An Overview of the Literature on Robots

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ABSTRACT

This paper presents a holistic literature overview of worldwide theoretical framework and descriptions of modelling approaches of robots, in particular, mobile robots. The paper also shows the current learning experiences in robot systems. The study results are captured in an integrated, concise and elegantly-distilled way, underpinned with collected data and information. The holistic literature presented here aims to increase our understanding in this widely-expanding field and stimulate a higher level of proliferation of research articles in the field. Generally, the robotics literature is composed of a wide range of studies in diverse areas, notably, industrial applications, healthcare, construction systems and technological education and training, among others. There is a dire need to develop an understanding, founded on scientifically-verified data, of the critical variables and success factors for successful implementation of robotics systems. This may lead to a substantial, sustainable long-term improvement in practical performance results, value for money and effort. A reader of this overview paper would expect pointers in answering these questions. The real value of this paper lies in providing readers with motivated pointers on the details needed to implement robots based on worldwide past experiences and latest thinking.

Key words: Robotics, Automation, Mobile robots, Literature review

INTRODUCTION

There has been a major development in the high-technology literature in all aspects of basic and applied research on the analysis, design, realization and use of robots, robot component and robot systems (Wilson, 1997; Carelli and Oliveria-Freive, 2003; Demirli and Moihim, 2004; Virk et al., 2004). The study of robotics systems is the theory and methodology common to all collections of interacting, functional units that together achieved a definite purpose. Practically, it is concerned with the engineering design of interrelated, flexible automated units in addition to the basic problems of individual robots and robot component. The various subject ranges of the basic robots are defined as mechanics, control and sensor design (Tachi, 1999; Ma et al., 2001; Khoukhi, 2002). Mechanics include the design and structure of manipulators, arms and effectors, hand locomotion, vehicles and peripherals; actuators, power and energy storage; kinematics, dynamics and simulation; control includes both theory (electrical and mechanical control, optimization of paths and task planning) and implementation (hardware and software) (Arkin, 2001; Kochan, 2001a). Sensors have many parts which include design, algorithmic development for sensory data acquisition and analysis.

Specifically to systems, robots may be classified by complexity level: robot level (integration of mechanical controller, and sensory components); robot-cell level (integration of robots, peripherals, cell control, and local area network; applications and "taskware"; interface with human operators); and robot-plant level (integration of robot cells, plant environment, CAD/CAM interaction, and planning and implementation of computer-integrated flexible manufacturing) (Shirinzadeh, 1996; Maxwell, 1998; Biros, 2002; Borges and Aldon, 2003; Barnes and Liu, 2004; Klanar et al., 2004). Robots systems have become increasingly more complex. However, major aspects of robotics and automative include dynamics, design, control, sensors, vision, speech and object recognition, image processing, safety, reliability, economics and social implications and applications.

Recently, some emerging fields are observed in robotics that are less conventional. Two areas of these emerging fields in robot system designs are: (i) distributed robotics, sell-organization, and swarm intelligence, a field concerned with the design and operations of distributed multi-agent systems and the cooperative behaviour of multiple robots. The topic includes the theory and implementation of robots capable of asynchronous and distributed control, cooperative behaviours, relationships to biological systems, cellular robots and evolving systems, (ii) robot and human integration, a field concerned with the coexistence of human and robotics components both "within an individual and in society". This is a newly-emerging field of robotic systems, and it is still being defined. It includes the input, representation, processing and communication of all non-conceptual (e.g., emotional) information. Thus, research in this area currently includes aspects of robot-human cooperation, facial expressions, human-aided robotic interpretation, multimedia communication, virtual reality, biorobotics and cyborgs as they pertain to robot-human integration.

Given the fact that the robotics fields is wide-ranging with diverse articles in practical and non-practical-based studies, there is a current need for an article that makes a valuable contribution in providing readers with an overview of what have been done so far theoretically and in practice (Alkhadaji, 1991; Engelberger, 2001; Jose and Juan, 2001; Kyriacoy and Klein, 2002; Filliat and Meyer, 2003; Hagras et al., 2004). Such a study should have motivated pointers for the members of the robotics community and researchers on how to extend the frontier of knowledge on robots applications to areas not yet or not fully explored. Researches on robot applications have shown growing trends in applications of robot technology in waste management, hazardous activities, industrial applications in the oil and gas industry, marine route surveys, near-shore nautical charting and military surveys, pipeline inspections and monitoring of sensitive coastal environments, among others.

Recent trends in robotics research have shown a rise of interests in applications of robotics in both manufacturing and service industries (Kim and Kleiner, 1990; Fink et al., 1992; Masory, 1996; Hollingum, 1999). It is amazing to note that the development in the field and of robotics in the past few years has open up totally-new and challenging research areas. In fact, this development in the 20th century has prompted observers to predict the use of robots in unusual places (Kochan, 2002), for dangerous tasks (Hollingum, 1999), and in space exploration (Weisbin et al., 1997), among others.

