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MASONRY CONSTRUCTION BY AN EXPERIMENTAL ROBOT

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ABSTRACT

Masonry is an important, traditional and conservative aspect of UK building activity. This mainly involves the use of bonded brick and block units which have significant dimensional tolerances and are easily damaged. Taking these factors into account, automation of masonry construction cannot be interpreted as being a simple pick and place operation. Quality control of the supply material must be included, and assembly performed on an intellegent basis. Though lacking performance speed, satisfactory damage detecting image processing algorithms have been established as part of the quality control provision and a high level programming approach has been adopted towards the provision of machine intelligence. Dry wall constructions have been made by the experimental masonry building robot which on completion will also perform bonded construction.

1. INTRODUCTION

Masonry construction in the form of brickwork and blockwork is a high volume, repetitive and labour intensive activity and, as such, is a natural target for automation. To this end, a number of automation solutions are being pursued, based on either existing robot hardware or new dedicated equipment.

The national characteristics of the masonry material, bonding method and construction applications have a significant influence on the automation requirements. In Finland and elsewhere[1,2], it is proposed that masonry units should be prepared to fine tolerances within the robot cell and bonded into place using glue. Sand-lime bricks measuring 270mm x 130mm x 75mm are to be used in this. Contrastingly, dry wall construction by an industrial robot has been demonstrated in Israel[3], where posterior wall reinforcement rather than inter-unit bonding is adopted. Large gypsum blocks measuring 700mm x 500mm x 90mm and weighing 27kg are used. A high capacity delivery and placement complex is being developed in Russia[4], which provides mass masonry constructions using brick material measuring approximately 230mm x 70 x 115. Bricks are prepared with mortar on their lower face prior to placement with vertical joints subsequently filled by injection. Slightly smaller bricks, and blocks measuring approximately 420mm x 220mm x 100mm have been adopted in research in Great Britain[5,6]. A modified mortar is used in this case.

Apart from these robotic and automation studies, attempts have been made to introduce mechanisation into the manual processes[7,8,9]. Where large and heavy masonry units are used, such delivery and handling devices can be beneficial and, to a certain extent, pave the way to full automation.

This paper relates progress in a research programme which is aimed at establishing the enabling technology for an advanced masonry building robot. Some of the objectives of this programme, which is funded by the Science and Engineering Research Council with contributions from building contractors, overlap with those of the EUREKA Famos Brick project[10]. The primary application targets differ however, in that the Famos Brick project focuses on the automation of steel convertor relining. This is a poor working environment in which men are employed to locate precisely several thousand heavy blocks. Unlike the reported project, no bond medium is used.

In common with the Eureka project, the reported research programme is premised with the recognition that acceptable automation must cover quality control in addition to reliable conveying and handling of masonry material. This is particularly relevant in the UK, where market forces dictate the use of masonry units which have significant dimensional tolerances and are easily damaged between manufacture and usage. On these accounts an automation cell must be capable of assessing and rejecting supply material according to preset limits. Apart from the higher cost factor, glue bonding is inappropriate, as a thick bonding bed (10mm - 12mm) is necessary to accommodate the dimensional variations of the masonry units. The dimensional accuracy of the wall assembly is a further quality factor which necessitates interim surveys and possible corrective action during the progress of the work.

An account of the provisions for quality control follow a description of the experimental robot cell and the motion control strategy. An outline of the approach to cell integration preceeds the conclusion.

2. EXPERIMENTAL ROBOT CELL

The experimental robot cell comprises a gantry type robot which operates the grippers is shown in Fig. 1 and Fig. 2, material conveyor and the laser beacon in Fig. 3. The mortar despensing unit has yet to be completed. This has been designed for automation experiments rather than construction site usage, where a different configuration and overall mobility would need to be considered. However, its working envelope allows masonry projects of up to 4.0m x 2.5m plan and 2.0m elevation to be completed.

