A MASONRY TASKING ROBOT

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ABSTRACT

A gantry type robot is being developed for performing masonry tasks, a traditional and extensive activity. For this, vision is considered to be the prime sensor mechanism for inspection and guidance. A CAD model of the block component has been investigated for use in the design, vision and planning tasks. Free of the restraints of the manual process, the block material itself is a matter of some sophistication in form and function. The presentation, transfer, bonding and incorporation of the block material necessitates a well structured, goal driven approach to the planning problem. A simple expert system shell environment provides a useful means for investigating the knowledge base for this.

1. Introduction

This paper records the progress of an interdisciplinary study in the application of advanced robotics to masonry tasking. The areas reported in this paper relate to considerations of the robot configuration, block design, vision sensing, and planning and knowledge representation.

2. Robot Configuration

A number of conceptual robots have been reported [1,2,3] in the area of masonry and surface finishing. In addition, there have been several attempts to automate brickwork construction on a mechanical basis, the brick laying machine designed and built by the Laing Technology Group (1970's) being one of the more successful. Recognizing the variations inherent in the material and construction, a flexible robot system, composing advanced sensing and task planning capability is clearly indicated.

Figure 1 illustrates the robot layout that has been adopted in order to study the detailed tasks. The manipulator arm is based on a cartesian coordinate system, with pitch, roll and yaw wrist articulation of the end effector, providing a manipulative capacity of about 20 kg. Material supply and rejection areas are provided in addition to the construction zone. Apart from general sensor requirements, defects, inspection and survey necessitate the use of vision. In its overall cycle, the robot will collect supply material from the area denoted 'good', discard this to the area denoted 'bad' on failure of quality check or locate the unit in a number of set piece constructions.

3. Block Design

In considering the type of unit to be used with the robot there are three strategies under consideration (i) the use of conventional bricks or blocks, (ii) adopting a normal block style of unit, but in a larger size, and (iii) the design of special units having characteristics which take into account the handling capabilities of the robot.

The first of these, whilst implying that the method of construction does not influence normal design considerations, clearly does not take account of the capability of handling larger and heavier units than can be used with traditional techniques. This is clearly inefficient from the robotics viewpoint. A natural extension of this is merely to increase the unit size so that the weight is in line with the capacity of the robot and the number of operations is minimised. However, special jointing considerations may then be important, the building layout will be subject to modular constraints and there will be a need for more than one single type of unit if other than infill panels are to be constructed.

If special units of a totally unconventional design are considered then such possibilities exist as a double skin unit, insulated and tied, for cavity construction, simple projections and indentations to aid location and ensure specified tolerances are met and features which enable the requirements of jointing to be taken into account. There are a number of constraints which must be taken into account, principally the mass of unit which can be handled and its implications for size, minimising the number of types of unit required, jointing considerations and aesthetics.

The capability of the robot could be most effectively utilised for internal infill panels which would then be plastered so that aesthetic considerations associated with very large units would not arise. To utilise fully the potential of the robot for external wall building, a major departure from conventional unit design is necessary. In both cases there is the consideration of the type of material from which such units might be made and the limitations which this would impose.

Three main types of jointing have been employed or proposed. These are (i) dipping the units in adhesive to coat two faces of the unit, (ii) spreading the adhesive along the bed joint as an automatic operation prior to laying the course of units and (iii) laying the blocks dry with subsequent strengthening [4]. However, the last option would necesitate close size tolerances and therefore tend to be more expensive than wet bonded blocks, where small corrections can be accommodated in the adhesive bed.

Having regard to the likely size of unit, the most effective jointing technique seems to be spreading of the bed joint for a complete course and simultaneous filling of vertical joints. For this, the end faces of the units would need to be specially shaped so that there is an acceptable cavity width formed between units, but narrowing to a conventional width at the edges.

