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Control Architectures and Operational Strategies for Intelligent, High-Powered Manipulators

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Abstract
Construction robots are typically required to move large loads at reaches of several metres and to provide and apply significant forces. In addition, they are required to interact in a safe manner with what is many cases a highly unstructured environment. The paper describes two approaches to this problem and suggests how these may be brought together to provide a generic 'core' around which the functional and operational requirements of a task specific manipulator can be structured.

1. INTRODUCTION

Industrial robots are conventionally used within a manufacturing process for the accurate manipulation, positioning and assembly of components and sub-assemblies and for physically arduous or hazardous tasks such as painting and stacking. In each case, the environment in which the robot is required to operate has, to some significant degree, been structured around the needs and performance of the robot, for instance to prevent human access within the working envelope. In most cases, the operation of an industrial robot is primarily concerned with achieving positional accuracy at high levels of repeatability in relation to a highly repetitive task and features such as an ability to exert a controlled force are not a normal operational requirement. This has resulted in an emphasis on control techniques and control strategies which emphasise positional accuracy, repeatability and speed of response onto which features such as collision avoidance, using integrated sensors, and an associated path planning capability have been added.

Robotic applications such as those that are being considered in the construction, forestry and shipping industries differ significantly from those to associated with a production process in that they may involve the direct application of a force, for instance in excavation, a long reach, heavy loads and, in some cases, variable inertias. In addition, the robot system is required to operate in what is usually an unstructured environment within which it must co-exist and collaborate with other machines and human operators. Finally, because of the nature of the tasks, the manipulator would typically, but not always, be mounted on a mobile base which itself must be accurately located in order for the manipulator to function effectively.

The operation of the generic class of large, high-powered manipulators for the above industries therefore requires the adoption of a control hierarchy and associated operational tactics and strategies which will enable them to function effectively in their particular environment. The uniqueness of real operating situations within these environments also requires that the manipulator must itself assume greater responsibility for areas such as task planning than is conventionally the case with industrial robots.

