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Path planning and sensing for an experimental masonry building robot

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Abstract
An experimental robot cell is being used to investigate the enabling technology for a masonry tasking robot. A CAD/CAM facility has been devised by which wall designs are translated into the robot's 'theoretical task'. However, this can not be directly implemented with out real-time adjustments derived from sensors. A further complication is that the form of a move influences the dynamic response of the robot structure. Rule-based intelligence has been applied to the solution of both these problems.

1. INTRODUCTION

Masonry is an important building element due largely to its high value and architectural significance. Considering the economics of automated masonry production in the UK, it has been shown [ref 1] that only 10% of blockwork construction need be amenable to this in order to justify the development of automation devices. This has provided the impetus for the reported research into the enabling technology for masonry production using an advanced robot [ref 2]. On the international front, substantial progress has been achieved in masonry automation research, each contribution reflecting the national character of masonry [ref 3].

The experimental robot cell described in pervious ISARC proceedings is being used to produce both dry wall and bonded wall constructions. Excluding overall mobility, all aspects of the automation are represented in the cell; delivery, survey and quality assessment of supply masonry units, navigation, mix dispensing and assembly. Apart from standard production masonry units, interlocking blocks and special bricks are under investigation . Interest in the later arises from the weight advantage that a robot can have over a human worker.

The CAD/CAM regime shown in fig. 1 has been adopted by which a CAD derived 'project description' is processed into a 'theoretical task'. This cannot be precisely implemented due to a number of factors. However, it serves to guide the closed loop, task-sensed operation of the cell. A particularly valuable aspect of the 'theoretical task' definition is the provision for optimised moves, which represent the reconciliation of the requirements for least cost and low vibration inducing motion. The determination of the robots theoretical task and the run-time implementation of this are the main subjects of this paper. This research is funded by the Science and Engineering Research Council.

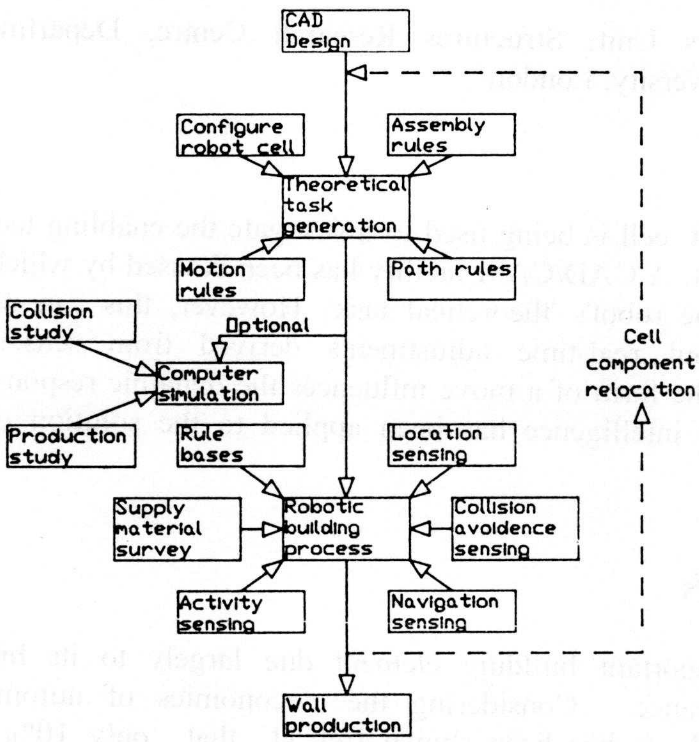

Figure 1 The CAD/CAM Regime

2. EXPERIMENTAL ROBOT CELL

The robot cell comprises a 5m long industrial conveyor, a vertical axis laser beacon that provides horizontal referencing, a mix dispensing station and a gantry type robot. The robot has a clamp type gripper with various sensors mounted on it. A working envelop of 5.0m x 2.5m plan and 2.0m elevation is available and masonry units up to 50kg weight can be manipulated on it's three prismatic and two revolute axes.

The robot's motion logic is implemented on three parallel SMCC's (Smart Motion Control Cards) which communicate with a master 80486 processor via a RS232 communication line. The master also communicates with distributed 80286 processors allocated to the conveyor and robot end effector. These credit size processors are combined with A/D (Analogue to Digital) convectors supporting the multiple sensing requirements. Further processors are provided for the navigation beacon and mix dispensing station.

