Intelligent Robotics - Automation in Unstructured Environments

by
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Abstract

This paper presents, in tutorial style, an overview of the field of Intelligent Robotics as a methodology providing powerful tools for auto in unstructured environments. Both the fields of robotic manipulator and mobile robot systems are covered. The interrelationship b sensors, artificial intelligence and motion control, which is central to this topic, is emphasised. Finally, some application domains are ex

Introduction

The most crucial aspect of 'Intelligent Robotics' is the interplay between perception, reasoning and action (see Figure 1), although there recent times, been energetic debate on whether 'reasoning' is essential [1,2]. This debate is often referred to as 'Reason versus Reaction'. former [3] there is assumed to be a need for analysis of sensory data and the development of plans, some quite complex, before action is It has often proven difficult to build reliable systems using this approach since the management of the complexity which results fr integration of many, relatively distinct subsystems has been more difficult than initially anticipated. In the 'Reaction' approach direct (usually multi-layered) links between sensors and actuators, supervised by relatively simple finite state machines, are forged without co analysis or planning being involved. These systems are capable of demonstrating behaviours whose complexity emerges, without de planning, from the interaction of sets of simple stimulus/response sub-systems. They are associated with fast and robust activity. How is often difficult to have the appropriate behaviour emerge in such a way as to allow the carrying out of specific tasks with detailed ch sequential actions.

In this paper the 'Reason' approach is focused on but it is conceded that aspects of the 'Reaction' approach are extremely attractive and probably be incorporated where appropriate, thus leading to hybrid systems which combine the best of the two, seemingly opposed, syst

Publications on research carried out at the Intelligent Robotics Research Centre at Monash University are liberally cited, particularly examples of this work will be presented at the conference in the way of descriptions, photographs and video clips.

The next section leads into the main topic of the paper by touching on the brief history of robotics as captured by the definition of gene of robotic devices. Then the main fields of Artificial Intelligence are commented upon. Then follows more detailed coverage of r hand/eye co-ordination and autonomous mobile robot systems and the various specialised sensors and methodologies which support the brief section introducing robot swarms follows. The paper closes with some exploration of application domains and concluding remarks.

A Brief History of Robotics (See Figure 2)

The immediate precursors to robots were fixed automation machines often associated with assembly line manufacturing, most easily with the automobile industry. Various individual machine tools could also share in this parentage. Such systems lacked flexibility an capability of reacting to varying conditions in the workplace. The first generation robots were slight extensions of fixed automation to that they could be adjusted to 'pick and place' objects to and from specific locations and could repeat these cycles of operation monoto and with high reliability. With second generation robots came the capability of programming them to carry out complex sequences of some of which could be 'taught' to them by a skilled tradesman leading them through complex trajectories, as required, for examp welding or spray painting. The flexibility of the first generation was thus extended through programming and teaching. Thus the s generation machines do enjoy some capability of change of action either through selection of various programs or through interacting w work environment via micro-switches and interlocks.

It is not until the third generation that sensor guidance is fully acknowledged as a means of increasing flexibility of action to accomm various degrees of unstructuredness and temporal change in the working environment. In general, the more unstructured the environme more powerful must be sensor technology and Artificial Intelligence methodology to cope with the situation.

There has been speculation on what should define a fourth generation, but no acceptable single notion has so far evolved. It may be th influence of biologically inspired systems, perhaps leading to the replication of human-like capabilities, which has been a dream of robo the world over, will help define the next generation. But without he emerging and frightening capabilities in genetic engineering which recently made animal cloning a reality, and human cloning a possibility, who knows what the future of a robot humanoid might be.

Artificial Intelligence (AI)

Artificial Intelligence [4] is largely about replicating the sensing and cognition capabilities of biological systems, and most partic humankind, in a computational device. As with many ambitious quests, the early promises of what AI would by now have brought to so have largely not been delivered, although steady progress is being made. Most AI concentrates on mental capabilities in calculating, thin reasoning and planning but a special sector of it is involved with machine perception which is about making sense (excuse the pun) of se input. The main sub-divisions of the field of AI are listed in Figure 3.

In recent times we have witnessed an IBM computer beating the world Chess champion; this victory for the machine came from many ye research into Game Playing and huge improvements in computer technology.

The area of Theoren Proving has not enjoyed the same publicity, although many groups around the world are still active in the area, which surprisingly, is very mathematically oriented.

