A ROBOTIC COMPLEX FOR BRICK-LAYING APPLICATIONS

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ABSTRACT

The paper deals with the problem of developing an automatically controlled complex of equipment to mechanize brick wall laying - one of the most difficult operations in construction. A research into economic and social aspects of this type of job enabled us to say that the system can be quite effective. An analysis of well-known efforts to adept existing industrial robots for the purpose and a feasibility study led to conclusion that the most successful combination will be a synthesis of a special-purpose robot and an automatic machine with rigid logic. In this case, the automate will serve as a working member to lay individual bricks while moved to a specified brick-laying point by a robot. Data are given about possible composition of a robotic complex which can perform all operations, auxiliary jobs included.

Key words: construction, brick laying, masonry, brick, robot, extruder, accuracy, navigation, complex, automation, laser.

1. Introduction

Despite impressive advancements made in precast and cast-in-place concrete construction, erection of buildings (residential houses, public facilities or offices) from single ceramic bricks still remains one of the most common and laborious processes in civil engineering. The ceramic brick is a unique material by its insulation and environmental properties. It is indespensable for solving many architectural and constructional problems, particularly in refurbishing old cities with an established infrastructure. In the USSR, for example, according to statistics, brick buildings make 30% in total housing construction while in offices their share is 80%. These ratios are forecasted to remain for many years to come. The traditionally non-industrial methods of brick laying are well-known. In effect, the procedures commonly adopted today have remained unchanged for hundreds of years and the modern engineer cannot help noticing the striking discrepancy between the existing highly automated brick fabrication technology at building materials factories - suffice it to point out to those of UNIMORANDO in Italy and CERIC in France - and the archaic manual brick laying methods at any construction site. The job of a brick layer is hard and dangerous, it becomes increasingly less attractive everywhere, the average age of the layers increases while the productivity remains steadily at a fairly low level or even decreases. According to Prof. Yuko Hasegawa (1988), this process is the same in different countries.

Considering that hundreds of thousands of builders do manual work in masonry (at least 300 thousand in the Soviet Union alone), the above can be regarded as quite sufficient proof for the need and urgency of serious research and development effort to carry out the task of creating appropriate new technologies.

2. Capabilities of an Industrial Robot

Brick laying has always been done by hand. Therefore, the first thing that occurs to an engineer who tries to make it automatic is to use the versatile capabilities of existing and commercially available industrial robots. He would attempt to solve the problem on paper by compiling an appropriate control program. This was practically the path taken by A. Slocum and B. Schena (1988) whose experiments produced some good results. The same ideas were developed by M.A. Muspratt (1988) who considered a whole scenario of using a set of industrial robots in construction. A critical analysis of these and other reports, the results of our own tentative experiments using a SKILAM robot make it possible to formulate at least 4 additional technical problems that must be resolved for the robotic technology to be introduced:

- The problem of the movement of a robot (robots) along a wall of an actual building being erected.
- The problem of necessarily precise reference of known relative axes of a robot's work envelope to the absolute axes of a building (of walls and bricks in it...).
- The problem of economically acceptable time of laying a single brick (2 or 3 sec are desirable instead of 7 to 9 sec that can be achieved by our experiments and 10 to 12 sec as reported by H. Lehtinen et al. in 1989).
- The problem of creating and programming complex interactions within the work envelope of the robot due to the fact that every single brick must not just be moved to a point with specified coordinates but all the joints should be filled with morter with aesthetically acceptable results.

Without going into details and not trying to estimate the complexity of each of the above-listed problems, we can just say that a reflection over technical means required to solve them lead to a "discovery" that a manual brick layer actively uses in addition to his hands also eyes, senses, and his head to do his seemingly simple work. Any attempt to introduce equivalent sensing, technical vision, etc. into a robotic complex would surely make the whole task economically and technically unfeasible. Obviously, the way out of the dead end can be found not in trying to imitate human actions by some devices but in developing an alternative procedure for brick laying itself to be adapted from the start to the work being done by machines only.

3. Machine-Oriented Procedures

Clearly, the brick laying process should be divided into two independent elements.

First, laying of bricks into a wall by some working member and

second, delivery of this working member to a specified work point with required accuracy.

Consideration of the first element leads to formulation of an alternative brick-laying procedure.

The idea of the new process is illustrated in Fig. 1.