The impact of robotics on the performance at various work places is complex and many-sided. On the surface, an appraisal of the impact of robots in practice bears some similarities to an appraisal of the audience in a movie theatre. A theatre can be judged to be half-full or half-empty depending on the perspective of the perceivers. By the same token, the impact of robots in practice can be judged to be considerable if one takes into account the multiple risks, cost savings, productivity and speed of production or service which the application of robots in work places makes possible and performable.

Some operations would be all but impossible today without robots. For example, it is not feasible for a human operator to convey materials from one part of the furnace in a steel rolling mill under extreme conditions of temperature and pressure. Such an individual may be roasted to death even at a distance from the furnace. As such, the family of the victim, the steel company and the nation at large may have to suffer the loss. Practitioners and researchers rely on robots in work places since they could be important tools from which one can collect data from process improvement studies. It saves countless years of tedious work by operators. The robot removes the necessity for men to monitor and control tedious and repetitive processes.

Despite the importance of robots, its potential is so little explored, particularly in the undeveloped countries that its full impact is yet to be realized. The motivation for this study is therefore the need to have a holistic form of the practical applications of robots for a number of benefits. Such knowledge would be useful for researchers willing to design, develop and implement robots in new work settings. In addition, new entrants into the field of robotics may be informed through this article of current state of knowledge.

The knowledge pool built up in this field has been enormous, thus creating significant economic, social and cultural benefits to the world at large. Although the use of robots is fascinating and very productive, the issue of the huge investment needed to have robotics in place and the high value of maintenance cost required to keep the system operating is retrogressive in expanding the concept to small scale enterprises (SMEs). It should therefore interest researchers to develop robotics that could manageably fit into the SMEs. This, therefore, calls for a radical change in the design and construction of robots, particularly for SMEs in developing countries.

Along this argument, Kim and Kleiner (1990) investigated into the investment decisions on the development of robotics technology. The literature on robotics is wide, covering diverse areas in technological education and training, construction systems, industrial applications, healthcare, among others. The following section is a brief review of the contributions of studies to the robotics literature.

PREVIOUS RESEARCH

Mobile robot

Extensive studies have been done on mobile robots as an important area of robot research. The variety of work done include localization studies (Engelberger, 2001; Borges and Aldon, 2003; Filliat and Meyer, 2003), and others (e.g., Normey-Rico et al., 2001).

Robot localisation research

In a study on localization, an extensive review of strategies for map-based navigation was made (Filliat and Meyer, 2003). The focus is a review on how robots use an external representation of the spatial layout of the environment to position itself as a very complex task, which raises numerous issues of perception, categorization and motor control that must all be solved in an integrated manner to promote survival. This point is illustrated here, within the framework of a review of localization strategies in mobile robots. The allothetic and idiothectic sensors that may be used by these robots to build internal representations of their emolument and the maps, in which these representations may be instantiated, are first described. Then map-based navigation systems are categorized according to a three-level hierarchy of localization strategies, which respectively call upon direct position inference, single-hypothesis tracking, and multi-hypothesis tracking. The advantages and drawback of these strategies, notably with respect to the limitations of the sensors on which they rely, are discussed throughout the text.

In another study, Demirli and Molhim (2004) introduce a new fuzzy logic-based approach for dynamic localization of mobile robots equipped with a ring of sonar sensors. In this approach, the angular uncertainty and radial imprecision of sonar data are modeled by possibility distributions. From sonar data, a local fuzzy composite map is constructed and fitted to the given global map of the environment to identify robot's location. As a result of this fit, either a unique fuzzy location or multiple candidate fuzzy locations are obtained. To reduce the multiple candidate locations, the robot is moved to a new location and a new local fuzzy composite map is constructed. Then a new set of candidate fuzzy locations is obtained. By considering the robot's movement, a set of hypothesized location is identified from the old set of candidate locations. The hypothesized locations are matched with the new candidate locations and the candidates with lowest degree of match are eliminated. This process is continued until a unique location is obtained. The matching process is performed by using the fuzzy pattern matching technique. The proposed method is implemented on a Numad 200 robot and the results are reported.

The paper by Huh (2000) proposes a navigation algorithm that simultaneously locates the robots and updates landmark in a manufacturing environment. A key issue being addressed is how to improve the localization accuracy for mobile robots in a continuous operations, in which the Kalman filter algorithm is adopted to integrate odometry data with scanner data to achieve the required robustness and accuracy. The Kohonen neural networks have been used to recognize landmark, using scanner data in order to initialize and recalibrates the robot position by means of triangulation when necessary.

In another study, Borges and Aldon (2003) studied the robustified estimation algorithms for mobile robot localization based on geometrical environment maps. The paper presents an improved weighted least-squares algorithm used for optimal 2D pose estimation of mobile robots navigating in real environment represented by geometrical maps. Following this map representation paradigm, feature matching is an important step in pose estimation. In this process, false matches may be accepted as reliable. Thus, in order to provide reliable pose estimation even in the presence of certain level of false matches, robust m-estimators are derived. We further apply some concepts of outlier rejection for deriving a robust Kalman filter-based pose estimator. Extensive comparisons of the proposed robust methods with classic Kalman filtering-based approaches were carried out in real environments.