Based on the CROCUS system, the gantry robot comprises five degrees of freedom; three prismatics (x,y,z cartesian), one z axis (vertical) revolute and one x/y axis revolute. Its handling capacity is 50 kg with full manipulation and 500kg with the x/y revolute locked in position. Motion control of the robot and cell integration is discussed in the next section.

Compared with the suction tools, clamp grippers are generally more reliable but present a more difficult rendevous problem with the picked material. For this reason alternative grippers have been built to enable comparison in respect to block and large panel handling. Figure 1 shows the pneumatically actuated clamp type block/brick gripper currently in use which has an opening range of 90mm to 120mm. Local sensing is provided for detection of the gripped condition and location of the picked unit relative to the gripper. For block and large panel assembly, the alternative gripper shown in fig. 2 can be used. This effector, which provides suction gripping, has a pneumatically actuated ram to one of the lower vacuum cups. Wide and narrow masonry units can be accommodated by this adjustment and it can also provide a controlled sideways force for use in placing units. Grip sensing is also provided for this tool.

For material supply, an adjustable height, continuous belt type conveyor powered by a 180 Watt DC motor/gearbox combination is used which provides a maximum belt speed of 100mm/sec. The complete system comprises a 8Mhz single-chip based microprocessor controller driven by assembly coded logic, multiple sensors and a companion vision system. Its main function is to provide the robot with material to a preset standard, this to be accomplished with minimum operator intervention. The controller is capable of operating the conveyor autonomously, monitoring its sensors to produce a high quality supply of masonry units for the robot. It has networking facilities and can communicate with a local PC or directly with the main robot controller. A detailed explanation of the roles of the conveyor and vision system in the quality control process are given later.

Whilst the robot has good absolute positioning accuracy (+/- 0.5mm), elements of navigation have been included for its operation. This has been done in anticipation of a future cell in which a mobile robot will be used rather than the experimental gantry