3. PROJECT DESCRIPTION GENERATION

The dedicated CAD facility is coded in AutoLisp, the programming language of AutoCad. This enables projects to be solid modelled as single skin brickwork or blockwork or cavity construction comprising both bricks and blocks. The cavity width can be varied and standard window and door openings introduced. For cavity wall construction, rule-based reasoning avoids small block lengths and vertical joint alignment. On conclusion, a 'project description' is generated. This is essentially a list of N sets of entity attribute lists, N being the total number of bricks and blocks in the project. The attribute list comprises the 'XYZ' co-ordinates of the target location for the centre of a unit relative to a ground datum, 'Oa' the orientation index (0/1 according to alignment on the CAD grid), 'Bb' the brick or block type identifier, 'Sp' the special unit indicator (standard/non-standard) and 'Ul' the special unit length if appropriate. Figure 2 shows an example of a cavity wall project having openings and special blocks.

In the context of the conveyor supply, where units may be rejected, operator intervention is necessary for special units. Whilst outside of the scope of the current programme, a microprocessor controller block cutter could be mounted on the conveyor.

4. THEORETICAL TASK GENERATION

To derive the 'theoretical task' from the 'project description' it is necessary to consider (i)the assembly method, (ii) collision freeways and (iii) move optimisation. The first item concerns the order of assembly and the bond application requirements. Whilst a matter for further study, the units are currently laid in a clockwise sequence, switching between the inner to outer leaf construction in cavity wall projects. As far as possible, access is kept to one side of the project. However, it is observed that potential collision zones arise for the end effector under this restraint. This matter is currently being studied by computer simulation in order to arrive at a generalised rule-base. This will append an access parameter to each of the N entity lists and reorder them. A bond application parameter will also be appended which indicates the faces

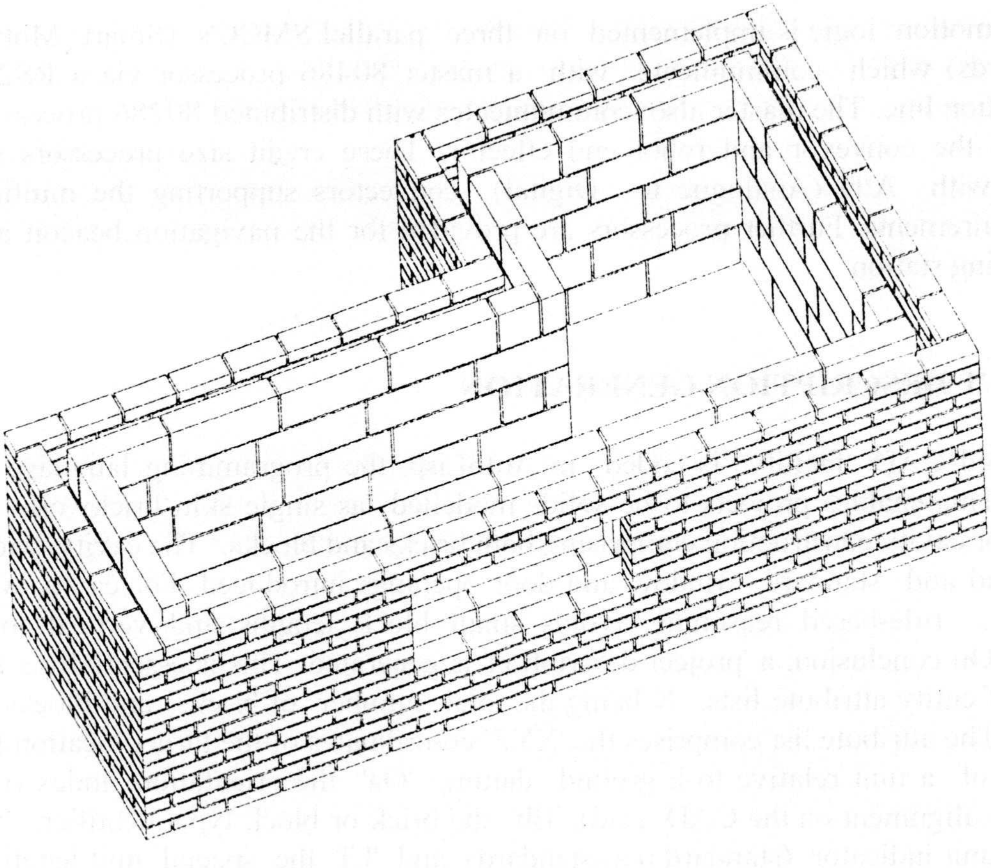

Figure 2. CAD Generated Project

requiring the bond mix.