The paper by Louchene and Bouguechal (2003) deals with the design and implementation of an improved localization methods. The study presented in this paper focuses on the displacement and heading errors. The technique proposed improves considerably on dead reckoning methods of reducing the systematic and non-systematic errors. Defection of the floor irregularities is the main feature of the designed method in the convection of displacement errors. However, for internal errors and correction, a trailing wheel is used, following that, a predefined trajectory is provided by the control of the trailing wheel deviation angle.

Research on robot tracking

There is a large number of studies on robot tracking. A review of prominent studies covered in this work is outlined below.

Sun and Cui (2004) investigated into path tracking and a practical point stabilization of mobile robot. Based on differential geometry theory, applying the dynamic extension approach of relative degree, the path-tracking controller of mobile robot is designed by the input/output feedback linearization. And on the foundation, the exact feedback on the kinematic model of mobile robot is realized. Its proof is different from and simpler than the literature (Robotics Comut. Integ. Manuf. 16 (2000, 353). A practical point stabilization controller is proposed, and a fault in the literature (Robotics Compu. Integ. Manuf. 16 (2000, 353) is indicated. Hence, the path tracking and point stabilization problems are solved in a unified approach. The designed controllers have the local asymptotic stability. Simulation results show their effectiveness.

In a paper, Klanar et al., (2004) studied the problem on wide-angle camera distortions and non-uniform illuminating on in mobile robot tracking. The paper presents some fundamentals and solutions to accompanying problems vision system design for mobile robot tracking. The main topics are correction of camera lens distortion and compensation of non-uniform illumination. Both correction methods contribute to vision system performance if implemented in the appropriate manner. Their applicability is demonstrated by applying them to vision for robot soccer. The lens correction method successfully corrects the distortion caused by camera lens, thus achieving a more accurate and precise estimation of object's position. The illumination compensation improves robustness to irregular and non-uniform illumination that is nearly always present in real conditions.

Another work on mobile robots is due to Normey-Rico et al., (2001). The paper presents a simple and effective solution for the for the path tracking problem of a mobile robot, using a PIF controller. The proposed method uses a simple linearized model of the mobile robot, composing of an integrator and a delay. The synthesis procedure is simple and allows the PID controller to be tuned, considering the nominal performance and the robustness as control specifications experimental results demonstrate the good performance and robustness of the proposed controller.

Other research areas on mobile robot

Another work by Nelson et al., (2004) describes the evolutionary training of artificial neural network controllers for competitive team game playing behaviour by teams of real mobile robots. This research emphasized in the development of methods automating the production of behavioral robot controllers. They seek methods that do not require a human designer to define specific intermediate behaviour for a complex robot task. The work made use of a real mobile robot colony (Evolutionary Robots) and a closely-coupled computer-based simulated training environment. The acquisition of behaviour in evolutionary robotics systems was demonstrated, using a robotic version of the game capture the flag.

In this game, played by two teams of competing robots, each team tries to defend its own from the other team. Robot neural controllers relied entirely on processed video data for sensing of their environment. Robot controllers were evolved in a simulated environment, using evolutionary training algorithms. In the evolutionary process, each generation consisted of a competitive tournament of games played between the controllers in an evolving population. Robots controllers were selected based on whether they won or lost games in the course of a tournament. Following a tournament, the neural controllers were ranked competitively according to how many games they won and the population was propagated, using a mutation and replacement strategy. After several hundred generations, the best-performing controllers were transferred to teams of real mobile robots, where they exhibited behaviours similar to those seen in simulation including basis navigation, the ability to distinguish between different types of objects and goal-tending behaviours.

Yet in another study by Surman et al., (2003) studied an autonomous mobile robot with a 3D laser range finder for 3D digitalization of indoor environments. The paper presented an automatic system for gaging and digitalization of 3D indoor environments. It consists of an autonomous mobile robot, a reliable 3D laser-range finder and three elaborated software modules. The first module, a fast variant of the iterative closest points algorithm, registers the 3D scars in a common coordinate system and relocalizes the robot. The second module, a next best view planner, computes the next nominal pose based on the acquired 3D data while avoiding complicated obstacles. The third module, a closed-loop and globally-stable motor controller, navigates the mobile robot to a nominal pose on the base of odometry and avoids collisions with dynamical obstacles. The 3D laser finder acquires a 3D scan at this pose. The proposed method allows one to digitalize large indoor environments fast and reliably without any intervention and solves the SLAM problems. The results of two 3D digitalization experiments are presented, using a fast octree-based visualization method.