4. Vision Tasks

4.1 The need for a CAD model

Wall blocks are 3-D objects, therefore sophisticated vision processing is required to cope with viewing the blocks at different orientations. The system under development is based on the use of a CAD model which is a perfect geometric description of the block. From the CAD model, the position of each physical feature (edge, corner etc.) can be determined in 3-D space. This information can be used in many ways to drive the vision tasks, namely recognition and inspection. Figure 2 shows various views of a simple CAD model of a conventional building block. Note that this is an edge based representation (no surface features are shown and no shading has been used). Hidden line removal has been used to display only those features visible from a particular viewpoint.

4.2 The Vision Task

The use of vision for blocklaying by robot is essential if the robot is to cope with the variable environment. Variations in the location of the supply material and its size tolerances are examples of this. A robot preprogrammed to grab blocks from a particular position and then place them, cannot take account of these variations and so requires feedback for guidance. Vision is the most effective method to implement this. In addition, each block requires inspection before use to detect cracks, chipped corners, geometric variation and damaged edges. Inspection is also a task that is well suited to vision.

4.3 The need for Recognition

Recognition is needed to determine the position or pose of the block in the image. In other words the 6 degrees of freedom (translations x,y,z and rotations roll, pitch, yaw) are determined which enable the model to be transformed into image space. This requires the spatial correspondence of the features to be determined for any viewpoint from the CAD model and compared with those extracted from the image. This application will extend the methods of Lowe [5] and Stockman [6]. The position of a block is detected if features from the model match those of the image.

The problem with this hypothesis and test strategy is that it can be slow as all possible viewpoints of the block need to be compared with the image to find the correct one. To reduce this search space a number of techniques are used. Perceptual groups are determined from the model and matched with those in the image. A perceptual group is a collection of features that can only occur for a particular viewpoint (or small number of viewpoints) of the block. For blocks pairs of parallel lines and vertices are good perceptual groups. In figure 3 perceptual groups can be easily identified by the reader.

An example of initial processing is shown in figure 4. Edge detection initially isolates edges from the image (a), after which straight edges are detected (b) using a line and arc detection algorithm [7]. The straight edges of each block are detected, from which the positions of the vertices can be determined. Note the incomplete feature extraction and the presence of other artefacts in the image. These are caused by the edge detection process that assumes that an edge is produced by a change in image intensity. This generally occurs at edges and shadow boundaries.

4.4 The Inspection Task

The CAD model is used in inspection to guide the search for potential defects on the blocks. Recognition has determined the model to image mapping, so that the position of each visible model feature is known in the image. A damaged edge is detected by searching in the region the edge is expected to be in the image [8]. Edge points must lie close to or on the expected edge position for the block to be good. Similar methods are used for chipped corners and geometric variations. Cracks require a different method. The presence of a crack in the face of a block will manifest itself as an edge where one is not expected.

To inspect all surfaces of a block, manipulation by the robot is used so that each face can be successively seen by the inspection camera. As the gripper of the robot obscures at least two of the faces, the block has to be placed on the ground and re-grabbed by the robot. For regular blocks this is a simplified process.

4.5 Block Placement and Pickup

Recognition (and hence pose determination) is necessary to guide the robot into the correct position to pick up each block and to place it in the wall. Ideally the configuration and position of the pallet should be known. However, in practice neither of these constraints will be realised. The pallets will be positioned only approximately in the correct position and the configuration of bricks will also vary. Assuming the blocks are stacked on a pallet, the image of the pallet requires examination to determine the positions of the blocks. Then the robot can be guided, via planning, to the next available block that can be picked up. Planning is necessary for this so the robot grabs the top block and is not obstructed by other blocks. Once the block has been picked up and inspected it is positioned in the wall. Again, ideally, the positions of the blocks already placed in the wall will be known. However, in practice variation in the positions will occur because of a number of factors, for example settlement and inaccuracy in positioning.

5. Planning Provisions

5.1 Skills In Traditional Bricklaying

Prior to considering the provisions for intelligence in the automation of masonry tasks, a study was made of personnel engaged in the traditional bricklaying activity. Comparing expert and novice activity, the significant skill differentials, those which directly influence the quality of the product were observed in the areas of (i) setting out and survey, (ii) providing appropriate mortar mix, (iii) proportioning and distributing the mortar mix, (iv) bedding down bricks, (v) planning spacing, (vi) opportune and appropriate surveying, (vii) selecting and executing remedial measures and (viii) cleaning and finishing joints.