Expert Systems grew out of the notion that human experts could provide rules over specific problem domains that computers could pick over, combine and chain together at great speed to provide advice and the reasons for giving it for applications spanning from how to run an electrical power supply grid to how to train jet pilots.

Artificial Neural Networks (ANN) and Genetic Algorithms (GA) are both inspired by biological functionality and have been applied to problems which have been difficult to solve using classical methods. ANNs are made up of nodes which sum weighted input signals, apply simple nonlinear functions to the result and fire this output to other nodes. It is claimed that this distributed computing model replicates the way in which the brain functions but this claim is barely justifiable, if at all. Nevertheless, some interesting and difficult problems have been solved using ANNs so that their biological inspiration, if only somewhat bogus, may not matter. GAs are based on the natural selection principle of the survival of the fittest where the most promising offspring of previous generations are 'genetically' combined to produce offspring, some of which may be even more promising, and so on until a very good solution to some complex problem is found (by encoding the parameters of the problem search space in the genetic code of the entities being bred). However, the areas of Machine Perception and Intelligent Robotics are of most interest in this paper. It is helpful to see them as part of the Artificial Intelligence field since they share many common concepts with and draw upon the tools of the whole field.

Machine Perception is concerned with interpreting the signals which come from sensors to model the environment so sensed and in a way that supports reasoning about that environment which leads to proper action in carrying out some tasks. This field includes Computer Vision, Force/Torque/Tactile/Thermal Sensing, Ultrasonics, Olfactory Sensing and Auditory Sensing. What distinguishes Machine Perception from mere Signal Analysis is the context of Artificially Intelligent decision making which it serves.

Intelligent Robotics leans heavily on Machine Perception but adds capabilities such as collision-free trajectory and path planning, strategic sequencing of operations and physical action control.

Robotic 'Hand/Eye' Co-ordination

Since, for sighted humans, vision dominates as providing in excess of 85% of all sensory input, it is not surprising that Computer Vision is the most promising mode of Machine Perception. For simplicity, whilst other sensors clearly have applications in Intelligent Robotics, Computer Vision will be focused upon here.

The term 'hand/eye co-ordination' used here is quite generic and covers all situations where vision is used to guide movement and/or manipulation using a robotic arm with an 'end effector'.

Figure 4 illustrates one, fairly classical, approach to robotic 'hand/eye' co-ordination, very much in the 'Reason' mould [5]. A TV camera and/or an optical range finder collects dense data about the working environment. This could be a set of x,y,z points on the surfaces viewable from the camera/range finder, plus a set of corresponding surface colours. This raw data is organised into clusters to create a scene segmentation which hopefully distinguishes between the essential components of the scene without knowing what they are. Parameters, such as area, colour, perimeter, location of centre of area or volume, are extracted from the objects isolated in the earlier process. Based on the extracted parameters the objects making up the scene are recognised against a data base of expected objects and their properties. From the recognition and geometrical data extracted earlier, the identity, location, pose and structural juxtaposition of all objects in the scene are composed into a total scene description; also included may be indications of how and where various objects might most easily be picked up. With reference to the overall task specification, a task planner determines the sequence of manipulation events and plans an optimal collision-free trajectory for the robot manipulator move to a selected grip site at which it can pick up a selected object. The robot controller actualises the trajectory plan and executes the picking up operation and the withdrawal operation and what ever else has been planned to complete one cycle of hand/eye co-ordination. Further manipulation may be carried out without new sensory data being gathered but it is safer to repeat the whole cycle so as to monitor the proper progress of the overall operation. The overall task being performed may be sorting, packing or assembling components or some other related operation.

The configuration (joint angles) of the robotic manipulator are usually known quite accurately on a continuous basis by the controller through the use of shaft encoders on each of the joints. Thus, it is relatively easy to get the robot to follow the intended trajectory with considerable precision and reasonable speed.

There are very many types of range finders which have been developed for these kind of operations [6]. They differ in expense, speed, precision, density of data, size, energy requirements, safety and cost and no one approach currently dominates.