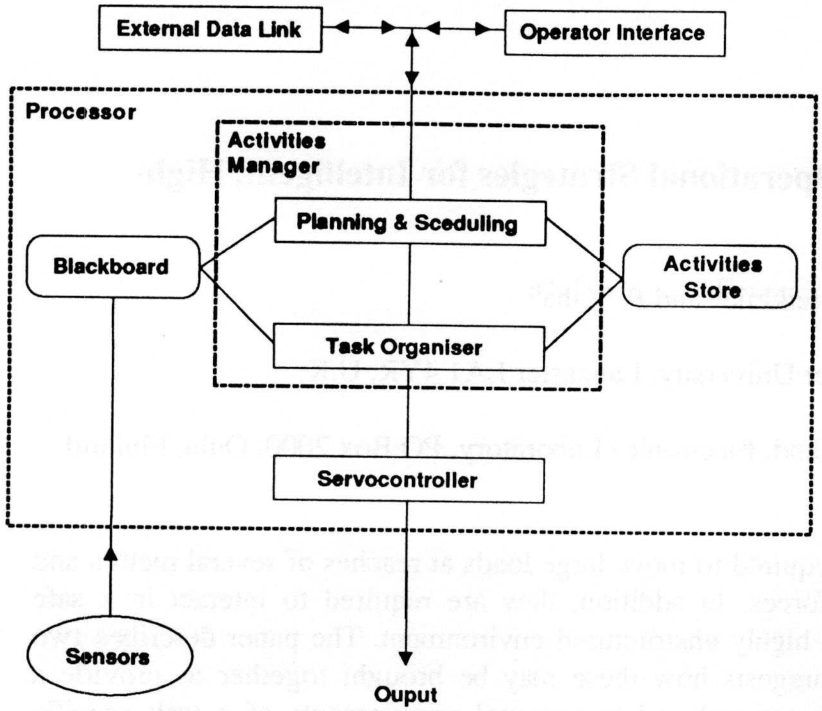

Figure 1. LUCIE architecture showing activities manager

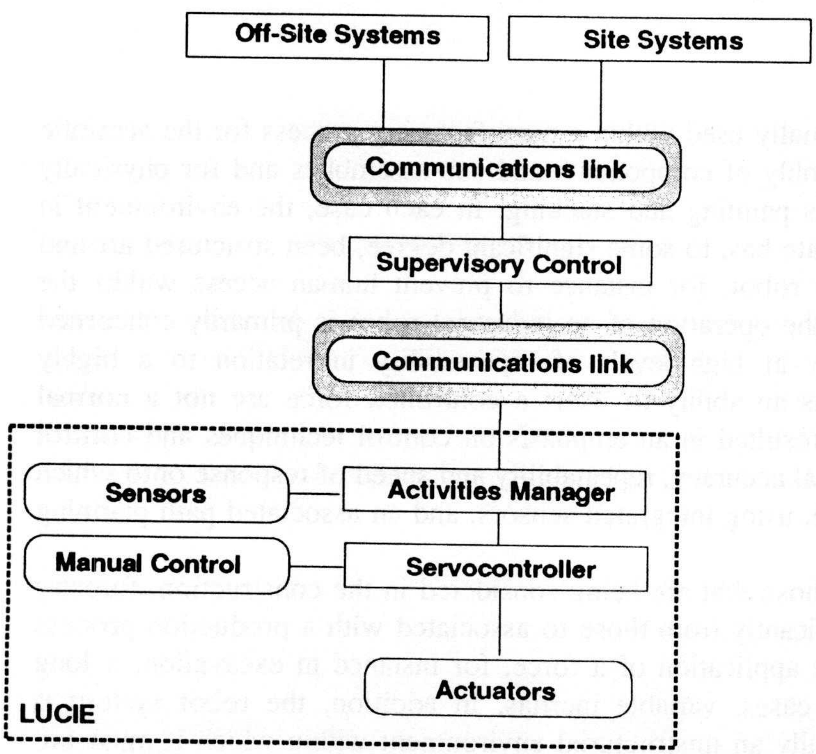

Figure 2. LUCIE communications hierarchy

In order to better understand the generic requirements for the control and operation of this class of intelligent high-powered manipulators, two examples, the Lancaster University Computerised Intelligent Excavator (LUCIE) and the VTT intelligent paper-poll manipulator (intelligent PRM) are considered and their respective control strategies compared and contrasted. From this base, a proposal for a generic control hierarchy for the general class of large, high-powered intelligent manipulators can be made which enables both autonomous and operator-collaborative forms of operation.

2. THE LANCASTER AND VTT SYSTEMS

Both LUCIE and the intelligent PRM are characterised by being essentially 4-axis, hydraulically controlled machines mounted on a mobile base which is positioned by an operator prior to the execution of the primary task. In each case the control hierarchy is essentially goal oriented with the definition of appropriate sub-goals within which the selection and execution of the associated task and sub-tasks is left to the control system. As will be demonstrated, this has led to the adoption of a similar control hierarchy onto which has been superimposed the specific, task oriented, control functions required.

2.1. The LUCIE system

The LUCIE system has been implemented on a JCB801 tracked excavator and has proved to be capable of autonomously excavating a rectangular trench in a variety of ground types and conditions and, in the process, of removing obstacles such as boulders from the line of the trench [1,2]. The control strategy adopted has been specifically developed to meet the requirements of achieving an effective motion of the bucket through the ground with the sub-goal of filling the bucket as quickly and effectively as possible. This requires the controller to autonomously make decisions as to the angle of attack of the bucket and the path of the bucket through the ground and has led to the adoption of a production rule based AI approach for task definition and implementation. The replacement of the bucket by an appropriate gripper would enable operation in other modes such as pick-and-place or formwork erection. In each case, the basic goal oriented hierarchy would be maintained with the integration of appropriate task oriented AI structures.

Figure 1 shows in generalised form the architecture adopted by the LUCIE system in which the 'activities manager' assumes responsibility for the selection of appropriate activities within the context of the current task. In this role, the activities manager is assuming responsibility for the current tactics that are adopted by the system in order to achieve its goal of a completed trench. Operation at the strategic level is largely determined prior to initiation of the task sequence by defining a generalised digging strategy which is used as the basis of system operation. However, figure 2 shows the proposed relationship of the system with site systems which would provide information on the nature of the task together with positional, survey and geological data upon which operation would then be based [3].

2.2. The intelligent PRM system

The prototype of the intelligent PRM system has been developed for Steveco Ltd, the largest company specialising in stevedoring and the handling of paper rolls in Finland. The manipulator is based on a wheeled base with a telescopic boom and a purpose designed gripper as end effector. The principal task of the intelligent PRM is relatively straightforward; that of stacking paper rolls in harbours, warehouses and ships. The control system is designed using to a hybrid approach the basis of which lies in a hierarchically organised Planning-Executing-Monitoring (PEM) architecture shown in figure 3.