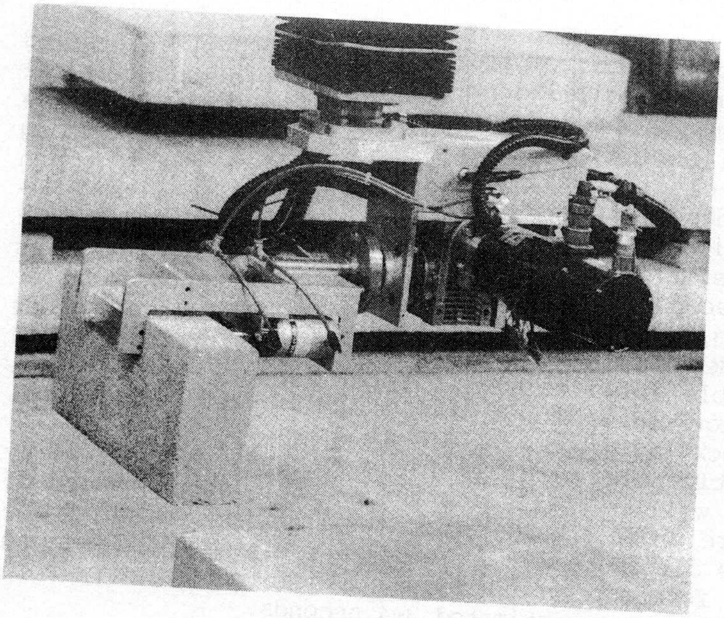

Fig. 1. Clamp Type Block/Brick Gripper

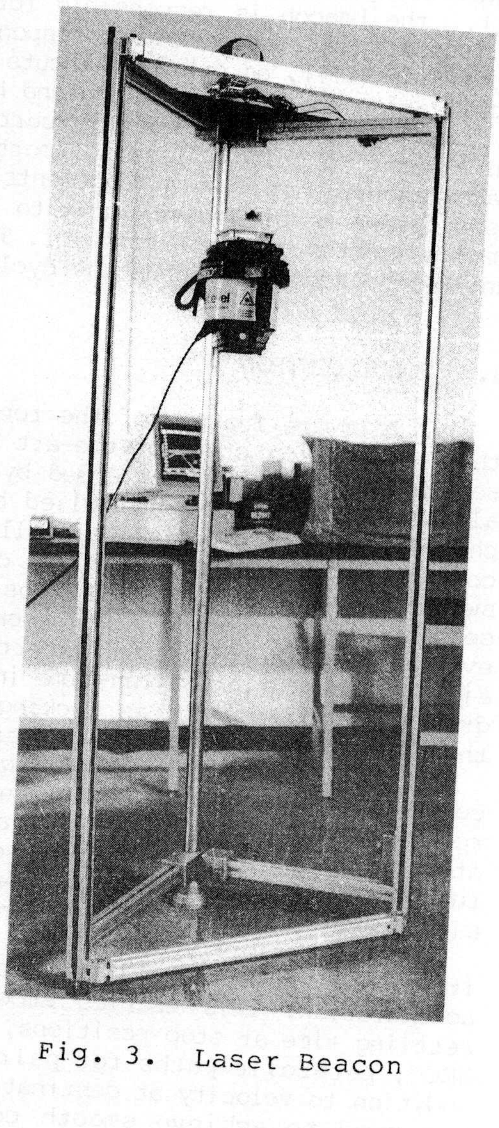

Fig. 3. Laser Beacon

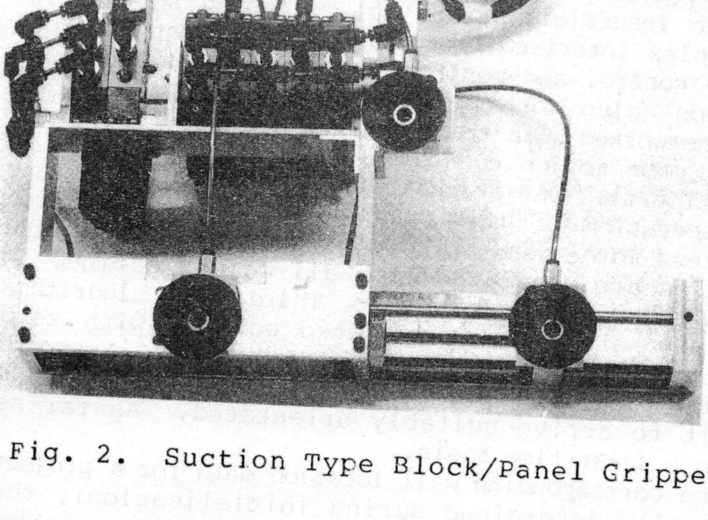

Fig. 2. Suction Type Block/Panel Gripper

robot. Figure 3 shows the laser beacon which comprises a Spectra Physics rotating laser level mounted on a microprocessor controlled drive axis which provides vertical positioning to an accuracy of +/- 0.3mm. A 400 watt DC shunt motor is used to drive the rack and pinion arrangement, with an optical encoder providing the positioning information. The laser, which is electronically self levelling from a rough inclination of up to 4 degrees, provides a horizontal planar reference to within +/- 1.5mm at a radius of 30.5m. A companion level eye detector, which is mounted on the robot, can detect the laser strike over a 20mm vertical window. Output from this is fed to the robot controller. The beacon's microprocessor controller supports three modes of operation (i) position finding, (ii) datum maintenance and (iii) manual. Under (i), the beacon is responsible for determining the robots current vertical position and under (ii) the robot is responsible for finding the datum plane. Under manual operation (iii), an operator inputs required levels through a numeric key pad, typical applications being wall tiling and block laying.

An auger type extruder is currently being modified for mortar mix dispensing. By this means, a uniform layer of mortar will be applied to the underside and one end of each masonry unit. Two arrangements are under consideration for this, one in which the robot presents the masonry unit to the dispenser and the other a rotating and dipensing device mounted over the conveyor. The former represents the most general solution but, unlike the second, extends the cycle time by an estimated 3-4 seconds.

