

## ROBOT CELL-CONTROL IN AN UNCERTAIN ENVIRONMENT USING CONSTRAINT MODELLING TECHNIQUES

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### Abstract

The paper reviews the latest advances in sensor data fusion technology indicating the importance of collecting sensor information as part of the robot cell-control strategy. The purpose of the review is to place in context a new model for a cell-controller based on constraint modelling techniques. The advantages of such a system, based on the RASOR programming language, and its relevance to practical applications are presented. A practical demonstrator for the cell controller is being created around the problem of handling of food pieces by a robot gripper integrated with tactile sensors. This example will represent the various inaccuracies which can occur when a robot is required to work in uncertain environment.

### Introduction

Modern robots possess capabilities of vision, speech, and can sense objects by touching. Grippers with intergrated sensors still have many problems in handling objets especially if the robotic system is to be designed to operate in an unstructured environment. Much research effort is being directed into gripper technology to provide generic gripper devices. These new devices should not only be versatile but be capable of fulfilling the semi-autonomous features of advanced robotic systems. To this end it is essential that the enabling technology for sensor diffusion and real time decision making is also developed. Over the years various handling techniques have been adopted which reflect the different types of sensors used within the gripper arrangement, for example optical sensors, proximity and range sensors, tactile sensors. Recently magnetoresistance (MR) tactile sensors have been fabricated and tested in the department of Manufacturing and Engineering Systems at Brunel

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University [1]. These sensors, consisting of two force and two slip sensing elements in an area of  $1\text{cm}^2$ , show a very good quality of performance. These sensors are incorporated into a parallel jawed servo-driven gripper specially designed for the handling of fragile or compliant objects, where the need for normal as well as shear force information is of utmost importance. The handling of, say, a vegetable piece or meat piece with the inevitable variation in both dimensions and mechanical properties, will require sophisticated handling routines and error recovery strategies.

This variation in object properties will be termed the uncertain environment. In this context the term has a number of components.

- (a) The characteristics of the object to be handled are not clearly defined and contain a number of variations.
- (b) Misplaced or misaligned presentation of parts for assemble/handling, and
- (c) The intrusion into the workspace of foreign bodies, or dropped parts.

### **The Gripper Control Problem**

The magnetoresistive sensors integrated into the gripper fingers will be used to sense the forces exerted by the object to be handled. For example if slip or shear forces exerted on the fingers of a gripper are detected, which would indicate handling failure, corrective action would need to be taken. The detection of these forces within the gripper are obtained in the form of an electrical signal. The phenomenon of conversion of force into the electrical signal is achieved by the action of the magnetoresistive transducers. The operating principle is based on changes in an external magnetic field producing changes in the resistivity of the MR element. The change in resistivity produces a corresponding change in output voltage and the signal can then be processed and interpreted. After completing a processing cycle, a signal is transmitted to the gripper servo-motor to move the gripper actuating mechanism or to incrementally increase the motor torque. This is done in order to make the applied grip on the object sufficiently tight to avoid dropping the object sufficiently tight to avoid dropping the object. These sequential events look so simple but in the real world, particularly in an uncertain environment, they become very complex.

### **Design of Cell Controller**

An analysis of cell controller to operate in such an uncertain environment, incorporating a servo-driven gripper of a robot, is the main objective of this

research. By constructing such a cell controller using constraint modelling techniques a new approach to general sensor fusion will be formulated.

At present various computer architectures are in use within a manufacturing cell to implement communications at various levels. These architectures are serial, parallel or a mixture of the two. The serial method is in broad terms cheap but slow, whereas the parallel method is fast but