Autonomous Mobile Robot Navigation [7] (See Figure 5)

There are five sub-systems which are needed to support autonomous mobile robot navigation. These are localisation, environmental modelling, path planning, motion control and communications and of course, consideration of the function of the robot must be properly taken into account. Localisation [8] is concerned with determining the location and orientation of the robot. Unlike the case of robotic manipulators bolted down to tables, the exact position/orientation of a mobile robot is not so easy to determine and many special sensory devices have been used for this purpose. The most promising, generally applicable but a difficult way of determining the location/orientation of a robot is to use the objects in its normal working environment as natural landmarks. Environmental modelling [8] concerns the application of Machine Perception to build a model of the world in which the mobile robot operates which supports path planning [9,10,11] operations. It may not be always possible to move the robot along a once only planned path as new parts of the environment may come into 'view' as the robot moves and continual pre-planning may be needed to accommodate the changes these observations will make on the environmental model. Localisation is essential as an ongoing capability to guide the robot along any path. Communications between the sub-systems of the sensors and computational support on-board the robot or between the robot and a fixed home station must be provided. The reliability and bandwidth of various parts of the needed communications network will be crucial to the proper operation of the robot. Constructing an entire operational autonomous mobile robot system which is reliable over extended periods of operation is quite a challenge [12].

Robot Swarms

In recent times there has been growing interest in the idea of marshalling numbers (perhaps even very large numbers) of robotic units in a way which allows the collection to exhibit co-operative behaviour (whether deliberate or emergent) in the carrying out of tasks too difficult or big for any one robot unit to execute in isolation [13]. Such tasks may include operations such as cleaning, carrying large or unwieldy objects, holding and manipulating soft materials, sorting items amongst many others. Such an approach takes its inspiration from the way in which swarms of insects operate collectively. Hence the use of the word 'swarm' when referring to this style of Intelligent Robotics. Such an approach has amongst its advantages aspects of graceful degradation through exploitation of redundancy, the application of app numbers of units to specific tasks rather than applying a single heavy and perhaps energy guzzling machine over a variety of jobs som and some large, and the capability of assigning specialities to units which can complement one another's actions. This type of research infancy but is likely to become an important part of the field, particularly if the 'Reason' and 'Reaction' approaches are sensibly combine than being considered as opposing views.

Application Domains (See Figure 6)

There are very many potential applications of Intelligent Robotics. To think about them in a generic way one should consider operatio any or all of efficiency, quality, safety, human support and tedium are issues of importance. The most obvious application dom manufacturing industry where the 1st and 2nd generation robots were first put to work. Being able to relax structure when new pr processes are being introduced may mean retaining high efficiency and quality without huge retooling costs.

However, it is when one comes out of the standard manufacturing industry factory to where the working situation is not naturally struc where structuring is very expensive, that Intelligent Robotics comes into its own.

In the service industries, task such as cleaning, painting, building, guarding (night watching) and food preparation come immediately The processing of soft materials (such as cloth and food stuffs (including meat) is a very promising area for the application of In Robotics because, in nature, one is nearly always dealing with variety of shape, size, weight, texture and quality and these variations be coped with by highly sophisticated sensors and manipulators (mostly belonging to humans at this time).

Mining and agriculture represent industries which are large in scale, expensive and tedious to operate and potentially dangerous an unstructuredness is almost a defining property.

Then there are the fields where hazards are more obvious such as a fire fighting, undersea operations, space exploration, bomb disp nuclear power plant maintenance.

Finally, there is the big question of how to better look after disabled people and the increasing proportion of our population which wi over the next twenty years. Robot aids to the blind, the immobile and the frail for feeding them, moving them and caring for them other ways is perhaps the most noble application domain of all and one with tremendous challenges which include bringing technology to the support of people who need it at low cost and without injuring their human dignity.

Conclusions

This paper has sketched out the topic of Intelligent Robotics as a tool for automation in unstructured environments and put it wi contexts of previous generations of robots, its Artificial Intelligence dependency and the potential application domains.

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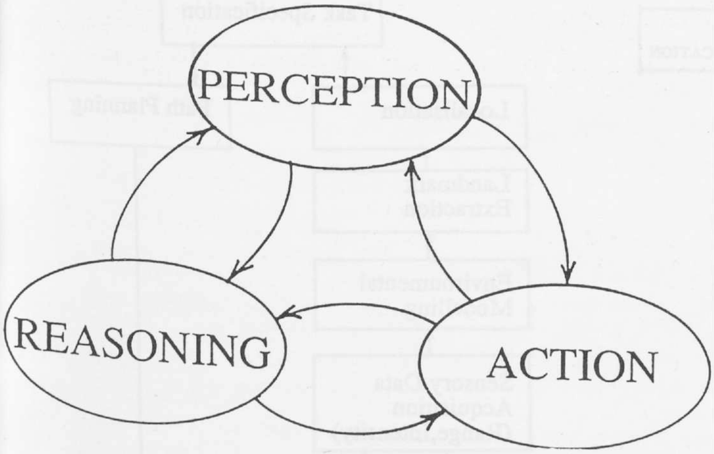