3. ROBOT CONTROL

A hardware feature of the robot is a smart motion control card (SMCC) which is a third-generation state-of-the-art device for high speed precision closed-loop digital servo control. It is programmed by means of a high level command structure using ASCII alphanumeric characters supplied by the cell's controlling PC via a RS232 or IEEE488 channel. For the experimental cell, a library of functions has been prepared using C++ coding, these generating groups of ASCII characters for diagnostics, initialisation, switching, sensing, general positioning and path generation. Apart from meeting sequential programming requirements, some functions are designed to act as object evaluators in a rule based expert system controller currently under development. This aids implementation of run-time intelligence which is particularly useful during sensor driven activities such as picking, manipulation for mortar dispensing and location in the wall project. Elements of obstacle avoidance are also planned on this basis.

Whilst the SMCC supports twelve input/output (I/O) lines in addition to motion control, this provision was found to be insufficient for tool switching and sensing requirements. To overcome this, a multiplex interface has been introduced at the tool attachment point which enables software control and monitoring of gripper sensors and functions. The conveyor and laser beacon (also mortar dispenser when completed) are also operated through the I/O lines or networked with the cell controller PC.

The superiority of the SMCC over common motion control devices largely partly in its ability to support linear acceleration/time variations rather than only constant acceleration. This enables smoother operation of the robot with reduced vibration settling time at stop positions, with less motor wear and power consumption. Using the SMCC, parabolic paths for pairs of axes are generated with all points defined in addition to velocity at destination and the time to make a move. Third order algorithms are used to achieve smooth continuous path and interpolated motion, with zero acceleration moves at path segment connection points. In the application, a smooth continuous path is calculated between the pick and place of masonry units, simultaneous motion on all axes enabling the unit to arrive suitably orientated. As far as possible, these paths are determined on a least time basis.

Using a masonry supply list and the corresponding wall location data for a project and the conveyor location (automatically determined during initialisation), the theoretical paths for all masonry units are pre-processed in order to reduce runtime processing. However, small run-time amendments are necessary on account of the sensed variations in the gripped unit's position and inclination relative to the gripper. The previously mentioned rule base will eventually cover this requirement.

4. OPERATING QUALITY CONTROL

Quality assessment of the robot's supply material is achieved by a filtering arrangement: masonry units are checked for overall length, gross defects and then edge and corner damage. The first two stages are provided by sensors mounted on the conveyor and the last by a companion vision system. Units can be rejected at any of these stages, these discarded to a bin at the end of the conveyor.

4.1 Conveyor Sensing

Fig. 4 shows the layout of the conveyor, its sensors and the vision system and Fig. 5 the top level operational logic. On power up the conveyor performs system initialisation and waits until Senr1, a retro-reflective beam, is interrupted by the arrival of a masonry unit. After a short delay for placement of a unit at the guide, the unit moves on to Senr2, a high repeatability through beam device, which both determines the apparent length and prompts further supply. The term apparent is used as units need not necessarily be aligned with the belt. However, grossly incomplete units may be detectable at this stage. Moving on, the unit arrives at the staggered array of precise analogue ultra-sonic sensors (+/- 0.25 accuracy) denoted as Uson1 - Uson3, which profile the three sides of the unit. This allows the dimensions, shape, position and orientation to be determined, and a further opportunity for rejection.

The ultimate assessment of clear units is provided by the vision station which is triggered by the high resolution fibre optic beam Senr3. An identical sensor Senr4, is provided at the robot pickup point.

4.2 Vision Sensing

Masonry units can suffer edge and corner damage during delivery and on-site handling. The extent to which such damage is acceptable depends largely on the application, facing masonry demanding near perfection for example. To meet these requirements, a vision system has been devised which attempts to quantify damage and compare this with rejection criteria. Masonry units have significant tolerances in their dimensions (see Table 1) and exhibit a variety of colours and texture so this is not a straightforward matter. On account of these factors, it was not possible to proceed on the basis of a known perfect geometric model, a device commonly used in image processing. The system has to determine its own model, building this from best fit edges [13].