An interesting study was conducted by Adamatzky et al., (2004). The authors discussed the first-ever experimental realization of the onboard excitable chemical controller for stimulus-guided navigation of mobile robots. The authors demonstrate that the Belousoy – Zhabotmsky (BZ) reaction in the form of an onboard thin layer chemical reactor can be used to execute primitive forms of positive taxes. To dynamically shape the robot's motion trajectory in an experimental arena, they stimulate a marginal part of the BZ reactor with silver and analyze snapshots of the spatial excitation dynamics. In this paper, the authors offer an experimental set up, including algorithms and interfacing, for an onboard chemical robotic controller, which contributes to the fields of non-classical computation non-linear physics, and unconventional robotics.

In another work, Kruusmaa and Willemson (2003) investigated into covering the path space: a casebase analysis for mobile robot path planning. The paper presented a theoretical analysis of a case base used for mobile robot path planning in dynamic environments. Unlike other case-based path planning approaches, the authors use a grid map to represent the environment that permits the robot to operate in unstructured environments. The objective of the mobile robot is to learn to choose paths that are less risky to follow. The authur's experiments with real robots have shown the efficiency of such concept. In this paper, the authors replaceed a heuristic path planning algorithm of the mobile robot with a seed case base and prove the upper and lower bounds for the cardinality of the case base. The proofs indicate that it is realistic to seed the case base with some solutions to a path-finding problem so that no possible solution differs too much from some path in the case base. This guarantees that the robot would theoretically find all paths from start to goal. The proof of the upper bound of the case base cardinality shows that the case base would in a long run grow too large and all possible solutions cannot be stored. In order to keep only the most efficient solutions, the case base has to be revised at run-time or some other measure of path difference has to be considered.

In another study, Hagras et al., (2004) present a novel fuzz-genetic techniques for the online learning and adaptation of an intelligent robotic navigator system. Such a system could be used by autonomous mobile vehicles navigating in unstructured and changing environments. The work focused on the online learning of the obstacle-avoidance behavior, which is an example of a behaviour that receives delayed reinforcement. The authors showed how this behaviour can be co-ordinated with other behaviours that receive immediate reinforcement (such as goal seeking and edge following learnt during the previous work to generate an intelligent reactive navigator that can deal with unstructured and changing outdoor environments. The system described uses a life-long learning paradigm whereby it is able to dynamically adapt to new environments and update us knowledge base.

Yet in another study, Hannel et al., (2003) presented an algorithm for all 30-shape reconstruction of indoor and outdoor environments with mobile robots. Data acquired with laser range finders are installed on a mobile robot. The approach combines efficient scan matching routines for robot pose estimation with an algorithm for approximating environments, using that surfaces. On top of that, their approach includes a mesh simplification technique to reduce the complexity of the resulting models. In extensive experiments, the method is shown to produce accurate models of indoor and outdoor environments that compare faviourably to other methods.

Flann et al., (2002) studied a small mobile robot for security and inspection operations. The omni-directional inspection system (ODIS) investigated is a small, man-portable mobile robotic system that can be used for autonomous or semi-autonomous inspection under vehicles in a parking area. Customers for such a system include military police (MP) and other law enforcement security entities. The robot features three "smart wheels" in which both the speed and direction of the wheel can be independently controlled and a vehicle's electronic capability that includes multiple processors and a sensor array with a laser, sonar and IR sensors, and a video camera ODIS. The robot employs a novel parameterized command language for intelligent behabour generation. A key feature of the ODIS control system is the use of an object recognition system that fits models to sensor data. These models are then used as input parameters to the motion and behaviour control commands.

In another work, Ma et al., (2001) proposes a hybrid intelligent method, including fuzzy inference and neural network which is presented for real-time self-reaction of a mobile robot in unknown environments. A neural network with fuzzy inference (fuzzy neural network FNN) presented can effectively improve the learning speed of the neural network. The method can be used to control a mobile robot based on the present motion situations of the robot in real-time; these situations include the distance in different directions between the obstacles and the robot provided by ultrasonic sensors, the target orientation sensed by a simple optical range-finder and the movement direction of the robot simulation results showed that the above method can quickly map the fuzzy relationship between the input and the output of the control system of the mobile robot.

Still on mobile robot, Fernandez et al., (2004) present a new approach to obstacle avoidance for mobile robots in cultured and unknown or partially-unknown environments. The method combined a new directional methods, called beam method (BM), to improve the performance of a local obstacle-avoidance approach called curvature velocity method (CVM). BM calculates the best one-step heading which is used by CVM to obtain the optimal linear and angular velocities. The resulting combined technique is called beam curvature method (BCM). Different experiments on populated and dynamic environments have proved to be very successful. The method is able to guide the robot safely and efficiently during long time periods. The authors present some of these results compared with other methods.

The paper by Boada et al., (2002) presents a reinforcement learning algorithm which allows a robot, with a single camera mounted on a pain tilt platform, to learn simple skills such as watch and orientation and to obtain the complex skill called "approach", combining the previously-learned ones. The reinforcement signal the robot receives is a real continuous value so it is not necessary to estimate an expected reward. Skills are implemented with a generic structure which permits complex skill creation from sequencing output addition and data flow of available simple skills.