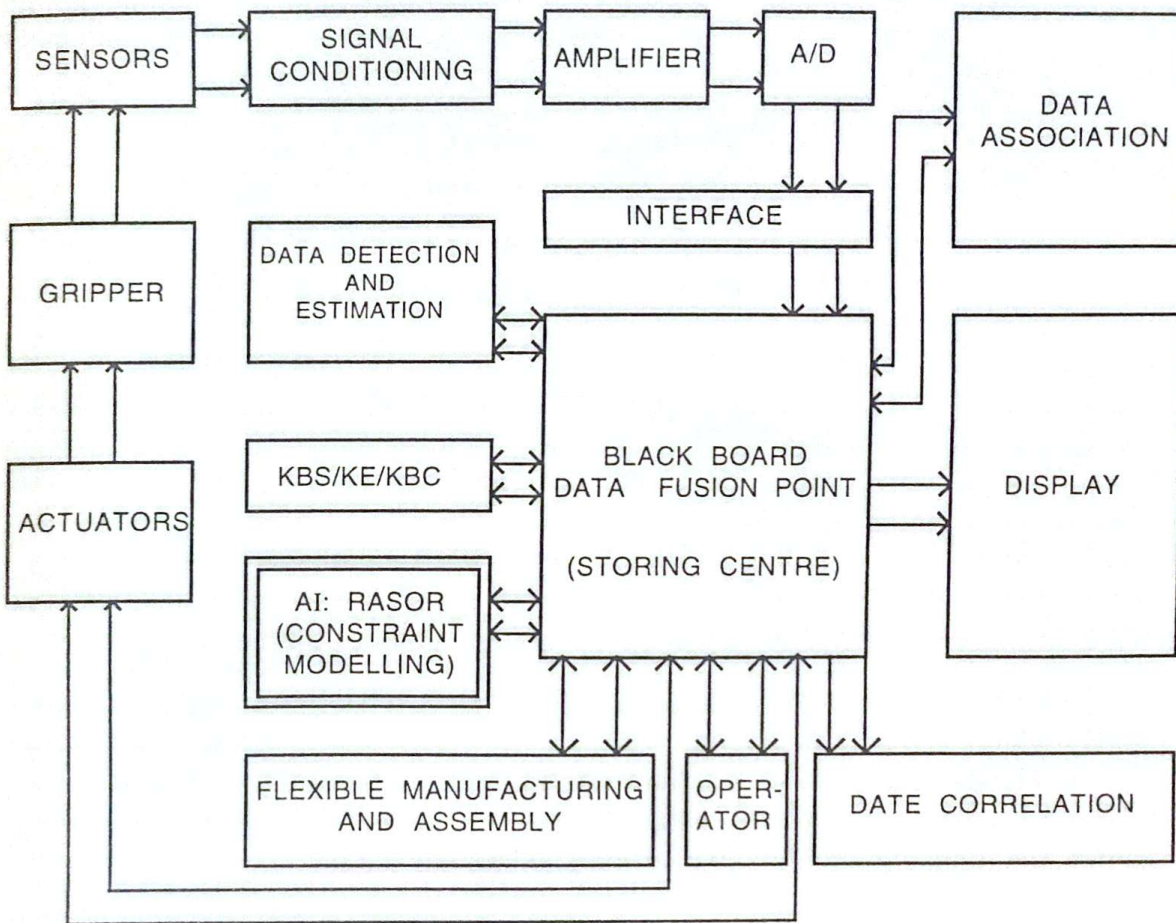


Fig. Multi-Sensor Data Processing for the Robot Controller.

costly. There is also a trend to provide a mixed mode combination of serial and parallel architectures [2]. For the purpose of a gripper controller, it is proposed to use a serial or mixed mode of communications compared to the costly parallel processing, which requires expensive hardware, complex programming and requires extensive personnel training. The controller will need to use the minimum number of sensors with a minimum software implementation time, improving the real time operation for the picking and placing of objects.

In figure 1 a general architecture is proposed which covers these fundamental requirements. It is worth noting that the architecture of the controller has been designed from the knowledge of data diffusion, knowledge based controlled systems and considering hierarchical control structures as proposed by the National Bureau of Standards (NBS), Washington [12].

To date, cell controllers have been designed using different techniques such as batch processing [3], hierarchical structures [4], and using information system concepts [5]. The conceptual knowledge required for a generalized flexible system tool to evaluate alternative configuration in a hardware cell design has been proposed by Dooner and De Silva [6].

### Data Diffusion

Data diffusion is a process performed on multi-sensor data at several levels, each of which represents a different level of abstraction of data. The process of data diffusion includes detection, association, correlation, estimation and combination of data. The results of data diffusion include state and identity at the lower levels, and assessment of the overall tactical situation at the higher levels. This approach will be adapted for the purpose of the servo-driven gripper controller. At the lower level the strategy for detection of data, association of data and state (position of gripper, and grip) is made. At the higher level, an assessment of object state (object movements, due to weight or friction, and object type) is calculated and necessary procedures are adopted to avoid object mishandling.