Regarding the second item, this is complicated by the changing workspace topography. However, the problem has been substantially simplified by considering only the end effector. The adopted search algorithm is of the 'combinational' type having a finite number of solutions for each stage of construction and region. In this, freeways [4] are identified in which vertical planes can be analysed for clearance using the CAD model. A move matrix is calculated which allows sufficient leeway for the end effector to rotate about its roll and yaw axes. In the event of a cell component being relocated during the execution of a project it would be necessary to reprocess this matrix. Whilst such events are foreign to manufacturing environments they are relevant to construction sites where activities tend to compete for work space.

The last item addresses the problem of move optimisation that is complicated by the dynamic behaviour of the end effector. This arises from the partial compliance of the jaw axis about which the combined inertia of the roll axis motor, gripper and gripped block is substantial. This effect is most pronounced when the axis of the gripper is set perpendicular to the motion path and maximum acceleration achieved during a short move. In this case the settling time is very significant. To understand this further,

the effective move time (Effective Move Time = Move Time + Settling Time) has been investigated. Fortunately the SMCC's are able to support motion control to 'S' curve order under point-to-point and continuous path control. By these means, experiments have been conducted to determine the influence of the move order on settling time. An accelerometer located at the furthest radial point of the end effector enabled the combined translational and rotational accelerations to be measured. Three types of moves ere run each covering the same distance in equal time using (i) linear, (ii) parabolic and (iii) smoothed 'S' curve velocity variations. Figure 3 shows the acceleration plots corresponding to moves of seconds duration. These are near system limit moves made on a single linear axis. Whilst the 'S' curve provides the smoothest path, the high value of acceleration achieved leads to greater settling time than with the parabolic move. However, 'S' curves do produce the least 'effective move time' for longer moves where induced oscillations have time to decay during motion.
A rule-base is currently being prepared which will select the appropriate form of moves.
For this, the least time moves will be determined by fitting cubic splines clear of collision points. Apart from under continuous path control, where these can be precisely followed, the motion requirements for good dynamic behaviour result in some noticeable departures between collision clearance points.