In another paper, Carelli and oliveria-Freire (2003) propose a mobile robot control law for corridor navigation and wall-following, based on sonar and odometric sensorial information. The control law allows for stable navigation avoiding actuator saturation. The posture information of the robot traveling through the corridor is estimated by using odometric and sonar sensing. The control system is theoretically proved to be asymptotically stable. Obstacle-avoidance capacity is added to the control system as a perturbation signal. A state variables estimation structure is proposed that fuses the sonar and odometric information. Experimental results are presented to show the performance of the proposed control system.

Yet in another work, Gemeinder and Gerke (2003) present a genetic algorithm (GA) based path planning software for mobile robot systems focusing on energy consumption. One special feature of this software is the consideration of changing textures, and therefore, changing energy requirements when moving within given environments. Problem-specific genetic operators are introduced, and especially the handling of exceptional situations is described in detail. After that, an active search algorithm is introduced which allows to overcome the drawbacks of an earlier version of that software. This algorithm is executed within two different phases of the optimization process. For each obstacle within the environment regarding a path circumventing, it is computed in a preparation phase, then, in the execution phase of use to find optimum paths. The mode of action within both phases is described in detail. Furthermore, the suitability of the approach is substantiated by an example.

The paper by Carmena and Hallam (2004) presents biologically-inspired engineering on the use of narrow ban sonar in mobile robotics. It replicates, using robotics as a modeling medium, methods CF-FM bats are used to exploit Doppler-shifts – a rich source of information not used by commercial robotic ultrasonic range sensors – in different tasks. The experimental platform for the work is ROBAT, a 6 DOF biomimetic sonar head mounted on a commercial 3 DOF mobile platform. The platform is provided with signal processing capabilities inspired by the bat's auditory system. The CF-FM bat modifies – increasing or decreasing – the carrier frequency of its own calls, compensating the Doppler-shift produced when the bat, the reflector or both are moving. Thus, echolocating behaviour called Dopper-shift compensation is successfully implemented in Robat. Inspired by this behaviour, a convoy navigation controller following a set of simple Doppler-dependent rules is successfully devised. The performance of the controller is satisfactory despite low Doppler-shift resolution caused by the lower velocity of the robot when compared to real bats. Finally, Muller's hypothesis on the use of acoustic flowby CF-FM bats for obstacle avoidance is also implemented in Robat, resulting in a crude estimation of the target's passing distance at small bearing angles, which improves as the angle increases, nevertheless, sufficing for avoiding the two reflectors of the experiment.

Pransky (1997) describes two types of mobile robots designed for the US military, one is the mobile detection assessment response system (MDARS), which is an automated robotic security and inventory system capable of patrolling interior and exterior warehouses and storage sites for the Department of Defense. The order is the spiral track autonomous (STAR), a multi-terrain military vehicle used to reduce risk to military personnel and equipment. Both autonomous robots allow the US military to decrease unsecured threats and to increase savings which arise from the prevention of expensive hardware loss.

Virk (1997) presents a state-of-the-art in industrial mobile robotics within Europe and how the future industrial requirements can best be satisfied. The author states that the focus for the development of mobile robotic vehicles has been in hazardous applications such as the nuclear industry, petrochemical plants and offshore operations, but the same technology has potential for use in other areas ranging from construction, outdoor applications (forestry, anti-personnel mine clearing), mining and leisure. He presents the results of the investigations carried out for the Brite Euram Thematic Network on climbing and walking robots where most of the countries in the European Union have been considered in the studies. The author also reports a major finding that mobile robots have an enormous potential for commercial exploitation but first some fundamental problems need to be solved; these concern improvements in sensors, actuators and powering technologies. He argues that the robots of the future also need to have strong autonomous capabilities, must be able to self-learn as well as be reliable for continuous operation. The author identifies modularity as a key feature requiring careful attention so that future machines can be easily and rapidly prototyped for new applications.

Rooks (2002) describes some of the papers presented at an international colloquium on autonomous mobile systems held to celebrate 10 years of the Frauntiofer Institute for Factory, Operation and Automation (IFF) in Magdeburg, Germany. Following definition of a mobile robot, papers on wheeled-and biped-robot platforms are discussed. These are followed by a review of some of the applications using dedicated robot systems, including an autonomous welding cell, a concept for process plant maintenance, a pipe inspection robot and systems for cleaning glass facades on high building. The latter work at IFF has resulted in two commercial systems, one already installed for the 1997 Leipzig Trade Fair and the other to be installed at the new Fraunhofer Foundation in Munich in 2003.