Survey and remedial activities are the most significant factors affecting productivity. Whereas the expert spends 10%-15% of his time on items (i),(vi) and (vii), the novice correspondingly spends 65%-80%. The final appearance is closely linked to skill levels in (iii) and (viii), the finishing element requiring considerable skill. Apart from these differential skills, there are general skill requirements for rejection of defective material, and handling and placement of the units. However, it is apparent that the most fundamental components of the expertise are the ability to execute timely, appropriate and effective remedial measures, and to sustain a relevent dynamic plan for the project. This has lead to the development of provisions for intelligent planning.

5.2 Goal Driven Planning.

An incomplete object-oriented representation, previously applied to piping construction [9], is illustrated in figure 5. for the wall construction project. In this there are three main knowledge types, process, object and causal. Appropriate representation for these are procedural representations, frames and production rules. For the purposes of investigating the planning provisions, the LEONARDO expert system shell environment (Creative Logic

Ltd., Slough, England) has been employed. Particular merits of this inexpensive software are its high level user interface and the ease of linking external utilities such as low level C code for sensory processing.

Each object owns a frame [10] which comprises protected slots, default slots and optional slots, the object attributes covering also properties and relationships. Class objects are apparent with MemberSlots: which are inherited with values, if appropriate, by Member objects. Individual units (blocks), for example, are members of the class 'unit' thus they inherit attributes such as 'unit_location: of current_unit', and 'unit_function: of current_unit' which are subsequently instantiated. In the case of process knowledge, this is operated by procedural representations (internal and external) accessed at various slots. Causal knowledge in the form of 'if < antecedent> then <consequent>' , is set in a main rule set and the RuleSet: slots of frames. By this means a readily comprehensible goal and sub-goal structure is achieved. The following is a typical provision for this:

```
Rule: use valid block
if the unit_selection is complete
and the unit_inspection is complete
and quality_check is pass
then the robot_activity is an assembly_task
```

In this, unit_selection, unit_inspection and quality_check are all sub-goals which are instantiated in their own frames during the inference process. By example, the incomplete frame of the object quality_check is as follows :

```
Name: quality_check
Type: text
Value: unknown
DefaultValue: fail

 .......various slots........

RuleSet:

 .......various rules........

     Rule: satisfactory block
     if unit_quality: of current_unit overlaps QA_facts: of wall_design
     and the check_list excludes failure
     then quality_check is pass

 .......various rules........
```

The rule set in this frame, which also relies on various procedures, is used to test the clause 'quality_check is pass' in the antecedent of the 'use valid block' rule of the main rule set. For the consequence to be true ie 'robot_activity is an assembly_task', the clauses relating to 'unit_selection' and 'unit_inspection' must also be true.

At run time, 'Why' and 'Explanation' access is available, and on termination access by 'How'. A graphical processor is currently being linked to the system for simulation studies. The CAD block description will be used in planning the assembly task, because geometric reasoning is essential in this.

6. Conclusions

It is apparent that vision will be a prime sensor, with a CAD model of the block unit utilized for inspection and guidance tasks. In addition, the CAD model will facilitate studies in block design, analysis and task planning. A preprogrammed device is thought unsuited, as tasks are complicated by general variability and the possibility of unplanned events. To this end, a knowledged based, goal driven, intelligent planning facility has been modelled using an expert system shell.