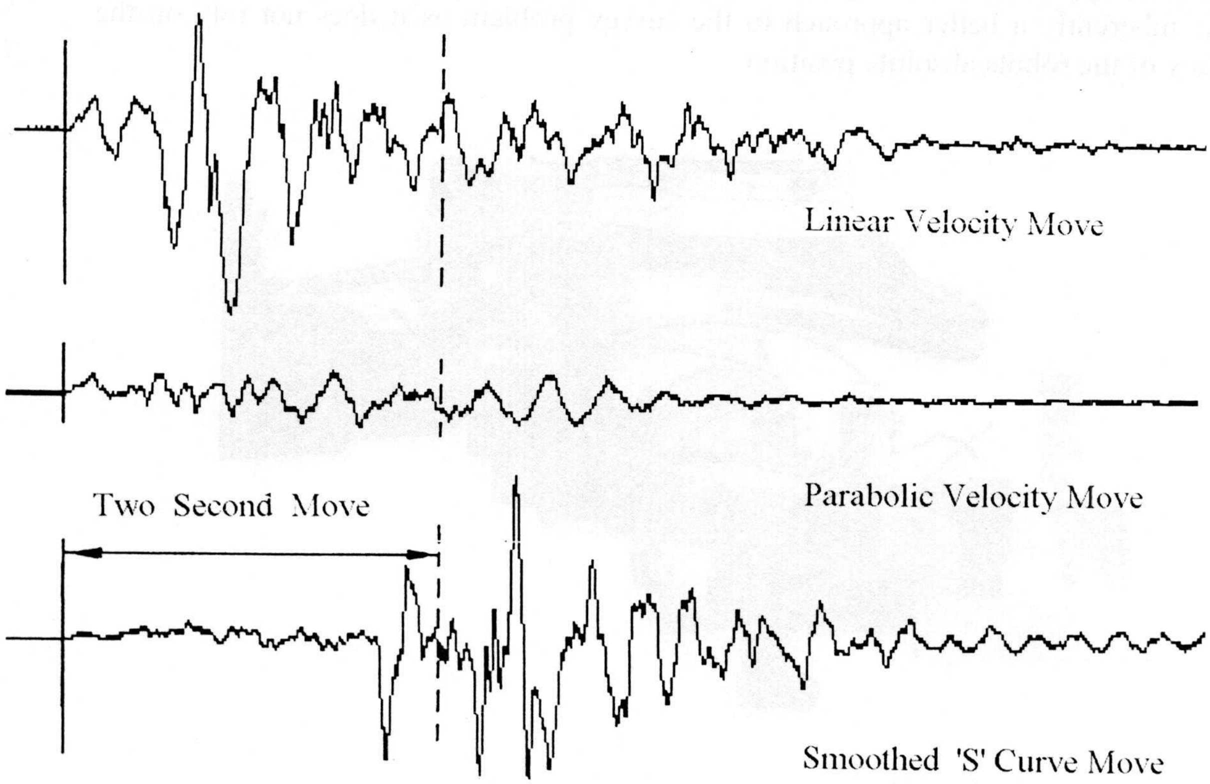

Figure 3. End Effector Dynamics

5. END EFFECTOR SENSORS

We confine our attention to the various sensors located on the end effector, these supporting the location, gripping and. placement of masonry units, survey of the assembly and collision avoidance. Of these, two highly focused near ranging Ultra-Sonic (700mm range) transducers and two displacement transducers are clearly visible in fig 4. The former are used to locate masonry units at the conveyor pickup point and avoid close obstacles during motion and the later to determine the angle and offset of gripped blocks relative to the gripper. Strain gauges are mounted on the side elements of the gripper that enable the contact forces to be monitored in relation to the offset information provided by the then vertical near ranging transducer. This combination avoids potentially damaging contact forces arising from misalignment of the gripper during pickup and also confirms the full or empty status of the gripper. Following pickup, the gripped unit is presented to a linear laser scanner that determines the transverse location of the masonry unit relative to the gripper. A pair of Polaroid ranging sensors are currently being investigated for overall collision avoidance, these operating on the 'bat's eyes' principle. For the purposes of work survey, a precise laser ranging unit is provided, this able to resolve the masonry features. Whilst not implemented on a real-time basis, image processing methods have also been successfully applied to the recognition of individual masonry units within an assembly. This is inherently a better approach to the survey problem as it does not rely on the accuracy of the robots absolute position.

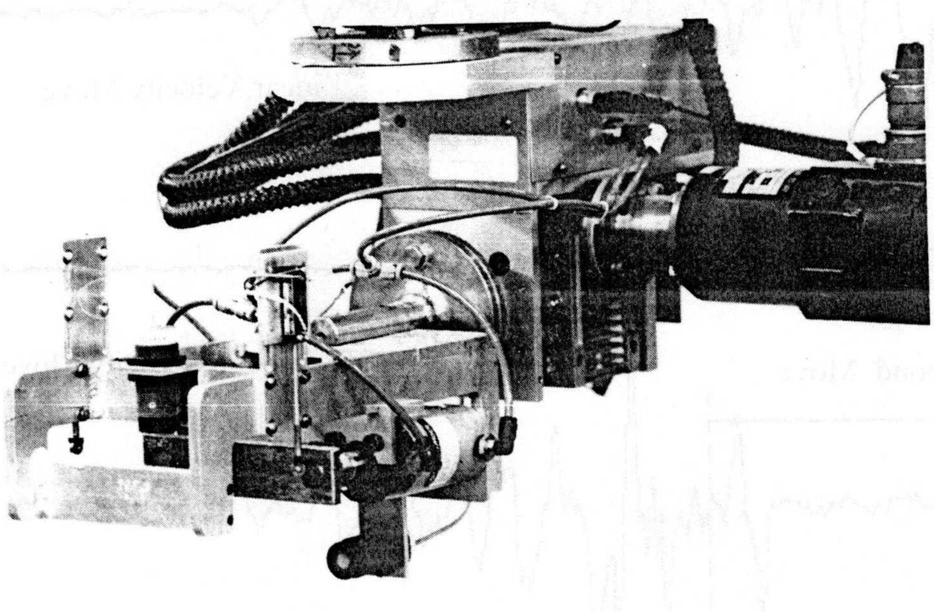

Figure 4. Robot End Effector Sensors

6. SENSING INTELLIGENCE

The runtime sensing intelligence is cast in a hierarchy of rule-sets that operate acyclic graphs. In this, reasoning is applied to the filtered and compressed sensor data in order to determine the required high level instructions for the robot. The use of trained Neural Networks is currently being studied for use with rule-bases. Whilst incomplete, these provisions should allow the robot to safety and reliably execute the 'theoretical task' with the sensor determined adjustments.