The paper by Khoukhi (2002) considers the problem of the dynamic optimal time energy off-line programming of an autonomous mobile robot in a crowded environment. First, kinematic model and planning are presented. Then, a dynamic model based on Euler-Lagrange formalism is developed and a mobility estimation function of the robot is considered. This dynamic estimation of the robot mobility takes into account of the velocity and the orientation of the robot. Then, the scene structuration and a pathfinder formulated as a non-linear programming problem under non-linear equality and inequality constraints. The Discrete Augmented Langrangian (DAL) is used to obtain the optimal trajectography. The author develops an extended DAL to DALAP, DAL adapture penalty. Robsin 1.1 simulator is developed to perform kinematic and DALAP-based algorithms on a large class of mobile robots optimal time-energy off-line programming. A comparative study with kinematic planning is considered. It is shown that the performance of the dynamic optimal time-energy control and off-line programming is such better than kinematic-and heuristic-based schemes. This strategy of trajectoring planning was implemented on the case study of the SARA mobile robot model.

In an article, Schraft et al., (2001) designed a new generation of mobile robots Fraunhofer Institue of Manufacturing Engineering and Automation (IPA), based on the successful hardware and software architecture of care-o-bot [tm]. The robots have been created to communicate with and to entertain visitors in a museum. Their tasks include welcoming visitors, heading a guided tour through the museum or playing with a ball. The hardware platform of the robots and their features such as navigation and communication skills, their safely concept and handling are outlined further, the underlying control software of the robots is described. Finally, the application of the robots at the Museum Fur Kommunikation in Berlin is presented. The robots have been running in this museum daily since 25 March 2000 without noteworthy problems.

Barnes and Counsel (2003) investigate the use of a haptic interface, which not only allows an operator to communicate motion commands to a robot but also allows the robot to communicate to the operation its motion when performing autonomous collision avoidance. This haptic interface provides total operator control, plus vital information that can be used to decide if and how a robot's autonomous operation should be overridden. This paper details the work in this area and presents the results obtained from operator/task performance experimentation with this new haptic communication approach.

The paper by Sun et al., (2000) presents an implementation of a mobile robot, which can sense and transmit the image of the internal surface of a remote analysis center, where the image is processed and recorded. A neural network-based pattern classifier is employed to assist inspectors to detect the flows that appear in the surface of the vessel. Because the real-life defects rarely exist in the pressurizer, the training of the network becomes very difficult. A new algorithm is exploited to solicit the problem. General considerations about the robot design are also presented.

Wilke and Braunl (2001) work on flexible wireless communication network for mobile robot agents. An overview of communication systems is being published and a discussion of their advantages and drawback is followed by an introduction into multi-agent systems and the problems were faced applying them to the task of playing sonar. Then, we describe the wireless communication network in detail including the Eye Bot platform, message structures, self-configuration and error recovery. The communication is with a remote computer workstation. The communication system is a layer beneath the multi-robot console, which is the user interface, and above the Eye Bot hardware.

Kleeman (1999) presents a new approach to rejecting between sonar systems. The approach is based on identifying a transmitter by sending a double pulse with known separation. Using simple delayed pulse subtraction, a sonar receiver can test echo pulses quickly and simply for acceptance. This approach is implemented on a sonar system that is capable of accurately tracking objects at measurement rates exceeding 10Hz. Two sonar sensors, each consisting of a transmitter and two receivers, are independently controlled to track objects from bearing and range measurements. Matched filtering is used to optimally estimate echo arrival times from which range and bearing angle are derived. Bearing accuracy is typically better then D.I. temperature gradients. Bearing errors are shown experimentally to have significant autocorrelation at times of the order of seconds. The ability to reliably reject interference is demonstrated experimentally by both sensors simultaneously tracking the same plane object.

Robotics in healthcare systems

The contributions of robotics to the healthcare system could be described as unprecedented, saving several millions of lives due to the precision introduced by the robotics technology during healthcare. Thus, human errors that may result in loss of lives during surgical operation is avoided. Application of robots in healthcare systems is having a compelling impact on healthcare by improving efficiency in the operating room (OR) with better communications, streamlined networks and effective personnel utilization, increasing the number of procedures that can be performed in a minimally-invasive fashion for reduced patient pain, trauma and recovery time; and enabling new procedures that would otherwise be impossible to perform due to human limitation.

The revolutionary surgical technology (2001) offered by robot extensively dealt within the classic study of Broeders and Ruurda (2001) who investigated into the concept of Laparoscopy in surgery. The introduction of robotics to patient treatment solved a seemingly-unresolved problem – reduced dexterity – through intuitive surgical "Davinci" systems. Cavus et al. (2001) gave support to the study by Broeders and Ruurda (2001) by probing deeply into the telesurgery aspect of healthcare system with an investigation on the second generation Berkeley/UCSF Laparoscopic telesurgical workstation. The study enhanced the dexterity and sensation of regular and minimally-invasive surgery through using millimeter-scale robotic manipulators under the control of the surgeon. The investigation introduced kinematic and control issues and the presentation of in vitro-experimental evaluation results.

The future holds much promise for robotic knowledge development and the expansion in the field if we realize and exploit what Kochan (1996a, 1996b, 2001a, 2001b and 2002) found out about robotics. However researchers and developers must understand the technology requirement for robotic surgery.