The inspection cycle has four stages, edge and line detection, model building and defect assessment. The first three stages constitute the main task which is to compose the model. Damage assessment is then a matter of assessing the local departures from this model, these indicating damage. Corners and edges are treated separately in this process. An efficient algorithm has been devised which combines both the edge and line finder stages, this using the Sobel edge detector and the modified Hough Transform[14]. It has proved to be much faster than the alternative approaches such as Canny, in conjunction with the other line finders. Fig. 6 shows a source image and its segmented image. The numbers shown on the latter are inverse damage indices, low values contributing to rejection of the unit.

Using a SPARC +1 workstation a cycle time of 20 s has been achieved which is far short of the runtime requirement. However, by implementation on suitable hardware it is estimated that a cycle time of less than 1 second achievable. Transputer and DSP (digital signal processor) based solutions are under consideration for this.

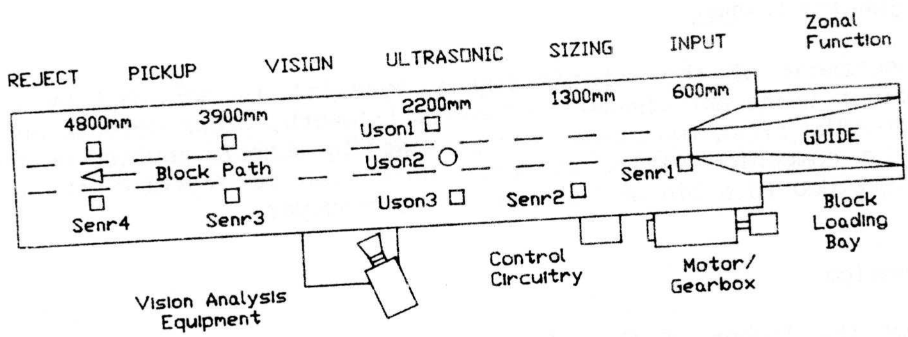

Fig. 4. Conveyor Layout

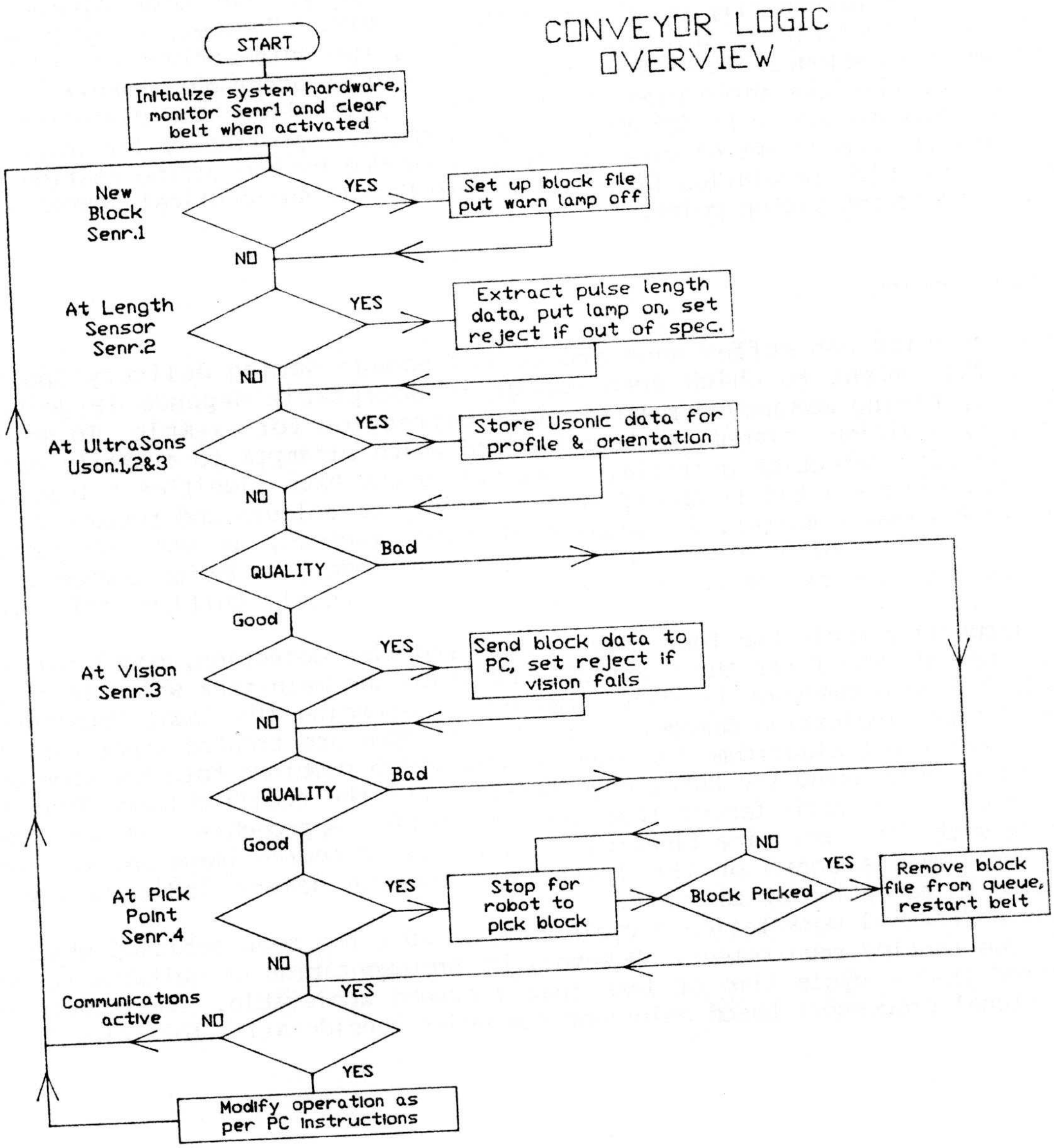

Fig. 5. Top Level Conveyor Logic

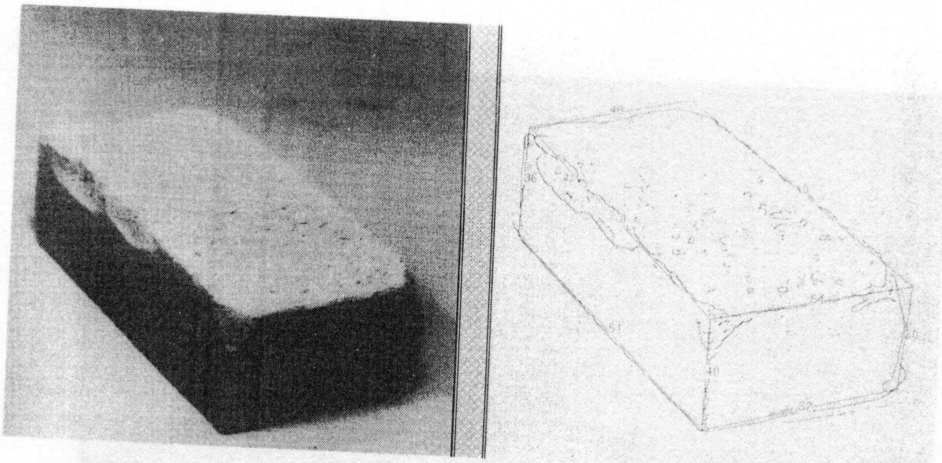

Fig. 6. Damage Detected By Image Processing

5. CAD/CAM INTEGRATION

A CAD utility has been prepared by which masonry projects can be interactively designed. This has been coded in AutoLisp, an X-Lisp variant, within the framework of AutoCad. Open and closed wall designs are possible, using whole or part masonry units. On completion of a design, a project definition file is automatically generated which contains an ordered parts list with corresponding location and orientation data. The output of a partly completed design is shown in Fig. 7.