Figure 1. Intelligent Robotics

0th Generation
Fixed Automation

1st Generation Robots
(limited flexibility - pick and place

2nd Generation Robots
(programmable and teachable)

3rd Generation Robots
(sensor guided, artificially intelligent

Applicability Domain
Unstructuredness, Complexity

Figure 2. Robot History

Game Playing

Theorem Proving

Expert Systems

Neural Networks

Genetic Algorithms

Machine Perception

Intelligent Robotics

Figure 3. Artificial Intelligence

Manufacturing Industry

Service Industries

Mining and Agriculture

Hazardous Environments

Space Exploration

Healthcare

Figure 6. Application Domains.

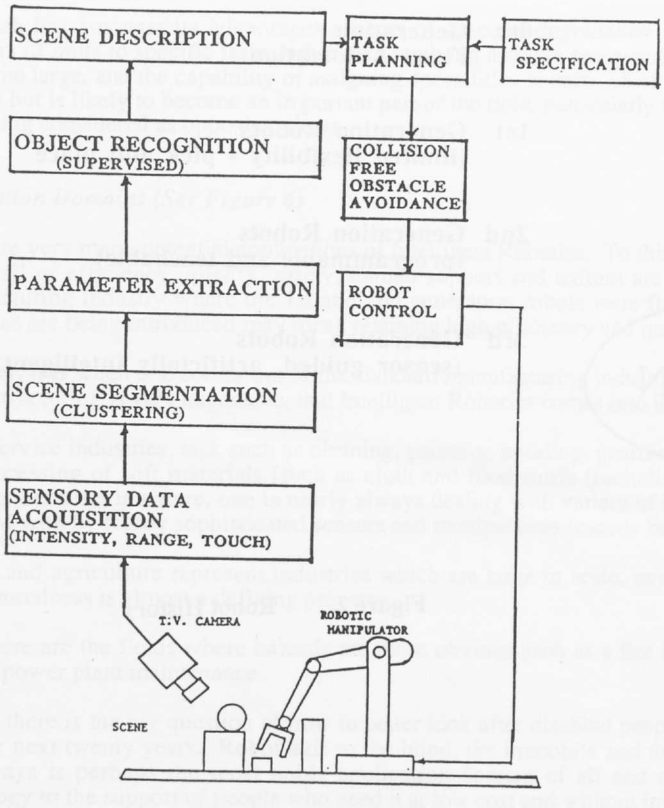

Figure 4. **Robotic 'Hand/Eye' Co-ordination**

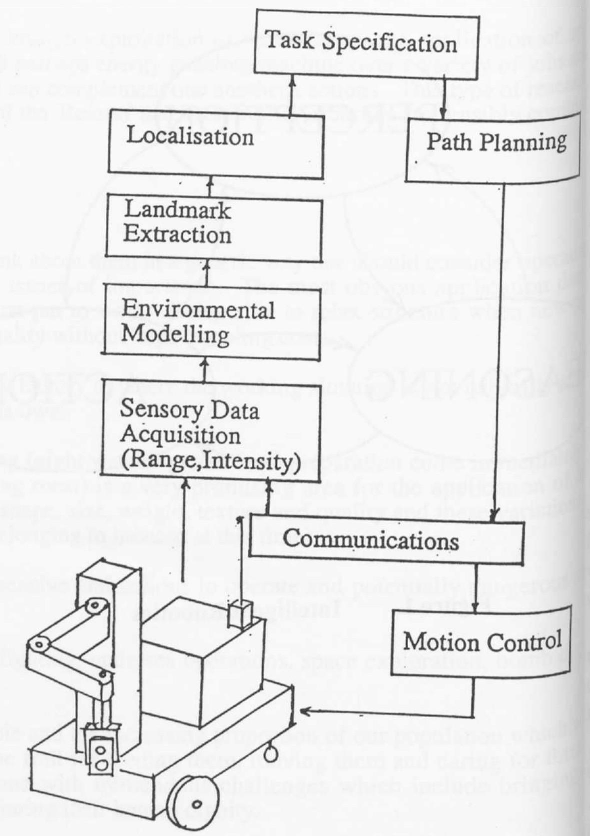

Figure 5. **Autonomous Mobile Robot Navigation**

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