In another study, Wright (2001) points out that the introduction of robotics in healthcare necessitates careful evaluation of the technology along several criteria: assessing the appropriateness of the technology or equipment under consideration: OR readiness; procedural compatibility; precision and dexterity enhancement; and open architecture and upgradability. Evaluating along these four cornerstones helps ensure the equipment or technology will meet the feasibility, accuracy, utilization, system longevity, patient safety and surgeon/OR team benefits required by today's OR environment and staff. Unfortunately, surgeon and other medical professionals may not have the technical knowledge and experience in the design, construction and implementation of robots in operating environments. This problem can be resolved through a multidisciplinary research effort which includes surgeons, engineers, psychologists, among others. Thus, there is a call for collaboration among professions – in order to have the "perfect robots" for the operating environments.

Robotics in the industry

There are several dozen of papers in the past few years on the applications of robotics to the industry. The case investigated by Spencer (1996) is a good example. The survey carried out explored the extent of implementation of robotics in the footwear industry. In particular, he focused on the application of advanced manufacturing techniques and automation technologies for production activities. He found out how many manufacturers in an environment have turned to robotics and automation for more reliable manufacturing system solutions. The study, emphasizing on the robotics integration and system-level products specifically targeted for footwear manufacturing operation provided by three specialist companies; ACTIS Engineering, DESMA and Intelliquent Machine Corporation.

The applications of robotics in the industry seem to have a strong base in the food industry. The strong reason behind this may be due to the repetitive nature of many food production systems. Another reason may be the need for more efficiency and productivity in food production environments where intensive pressure and temperature under which production is carried out may not allow human beings to perform at the optima, and may also be injurious to human health.

The wide application of robotics in the food industry must have motivated Wallin (1995) to review the use of robotics and opportunities in the food and drinks industry. The review is based on a report commissioned by MAFF (Ministry of Agriculture, Fisheries and Food). It outlines trends and changes, robot sales figures in the food market, problem areas and technology limitation. It further stresses the need for adequate research projects to fully realize the potential of robotic systems so that known technology can be applied to specific food – manufacturing solutions. It concludes that there is a huge potential for the development of automated systems for the food industry, however, technologies need to be integrated to enable specific food machine to be developed which meet the necessary hygiene and food industries requirements.

Still on research in the food industry, Tillett (1995) examines the effectiveness of using expensive robotics equipment in the food industry where profit margins are low and labour is less expensive than in other industries. The study looks at the work undertaken at the Silsoe Research Institute into developing appropriate low-cost technology for basic food applications. The project discussed include robotic teat cups for milking cows and a robotic mushroom harvesting; both using pneumatic power transmission. It concludes that food production will become an important application for robotics when it is generally accepted as cost-effective.

Another paper on the food industry research was presented by Fitzpatrick et al., (1997) who investigated into the post-production activities with an investigation into the several characteristics of the first unmanned harvester - Robot Windrower. The study describes how lunar rover and terrestrial military vehicle technology is combined to define two core technologies for mobile agricultural equipment - field-Nav, the digital machine; and fieldhand, the digital operator. Outlines the hardware and software used; standard and custom components used for safety and customized electronics; modifications for driver by-wire; the event-driven, behaviour-based architecture (SAUSAGES); sensing for crop line tracking; other detectors, trackers and GPS used for guidance. It explains the benefits of such automation to agriculture and what the future holds for commercialization of Demeter.

Research on robots applications in industrial organisations also extends to occupational health and safety control, applications in dynamic assembly systems and its use in ship building. In occupational health and safety control, McAlinden (1995) considers the use of robotics in the workplace as a means of protecting workers from exposures to hazardous substances, environment and physical agents. The paper gives example of robots being used to handle radioactive material and working in the high dust-exposure atmosphere of a plastic factory.

In dynamic robots assembly systems, Su et al., (1998) find the best placement sequence and magazine assignment. Before conducting the research, scholars utilized the fixed coordinate of placement points and magazine of the traveling salesman problem (TSP) method to sequence the placement points after the magazine has been arbitrarily assigned. This hinges on the fact that robotics travel routing should be based on a relative coordinate because the robotics, board and magazine simultaneously move at different speeds during assembling. Consequently, the coordinates of placement point and magazine are constantly changing. The proposed approach can arrange the placement sequence and assign the magazine slots to yield a performance better than the conventional one. The results presented also demonstrate that the larger the number of placement points and/or part numbers, the better the performance.

Robotics in the construction industry

In the construction industry, research on robotics has been investigated into a wide varieties of areas. The automation and robotics, the interdependence of design and construction systems; and the enabling technology for a mansory-building advanced robot are representative aspects. In the work by Cusack (1994), an examination of the potential for introducing robots into the Construction Company was made. The paper outlines some of the problems to be tackled, including the technical and organizational problems of site layouts and the role of automation and robotics in construction. It further discussed the advantages of using task-specific robots and the development of mechatronics. Emphasis was made on the need for the development of CAD in architecture and construction, private design description of a building to make available the necessary information about the developing building geometry on the construction site.