In the robot's operation, two classes of moves are apparent, interference moves in which controlled contact is required between objects and clearance moves in which contact between objects is forbidden. For the masonry robot the former applies when picking units, presenting them for bond mix application and locating them in the assembly. Other than these, all moves are of the latter class. For collision avoidance, 'active' and 'semi-active' sensing regimes are being studied, the top level structure of the latter shown in fig. 5. The essential difference between these is that the 'semi-active' delivers the move requirements to the master processor whereas the 'active' delivers notification only when changes in prescribed states occur. The former is compatible with point-to-point adjustments based on relative positioning and the latter continuous motion relative to objects.

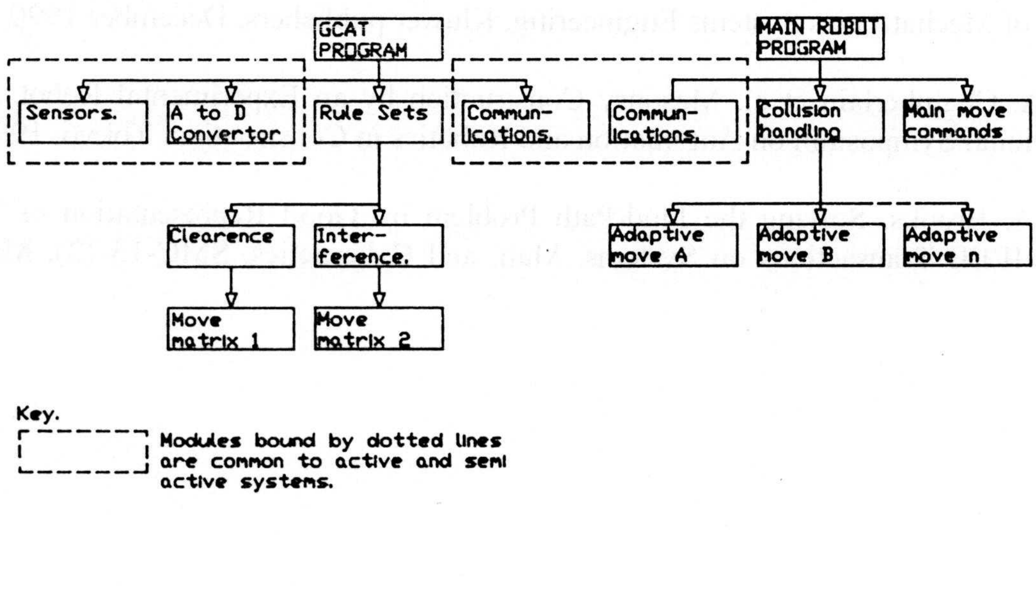

Figure 5. Semi-Active Sensing Regime

7. CONCLUSIONS

The CAD/CAM regime for an experimental robot has been described in which readily designed masonry projects are translated into robotic construction. In this, a theoretical task description is determined from the project design and implemented using closed loop sensing. Parallel processed rule-based intelligence is used in this. Concerning the robot's motion, it has been demonstrated that the form of move can substantially affect the end of move settling time.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

1. D.A. Chamberlain, Developments in Construction Robotics, Construction Robotics and Automation Symposium, Reading University, 21st. March, 1991

2. D.A. Chamberlain, G.A. West and P.R.S. Speare, A Masonry Tasking Robot, Journal of Mechatronics Systems Engineering, Kluwer publishers, December 1990

3. D.A. Chamberlain et al, Masonry Construction by an Experimental Robot, 9th. International Symposium on Automation and Robotics in Construction, Tokyo, 1992.

4. R.A. Brooks, Solving the Find-Path Problem by Good Representation of Free Space, IEEE Transactions on Systems, Man, and Cybernetics, SMC-13 (2), March 1983