7. References

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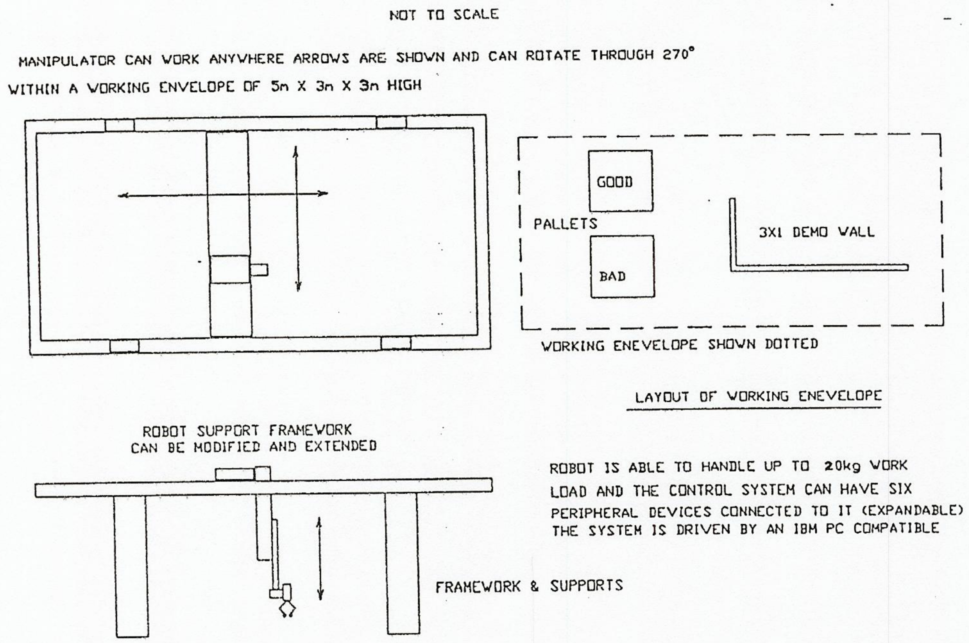