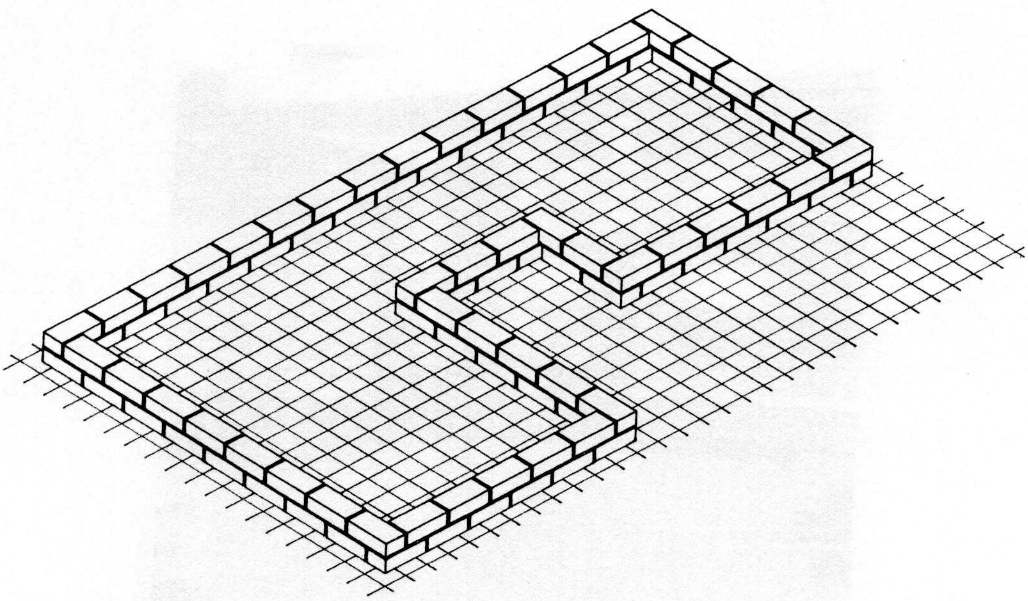

Fig. 7. CAD Design Of Masonry Project

This project definition file is prepared as compatible with a simulated cell model (shown in Fig. 8) which has been prepared using the GRASP software. In this, all components of the cell; robot, conveyor, laser beacon and mix dispenser, are modelled as cooperating robots driven by coordinated tracks which support masonry assembly. Using this model, project completion times are estimated and potential collision problems predicted.