Sensor data fusion has wide applications in communication decision theory, digital signal processing, computer science and artificial intelligence. This field is gaining popularity because in modern automated systems, many human functions have been emulated and various data is fused to obtain meaningful information for useful purposes.

In various universities in the U.K., research in the field of sensor fusion is in progress. Durrant-Whyte [7] of the University of Oxford looks at sensor data fusion from two perspectives, one quantitative and the other qualitative. Quantitative data fusion methods are well defined and understood [7]. For the purpose of developing design architectures, Kalman filters, geometric modelling, probabilistic estimation are all used. The areas of application of these methods are in distributed sensing and control. In qualitative sensor data fusion the methods, although well defined, still have some inherent problems. These methods are beneficial in the fields of expert systems, behavioral modelling and structural modelling.

The use of constraint modelling techniques for a servo-driven gripper controller is new, in the sense that it uses both geometric modelling and

behavioral modelling methods, with the constraint modeller selecting the easiest strategy at its disposal. It is thus possible that the benefits and disadvantages of the two methods could be averaged, as suggested by Durrant-Whyte [7].

### **Advancements in Sensor Data Fusion**

Single sensor data are not reliable and when accompanied by an error fails the whole system. Multisensor data are much better and more reliable because they provide data for comparison, estimation, and help in error detection in the system. For processing purposes the sensor data are arranged in the form of arrays. The area of sensor data fusion is also well known because in modern automation systems, many human functions have been emulated.

In fact the purpose of data fusion is to obtain meaningful information for useful purposes. Data fusion has by itself some advantages and some disadvantages. The drawback of data fusion is that when information is collected from many sensors it produces diverse sets of sensed information. Sensors for data fusion have many applications such as intelligent control, industrial automation, use of artificial intelligence techniques and hierarchical control. The sensor information is processed from the signals obtained by a single or multiple sensor system.

The application of quantitative sensors is normally found in the area of distributed sensing and control, although they can also be useful in expert systems, behavioural modelling, and structural modelling. A decentralised architecture for multisensor data fusion has been discussed in detail by Edward and Linas [8]. This architecture has no central processing, no centralised communication medium and does not use hierarchy. Each sensor node has its own processing element and its own communication method and extended Kalman filter equations have been used. Data fusion is achieved using a recursive object architecture which could lead to a real time expert system being built for command and control purposes.

Research is in progress in the area of automatic tactical picture capture or data fusion, in these cases blackboard and rule based examples are used in conjunction with object oriented programming technique. Initial work with recursive processing suggests that significant speed increase should be possible. ADA and C version were compared with processing on a recursive board. Logo is now available on recursive architectures.

## Knowledge Based Control

The industrial automation achieved through the use of knowledge based systems is usually presented to increase flexibility and to cope with the complexity of interactions in automatic operator expertise, automatic complex plans and extended range of automatic tasks. But limitations of conventional methods, invalid modelling assumptions, suboptimal performance, lack of knowledge, restricts expansion of the system. Although these techniques provide a unique and practical solution to manufacturing tasks, they have difficulties in implementing heuristic methods to obtain their goals. This is because a full and complete knowledge of the system is essential. Further problems occur when the operating environment is uncertain or ill defined, requiring complex modelling and control algorithms. Hence to provide satisfactory solutions to this problem, symbolic computation is adopted.

A key feature of this paper is to justify the selection of the RASOR computer language. RASOR is an implicit or task oriented language and it should, therefore, be easy to implement the functions of a robot in an application oriented manner. By assigning constraint modelling methods to the gripper controller task it is hoped to nullify the inaccuracies associated with the uncertain environment through the use of sensor information. To understand how RASOR fits into the area of cell controller design it is necessary briefly review the computer languages used in the various techniques of artificial intelligence.

## Techniques of Artificial Intelligence

### *Advantages and Disadvantages of Black Board Theory*

The first black board theory, processing approach, was proposed by Newell in 1962. The black board is a global data base of a hypothesised solution to a problem. The processing architecture considers three major components.

