanism automatically raises the construction plant and at the same time raises the on-site factory, called *field factory*. More recently the Dutch companies develop the new whole building erection technology but in opposite way of the previous system. The building is totally constructed in like factory environment and then transported to the final location. The 10 floor building called Bolder was transported by water in a three day operation.

II. SOFTWARE AND IT TECHNOLOGY IN RAC

As discussed in earlier sections, software and IT technologies (also called soft robotics in earlier publications by the authors) is not only limited to software itself but also includes other related technology as sensory data acquisition and processing, human operator’s field safety and security, chip-based process control, etc. This section describes the main applications and some examples of the actual software and IT trends in the automation of the construction industry.

III. SOFTWARE INTEGRATION

Software integration in the field of RAC is crucial for implementing the concept of the Computer Integrated Construction (CIC). The idea is to integrate in a common exchange format all the stages of the construction, i.e. from architect’s desk and planning tools to site robots. The EU Future Home projects develop the AUTOMOD3 system (Fig. 14) that integrates in a common CAD environment several tools like design, planning and automatic robot and machine programming (Balaguer et al., 2002). Due the high level of conservatism of building designers, the main idea is to use the common 2D architectural design (drawings) and automatically transform it into 3D drawings. In this way it is possible to perform also automatically the modularization of the traditionally designed buildings. This process permits to industrialize the house-building by modular pre-fabricated construction. Schedule management software packages are used more and more in construction. Nevertheless, its dynamic integration whit all the actors participate in the construction is not yet done. In a construction project, although the completion day is clearly decided, construction schedule is often changed by the weather or the actual progress situation of the project. When a difference arise between present state and the master schedule, it is necessary to adjust the construction schedule and to execute it immediately. The communication with part’s produced factory, transport agents, stores and other suppliers is performing in real-time and in automatic way (Lipman & Reed, 2000).



Mobile computing systems for data transfer between constructor managers and different web-sites have been implementing. The progress monitoring wireless mobile system permits to check the progress of the work. At the same time field note system is used to note unacceptable parts of works (Fig. 15). Inspection system is also used for inspect the result of construction. The document management system not only can communicate with the designers DBs in order to download the CAD drawings, but also permits the on-site modifications of these drawings. This soft technology is very useful and has a low cost which make it candidate for massive introduction in the site environment. The day when construction managers and operators carry only some paper drawings will be finished soon.

IV. Virtual Reality System

The Virtual Reality (VR) software together with an immersive projection display (IPD) allows construction managers to enter and interact with the contents of a full-scale building, before start of the construction or during the execution of the project. The virtual mock-up offers first person presence, or the feeling that you're actually in the room when you're just standing in a space bounded by five large screens that surround you with a projected image. The virtual mock-up experience is real enough to enable welders, for example, to crawl under virtual structures and hit their heads on virtual pipes to determine if there's enough room to work. Several immersive VR systems were developed during the last years, like at the Penn State University (http://www.arl.psu.edu), at the NIST (http://cic.nist.gov/vrml/ equip.html), etc. In the world of construction operations analysis, the ability to see a 3D dynamic animation of an operation that has been simulated allows the experts, field personnel, and decision makers can discover differences between the way they understand the operation and the way the model developer understands it. The dynamic VR is more close to animation than geometrical visualization. The actual research is focusing on designing automated, discrete event process simulation-driven methods to visualize construction operations and the resulting evolving products in dynamic, smooth, continuous, 3D virtual worlds. The discrete-event simulation systems, allows a computer to create a world that is accurate in time and space; and which shows people, machines, and materials interacting as they build constructed facilities.

Using VR system for simulation and training is another software and IT technology (also designated soft robotics by some authors) area. For complex machines like excavators, the VR system needs not only to simulate the geometry and kinematics of the machine but also the terrain and the interaction between the machine and terrain (Lipman & Reed, 2000). The simulation of digging and driving over the terrain is the crucial test. The terrain model is generated with an elevation grid technique which specifies a height field over a uniform grid. If the size of an individual grid in the simulation is smaller than the footprint of the excavator the system will work correctly and the operator’s sensation will be good. The system permits the simulation of the view from inside or outside the excavator cabin. To visually represent the digging process, the location of the bucket relative to the terrain and relative to the excavator needs to be known.

V. Discussion

Initially, robots were developed for the manufacturing industry and were intended to perform routine task in a very familiar environment. Unlike such robots, those designated for work on construction sites must be mobile, maneuver in changing environments, and perform a different task at almost every step. Construction engineering is changed by the application of more industrial production, sustainable production, mass individualization, and intelligent building to improve constructability. Therefore, recent research indicates that robot technologies can; in fact; significantly improve quality and equipment control in several construction automation applications. The ability to automate construction would be useful particularly in settings where human presence is dangerous or problematic; for instance, robots could be initially sent to underwater or extraterrestrial environments, to create habitats to await later human travelers. Actually, there is plenty of room for improvement in all process elements concerning robotics and automation.

VI. Conclusions

Changes in the work culture and environment of the construction industry in the past decade have brought to the fore innovations in construction technology and the approach in which construction work is performed.

With the implementation of automation and robotics technologies in construction, the industry could improve in terms of productivity, safety, quality and global competitiveness. The common barriers that have been identified which hinder greater automation application are, economics and cost, structure and organization of the construction industry, technology and culture or human factor. The importance of these factors towards the adoption of these technologies in construction is seen in the form of current automation and robotics technologies available and its real time application in construction. The degree of implementation and level of investments vary across the world from country to country, with the greatest concentration of robotics application in Japan. The difference can be explained through the different work cultures, government policies and incentives, and organizational point of responsibility. By taking advantage of the positive aspects to be gained in greater use of automation and robotics technologies, the construction industry may gain a competitive edge in the global market in the future as compared to other industries.

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