The PEM architecture then allows the computational functionality and connections to make intelligent, reactive and 'skilful' control possible. Within this structure, global complexity is treated by a vertical decomposition and local complexity by a horizontal decomposition. A total task such as "transfer paper rolls" is thus divided into lower level actions such as 'move' and 'grip' in a sequential manner. Feedback information from external sensors is used to reduce uncertainty related to *a priory* model data and to react to changes in the operating environment. Strategic requirements based on the positioning of the delivered rolls are

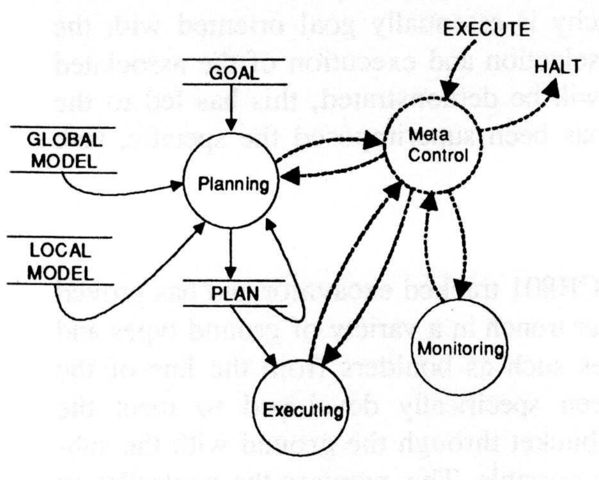

Figure 3. Decomposition of PEM architecture

determined by scanning the local environment prior to the initiation of operation to establish an appropriate map of the local environment.

Implementation is based on the use of a 486 processor for computation at the task and action levels within the PEM architecture supported by 386 processors for the user interface and for trajectory and servo control and has the structure shown in figure 4 [4,5]. Overall, the applied control architecture contains a basis for the systematic design and implementation of complicated control systems with different functional requirements.

3. DISCUSSION

LUCIE and the VTT paper roll manipulator are two examples of a more general class of intelligent, high-powered autonomous manipulators which could be extended to include forestry machinery, derrick and mobile cranes and construction plant. An interesting contrast between the two systems as developed is the fact that *positional* control seems to be more appropriate for the deterministic movements of the paper roll manipulator and for the excavator out of the ground, but that a *velocity vector* control is more appropriate for the unpredictable conditions below ground. In each case however the architecture is designed to allow for the maximum flexibility of operation in relation to the defined goals with the selection of sub-tasks being left to the system.

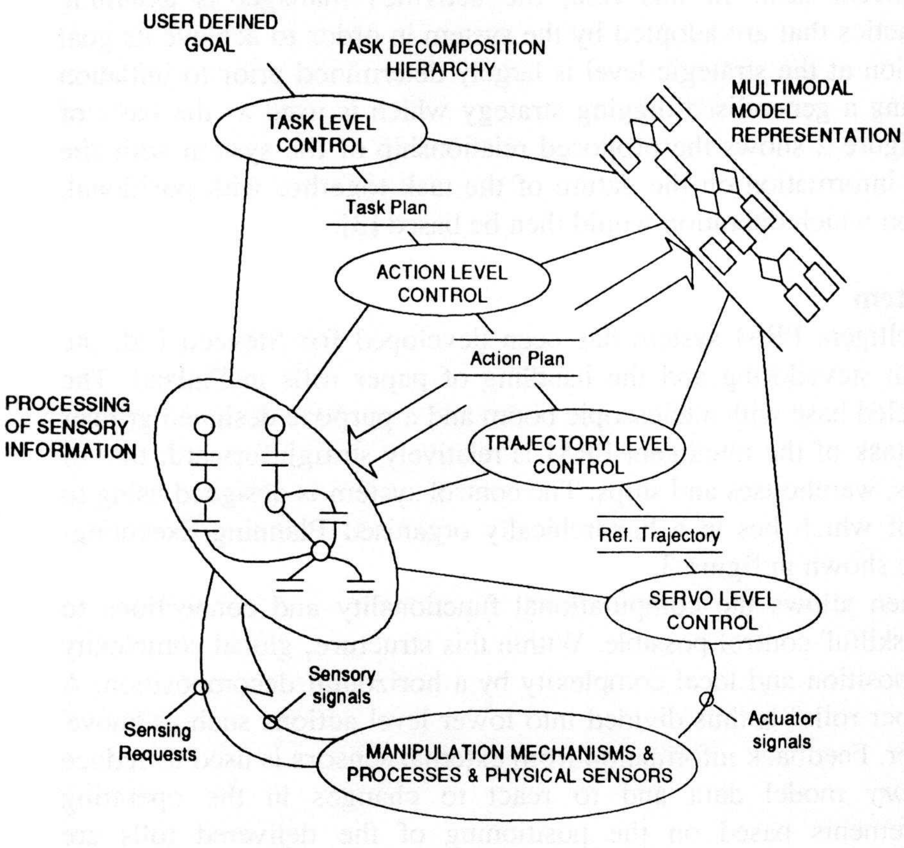

Figure 4. Intelligent PRM control hierarchy

For each of the operating environments and task considered, a number of specific modes of operation have been identified including:

Fully autonomous — The machine is responsible for its own task planning once the general goal has been defined.