However, Chamberlain (1994) initiated a research program into the use of robotics in masonry building. The four main objectives of the project were to establish the requirements for the application of robotics in masonry construction; construct a prototype robot; develop the operation software system; and evaluate suitable blocks for construction using robots. The work describes the construction of the prototype robot cell and the research methods used and concludes that combining the research findings with work elsewhere, it should be possible to achieve a commercially-viable robotic solution for masonry and similar tasks on the construction site.

In ship building, robots technology has been extensively applied in welding processing (Dalton, 1997; Sorenti, 1997). An investigation by Sorenti (1997) on the efficiency of robotic welding for shipyards describes how virtual reality simulation technology is being used and developed to support the design and programming of large-scale robots, welding cells in two of the world's largest and most modern shipyards. GRASP-VRI is a shipbuilding-specific software simulation and offline-programming tool, developed as part of a highly-productive method for rapidly-crating arc-welding programs for robots. The work describes the integrated program creation concept that uses pre-defined, parametric libraries of generic arc-welding tasks that were created and verified prior to, and during, cell commissioning. The author concluded that the approach is applicable to other robotics applications such as cutting, gluing and inspection.

Education and training on robot technology

There is a wide array of studies on robotics education and training. A few of these studies are discussed here. A primary study on this aspect is credited to Taylor (1996) who examines the development of courses in robotics and advanced automation at UK universities and describes the relationship between industry, research and the courses. The study looks in detail at undergraduate courses offered by the universities of Hull, Bristol, Plymouth and leading metropolitan universities. It describes the pioneering postgraduate course at Cranfield Institute of Technology and states that the collaboration between these universities and industry and the support this collaboration provides has been essential for the viability of the courses. It concludes that the future is bright for these courses so long as they are well presented to potential students and the industrial sector remains committed.

In Robinson's (1996), the focus is on strategy for development. The paper examines the importance of training engineers, particularly in the field of robotics. It discusses the paucity of courses at universities and compares this with the greater number of courses at technical colleges. It explains factors that inhibit the development of relevant courses; and discusses specific course aims, recent development of relevant courses; and discusses specific course aims, recent developments, and practical issues.

General aspects of the literature

There are several studies that may not be classified under any of the works discussed above but could be treated under the general umbrella of robotics. A body of research treats the extent of development of robotics technology in different nations. The coverage areas are not limited to the industry but expand to the academia and other areas. Primarily, documentation has been made on general applications on robots in Finland, United States of America (USA), outh-East Asia, and the United Kingdom (U.K).

The work by Monkman (1994) reports on the 1992 Finish Robotics Conference in Helsinki that focused on the application of robotics in Finland. The areas covered include medical robotics, advanced flexible robotic systems for small-batch manufacturing, and automated laboratory systems and waste-disposal systems.

Hollingum (1997) shows how two events pointed the way for the U.K to put itself in the vanguard of the next stage of intelligent robotics development, the first came the publication of a report Technology and Market Review of the Robotics Sector which studied the state and prospects of robotics in seven sectors of UK industry and proposed that special efforts, including demonstrator projects should be focused first on the food industry sector and then on the medical sector. The second event was the launch of SILVER SIG, a Special Interest Group for intelligent vehicles and Robotics. A major participant in Silver is the Defense Evaluation and Research Agency, DERA, which is committed to linking commercial industry with government research – in this case in the development of intelligent vehicles.

CONCLUSIONS AND FUTURE RESEARCH

Generally, the robotics literature is composed of a wide range of studies in diverse areas, notably, industrial applications, healthcare, construction systems and technological education and training, among others. This paper has presented the robotics literature in an integrated form. As such, the work seems to be beneficial to the robotics and the wider automation research community. The work is motivated by the urgent need for researchers to understand what others are doing in the field. Thus, will we not continue to be workers in the Tower of Babel researching into an area without a full understanding of what others were doing with us.

From the findings of this study, it is recommended that many areas warrant further investigations. The area of offshore engineering has much promise for the application of robots technology. With an expanding range of research on pipelines buried in ocean waters, there is an opportunity to introduce robot to aid a more-effective installation, development, implementation and maintenance of oil pipelines for improved profitability and productivity. For instance, the traditional method of pipeline laying and installation needs to be revisited and improved upon from human-centered to automatic-driven systems. Traditionally, a large amount of resources are invested in construction works inside oceans (at the seabed and beneath the seabed). As a result, the human-driven system is exposed to a large number of risks with occasional death of the human operators or installation personnel. This has a significant effect on the morale of workers engaged in construction work. It also causes huge wastes of financial and non-financial resources.

As opposed to this approach, the development of robots that could work effectively at the seabeds and below the level would be a significant contribution to productivity and reduction of risks. At the operation stage, the use of robots is essentially necessary for timely and precise control of oil exploration activities when pipes are buried below the sea levels with a dire need to monitor the controls where human limitations exist. A top priority research is the development of robotics technology for small-scale enterprises (SMEs) in view of the huge investments that the adoption of robotics technology in SMEs implies.

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