- (1) Knowledge Source (KS)
- (2) Black Board Data Base (BBDB)
- (3) Control Function (CF)

The advantages of these methods are their flexible structure, modularity for a broad range of applications, and usefulness for both static and dynamic aspects of a problem. With good design one can achieve graceful information flow in the black board hierarchy, easier overall knowledge base control, and validation through knowledge partitioning; growth is also relatively easy

by adding further KS's. The simple KS-KS communication protocol provides a useful example for exploratory research, rapid prototyping, and incremental development. The disadvantages of these methods are that scheduling or control become complex and domain dependent, communication is limited among KS's, a truth maintenance system is required, and the system can be expensive to build and run. Incorrect problem decomposition, often discovered late, will require system restructuring [8].

### **Advantages and Disadvantages of Ruled Bases Systems**

Knowledge based or production ruled based methods for knowledge representation in KS's have dominated other approaches to knowledge representation in most expert systems. This method is a unique, convenient formation for knowledge representation, and provides a programming environment for data driven control and logic representation. The disadvantages of rule based systems are that larger systems require deductions which are created by a set of intersection operations.

### **Languages of Artificial Intelligence**

The languages of AI are different from high level languages such as BASIC, FORTRAN, PASCAL, on the basis of physical symbolic system hypothesis. Physical symbol systems are essential for representing knowledge in both mind and machine. The characteristics of artificial languages are:-

1. Conventional languages consist of a fixed program with variable data, whereas symbol based AI data are much more fluid in their organisation. The sharp distinction between program and data frequently disappears in AI languages.
2. Conventional languages are procedure oriented whereas AI languages are concerned with relationships between symbols which are more amorphous or dynamic.
3. Conventional languages are sequential, procedural or imperative whereas artificial intelligence languages are relational, declarative or descriptive.
4. Artificial intelligence languages are useful to improve a programming environment, have interactive time sharing, powerful debuggers, tree options, friendly editors, bit-maps graphics, and techniques for object oriented programming.

Examples of AI languages with their main characteristics are:

### *Lisp*

1. Highly extensive and flexible
2. Recursive
3. Symbol oriented data structure
4. Interactive language
5. Provide automatic dynamic storage allocation
6. Ideal Meta Language

### *Prolog*

1. Declarative language
2. Use language of predicate calculus
3. Compound train consists of functional symbols
4. Consists of four statement types:
  - (a) Facts (b) Rules (c) Questions and (d) Commands.

### *Object Oriented Languages*

The examples of object oriented languages are Object Pascal, Object Logo, Object C, C\*\*, and Neon.

1. Information hiding
2. Data abstraction
3. Dynamic binding
4. Inheritance

### **Rasor**

A RASOR is a BASIC like language and allows the user to build functions that involve algebraic expressions in named variables. A particular command with RASOR is "rule" and this is used to specify the constraint. RASOR actually searches for feasible solutions to a number of constraints presented to it. This differs from a normal expert system. Here the computer and user both learn together. The constrain modelling technique provides the CAD system with the capability of "knowing" about interactions between graphical entities that it holds and this is described in terms of constraints [9].

In the case of an expert system the rules are previously known. In design tasks, where previous rules are generally not known, constraints on the range of allowable design solutions are compared with initial and emerging rules. The redesign of a guillotine mechanism [10] has shown

the power of constraint modelling techniques for solving problems in real industrial applications. The major benefit of constraint modelling method are that rules can be build up gradually by the user as the understanding of the problem increases.

In RASOR, the geometric entities (points, lines, curves) are so designed and computed that they can be manipulated intelligently. Normally CAD systems have no knowledge of what the entities described are and how they are related to each other. In this case intelligence lies on the part of the user more than the system. Whereas in constraint modelling the constraints make decisions. The constraints relate to geometric entities and solve equations on the basis of their "truthfulness" or "falseness". An expression or equation becomes true when it equals to zero, otherwise a false result is generated [11]. These constraints, therefore, are solved by using a graphic interface language RASOR which allows communication with the geometric data base of a CAD system. Here constraints are treated as algebraic expressions in variables that relate to geometrical entities.

In a robotic assemble cell it is easier to establish cell boundary conditions and operating constraints rather than establish rules for every possible eventuality. In April 1991 a research project was established to look into the use of constraint modelling to control the fingers in a servo-gripper for the purpose of handling objects. It was decided to use RASOR as the methology for creating a handling/cell controller because of the following advantages.