Figure 1
General Arrangement of the Proposed Gantry Robot

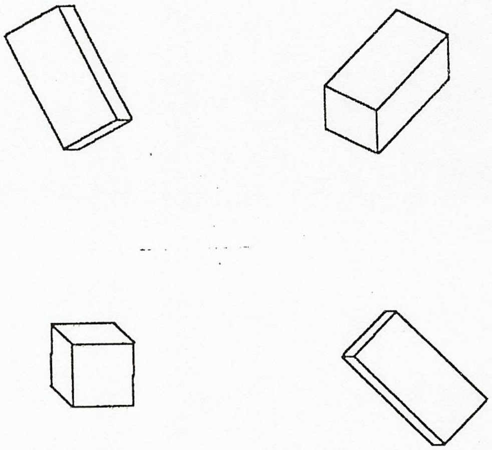


Figure 2

Various Views of CAD Block Model

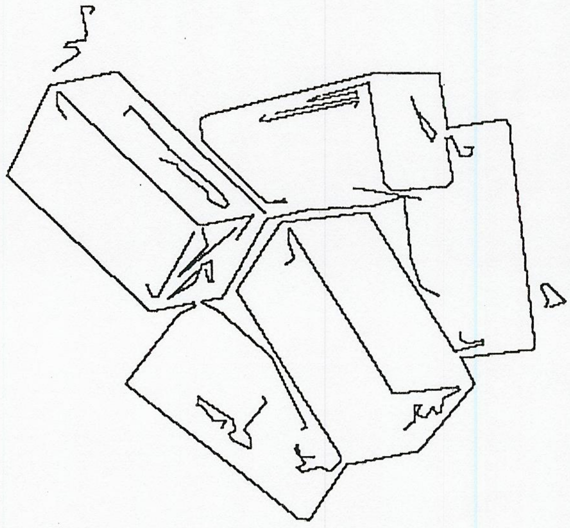
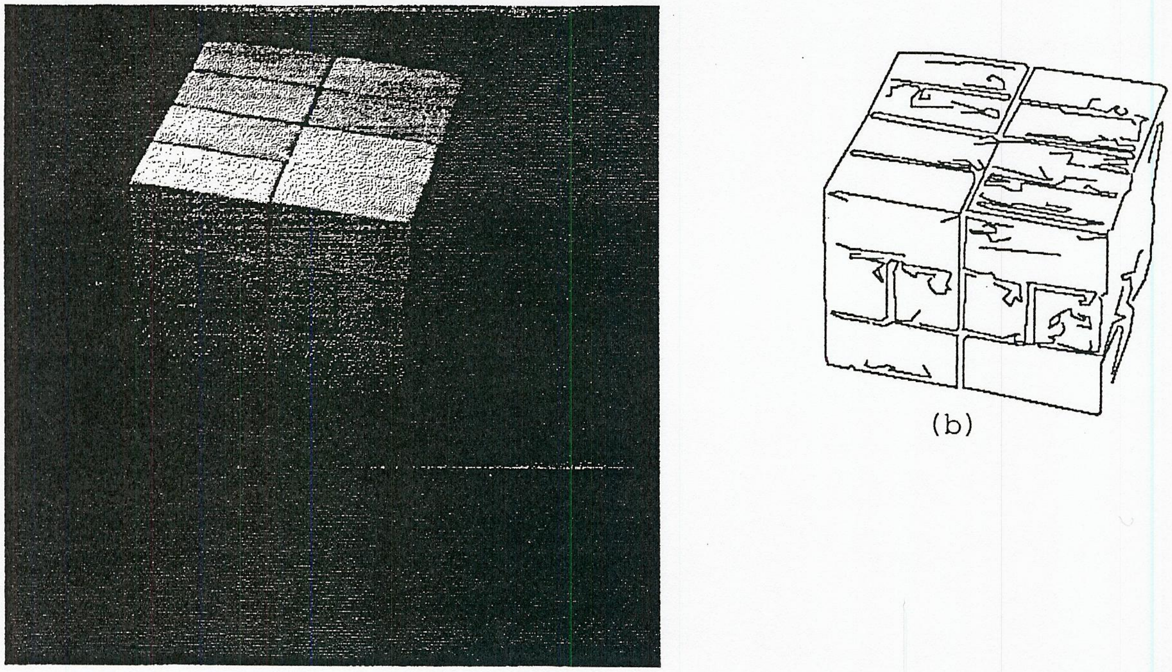


Figure 3

A Randomly Orientated Group of Blocks



(b)

(a)

Figure 4
Initial Processing for Block Edge Detection

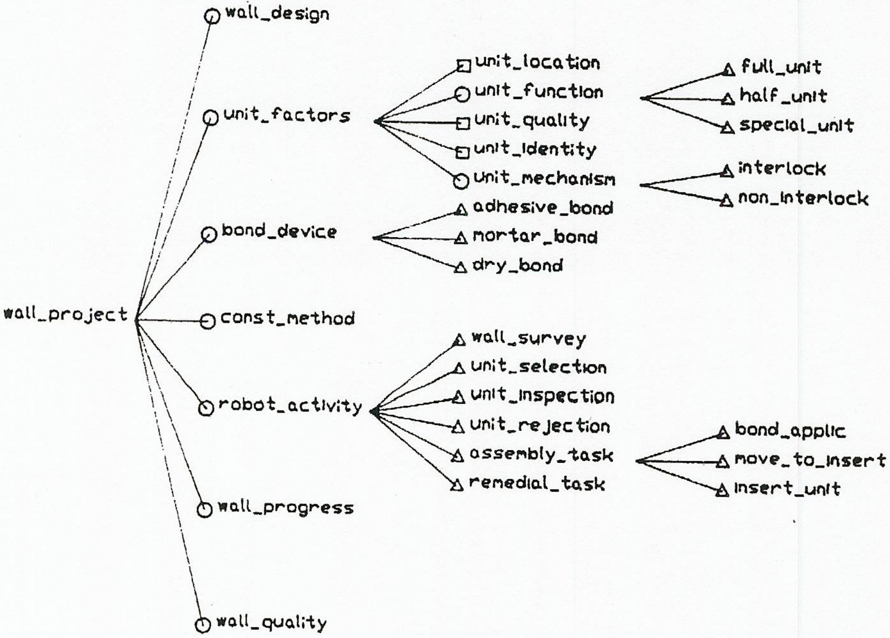


Figure 5
Object - Orientated Representation of the Wall Project