Operator-collaborative — The machine is operating under operator control but superimposing its own commands and instructions in order to facilitate performance.

Operator control — The machine is operating under operator control with modes such as XY motion selectable by the operator and including features such as force feedback.

Each of these operating modes places different constraints on the way in which the system operates and must be accommodated by any generic control architecture at the design and development level.

Safety is an important consideration of any autonomous system and must therefore be a major feature of the control hierarchy with the prime requirement being that the control system, and hence the manipulator, must not itself be the initiator of any hazard condition [6]. In the case of the intelligent PRM, sensors have been included to detect the presence of personnel in the vicinity and to inhibit operation accordingly.

4. A DEVELOPMENT ARCHITECTURE

It is proposed that any development architecture for the general class of large, high-powered manipulator must be structured around some form of generic core capable of accommodating each of the operating modes described as well as the various geometries of manipulator that may be necessary for specific types of task. It is further suggested that core should assume the major responsibility for overseeing the general operational safety of the system. Finally, the core should support, through appropriate intermediaries, task specific functions, including the application of AI, together with operator interface structures.

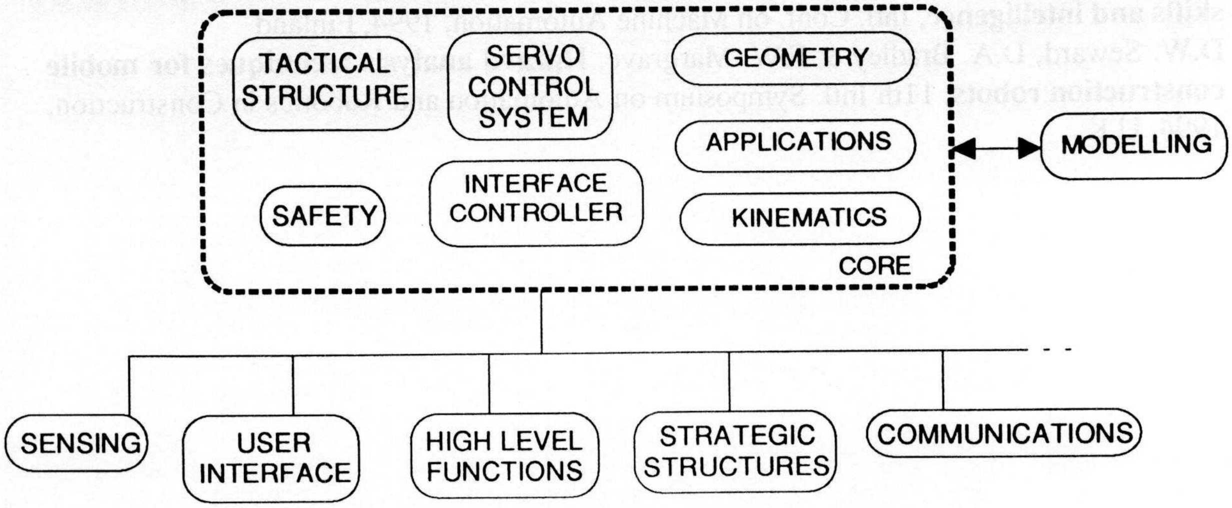

Figure 5. Component elements of proposed architecture

Devolved responsibilities would then include the management and verification of sensor data, the servo control level, site position control and communications. A possible structure for such a core and its peripheral functions is suggested by figure 5.

In operation, the structuring of the generic core should be related to an appropriate modelling of the operation of the manipulator and its task environment. This would enable the core to be 'loaded' with the appropriate information off-line and tested prior to implementation. Further, by modelling the task environment, the development of both strategic and tactical level functions would be significantly enhanced.

5. CONCLUSIONS

At present, systems such as those described in the paper are being developed using a number of different control strategies and hierarchies. A comparison of two such systems suggests that there is sufficient commonalty in operation principles, functional requirements and task structures to suggest that a common core architecture for such large, high-powered manipulators should be feasible which, when linked with appropriate modelling and simulation, should facilitate the design of an appropriate architecture.

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