1. Easy language to learn and modify.
2. Structural type
3. Decision ability to control graphics.
4. Make decisions on the basis of solutions of equations.

### **Research Proposal Conclusions**

The project is concerned with aspects of a robot cell controlling program depending on available computer hardware and operating systems.

The computer science departments mostly control robot motion through computer languages. The present trend is to develop implicit or task oriented languages in which the functions of a robot are stipulated in an application oriented manner. Flexible automation can be obtained by hierarchical control systems, where programme design works at a series of levels of increasing abstraction and generality. The use of the National Bureau of Standards for Robot Control Systems (RCS) [12] can provide

the workcell controller with a "plug compatible systems". In this way the equipment could be upgraded within the existing manufacturing facility with the minimum of inconvenience and cost, by using standard control structures to achieve an ideal system.

Another way to develop a cell controller is using an expert systems where solutions are task oriented. Such an approach has been taken by a research group at the University of Karlsruhe [13] who have developed a KB expert system. The essential feature of this system is the use of implicit programming which is textual and can be developed off-line, without directly interfering with the robot. The KB of such a system constitutes rules and data. The control of the KB is carried out by an inference engine, on rules (conditions and consequences) similar to cause and effect basis. The disadvantage of such a system is that it is limited in dealing with "uncertainties" in a real situation. To cope with this sensors can be used to handle uncertainties in assemble tasks. This suggests that programming in terms of task achieving behavioral modules would be beneficial.

Research work at Brunel University has so far shown that constraint modelling techniques using RASOR programming method meets both the demands of task orientation and NBS standards. The benefits of RASOR are that it provides features of both low level and high level languages.

Research work is continuing in the following areas:

1. To model a servo-gripper and simulate the properties of gripping.
2. Implement the sensor properties into the gripper model, particularly the characteristics of the magnetoresistive tactile elements.
3. Design rules based on constraint modelling to achieve proper gripping.
4. Check the possibilities of any improvement and compare with other methods now in use.

## References

1. Abl, P., Memon, Z.A., Mapps, D.J., Rakowski, R.T., (1990), 'Serpentine Magnetoresistive Elements for Tactile Sensors Applications', IEEE Transactions on Magnetics, Vol: 26 Iss 5, pp. 2047-2049.
2. Hwang, K., Briggs, F.A., (1985), 'Computer Architecture and Parallel Processing', McGraw-Hill International Edition.
3. Appleton, E., (1990), 'Robotic Assembly of Aerospace Fabrications- A case study', ARA 3rd National Conference on Robotics, Melbourne, Australia.

4. Elkins, K.L., Maimon, O.Z., (1987), "Information Flow Controller and its Robotic Sub-System"., Elsevier Science Publishers B.V. (North Holland).
5. Camarinha-Matos, L.M., Steiger-Garcia; A. (1988), "An Integrated Robot Cell Programming System"., Int. Symp. and Exposition on Robots, Nov: Sydney Australia.
6. Dooner, M., and De Silva, (1990), "Conceptual Modelling to evaluate the Flexibility Characteristics of Manufacturing cell designs", MATADOR.
7. "Intelligent Control", Computing and Control Division Colloquium, IEE, Feb: 04: 1991, England: U.K.
8. Edward, L.W., and Llinas, J., (1990) "Multisensor Data Fusion" 1990, Artech House Boston-London.
9. Medland, A.A. (1988)", "Approaching CAD through Constraint Modelling", CAM-I Design Automation Workshop on, Current Trends in product Modelling and Design and Automation, Dorset Institute, 7 March 1988.
10. Leigh, R.D., Medland, A.J., Mullineux, G., Potts, I.R.B., (1989), "Model Spaces and their Use in Mechanism Simulation", Proc. I.Mech.E. Part B: Journal of Engineering Manufacture, 203, 167-174.
11. Mullineux; G., (1988), "The Introduction of Constraints into a Graphics System"., Engineering with Computers 3, 201-205.
12. Haynes, L.S, Barbera, A.J., Albus, J.S., Fitzgerald M.L, McCain, H.G. (1984) "An Application Example of NBS Robot Control System" Robotics & Computer-Integrated Manufacturing 1,1,81.
13. Rembold, U., (1987), "Programming of Industrial Robots: To-day and in the Future", Languages for Sensor-Based Control in Robotics, Springer-Verlag, Berlin.