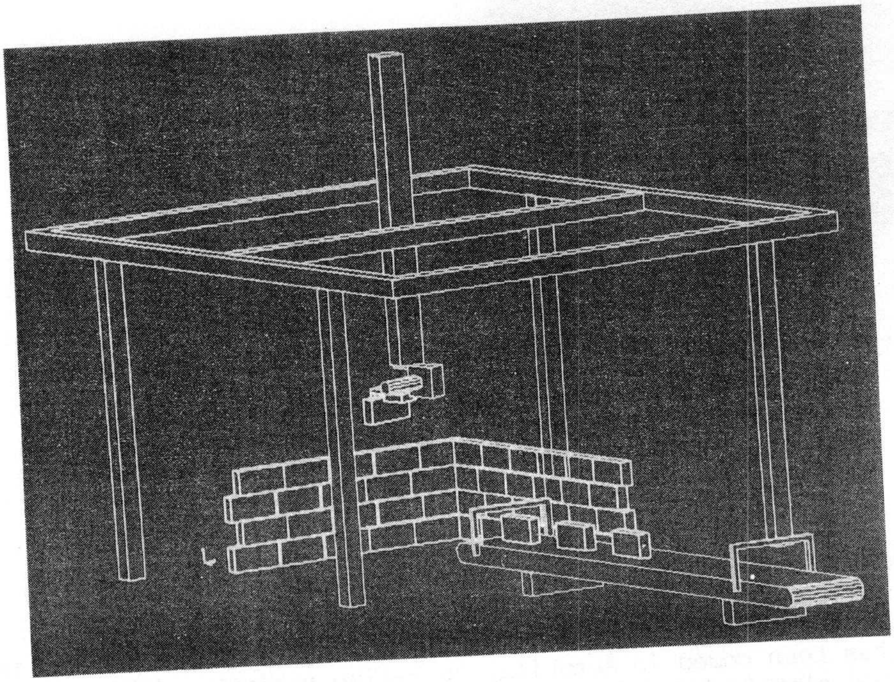

Fig. 8. Simulation Of Robotic Wall Building

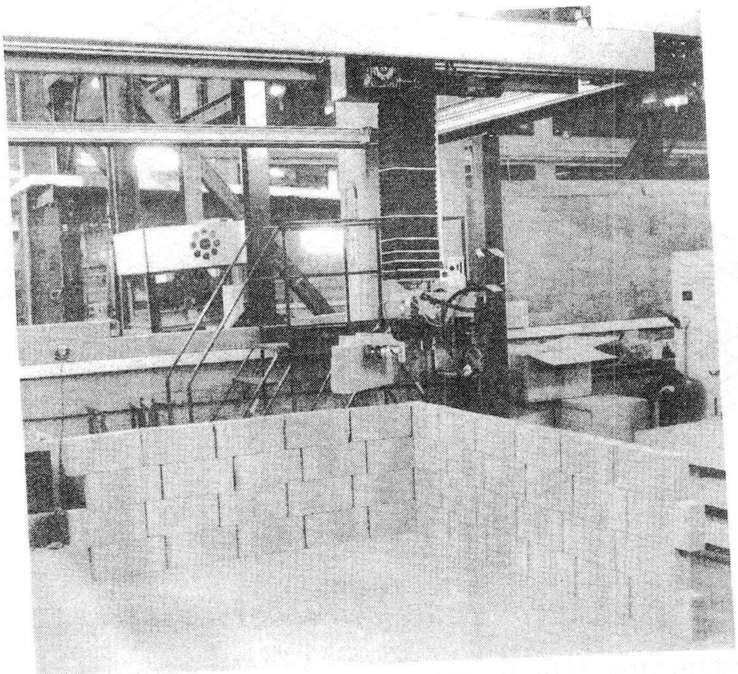

Fig. 9. Robot Building A Dry Wall

A particular feature of this facility is that the transfer of a masonry unit from the conveyor pick point to its wall location is referenced to the belt pick-up point and the wall location point respectively, with only the path type defined. This is of great value as, by this means, the influence of the conveyor's location relative to the project can be easily assessed for example. A study to determine the influences of the project design and the relative locations of cell devices on productivity is in progress. Consideration of overall mobility and alternative robot configurations is included in this.

Whilst off-line programming is obviously feasible, it cannot be explicitly implemented on account of the need for the run-time path adjustments previously discussed. In the current implementation the project definition file is used to determine the theoretical optimal clear paths and this information appended to it. This file is then used in the command of the robot. Fig. 9. shows a partly completed assembly project.

Masonry Unit Tolerances* (mm)

Unit Types	Working Sizes	Tolerances
Concrete Block	440	- 5 to + 3
	215	- 5 to + 3
	100	- 1 to + 2
Concrete Brick	215	- 2 to + 4
	103	- 2 to + 2
	65	- 2 to + 2
Clay Brick		
(i) Individual	215	+ 10
	102.5	+ 10
	65	+ 10
& (ii) Group of 24	5160	- 75 to + 75
	2460	- 45 to + 45
	1560	- 45 to + 45

* BS 3921: 1985/BS 6073: 1981 (Refs. 10 and 11)

Table 1: Dimensions and Tolerances of Masonry Units

6. CONCLUSIONS

The characteristics of masonry construction in Great Britain favour the use of imprecise bricks and blocks for which a thick bond system is necessary. An experimental masonry building robot has been described together with its motion control provisions. In particular, SMMC hardware has been adopted which is enabling a high level control environment to be developed. A means for quality assessment of the supply material, an integral part of the cell's function, has been establish. However, for acceptable run-time performance of the image processing part of this, further processing hardware will need to be incorporated. Between the CAD based design stage and the robot's commencement of a project, it is expedient to undertake a simulation of the project.

Whilst only dry wall constructions have been attempted so far, the completion of a mix dispensing station will enable bonded masonry projects to be undertaken.

7. REFERENCES

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