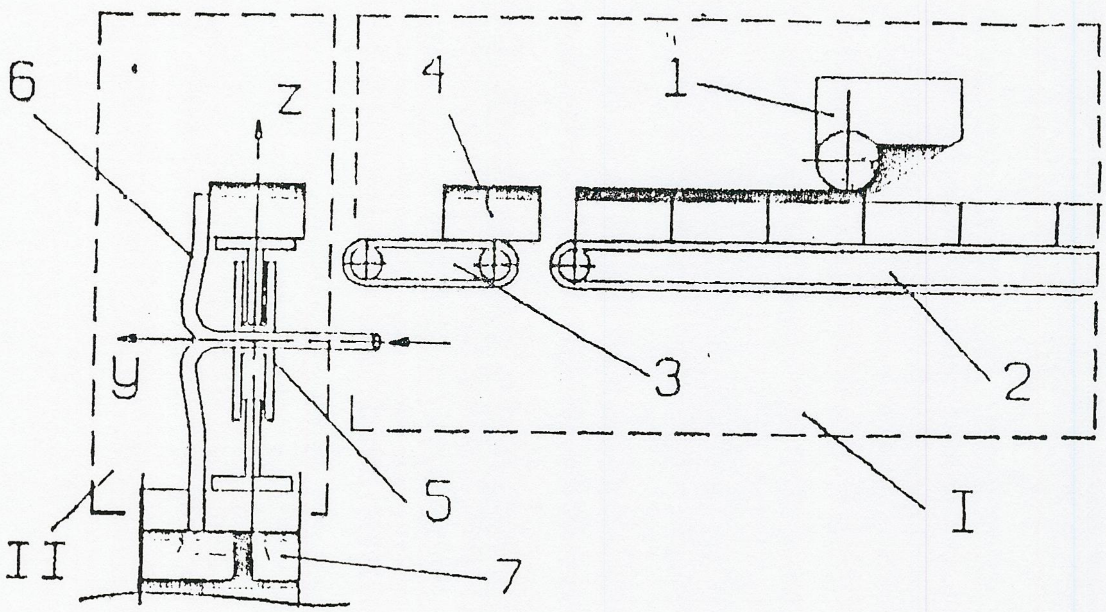

Fig. 1. Schematic diagram of brick laying by a machine. 1 - extruder, 2 - feeder; 3 - accelerator; 4 - bricks ready for laying; 5 - working member (rotor); 6 - injection nozzles; 7 - finished wall.

The diagram shows that the brick-laying process is divided into two stages. The first stage (I) performed outside the wall includes spreading a thin layer of mortar over the broad surface of a brick by an extruder. This will become an underlayer later on. It can be seen that the mortar-brick layer coming out of the extruder will be preset to a specified thickness regardless of actual accuracy of fabrication of the brick. The second stage (II) is the brick-laying proper which can be carried out by many types of mechanisms that can grip a brick, turn it about the Y-axis, then about the Z-axis if necessary and set it along the Z-axis.

Vertical joints can be filled with proportioned injection of mortar into the slot formed when the brick is laid in place. The productivity of this mechanism is limited practically only by the forces of adhesion of mortar to the brick surface since all the manipulations with the brick are naturally done while the mortar is still fresh. The experiments have shown that due to some chemical treatment of mortar with plasticizers and well selected extrusion conditions the normal mortar bond strength is limited to a value at least 3g. So it becomes possible to design a mechanism that can lay one brick in 1.5 to 3 sec, which is quite satisfactory.

The tentative experiments simulating the above procedure have shown that the masonry made by this mechanical method has 10 to 15% higher strength than the one made by hand (which is quite natural) and is satisfactory in terms of appearance although it does not eaxctly meet specificatios of traditional standards. The overall accuracy of brick laying depends naturally on the achievable accuracy of moving and holding the working member in the absolute system of axes of the structure being erected.

4. The Layer, a Machine for Brick Laying Operations

The following questions must be answered first to form the structure of the machine:

- Should the machine be self-propelled and be able to move by its own accord at the construction level or should it be moved by exterior means?
- Where is the supply of expendable materials (bricks and mortar) be stored? On the machine itself or nearby somewhere and how should the materials be transferred in the latter case?
- What will the navigation system be to refer the axes of the machine to the structure being built?
- What absolute dimensions should the machine have and what part of a structure could it erect at one setting of axes?

Acceptable answers to these questions become even more difficult to get considering that the machine should stay (work) on a floor of a residential house above all, i.e. a building structure whose safe loading is rigidly restricted. Besides, the specifications for erection of a wall require that it should rise evenly enough over the whole work area.

An analysis of the set of the above-listed contradictory requirements and many design feasibility studies regularly verified by performance calculations made it possible to formulate specifications for the general outline of the Layer machine. It appears that the machine should be made as a fully revolving portable cantilever robot that can serve an area with a radius of at least 5.4 m (with necessary overlapping) at one setting in the centre of a common construction module of 6 by 6 m. The height of the wall thus handled naturally should be equal to one storey. The general appearance of the Layer is shown schematically in Fig. 2.

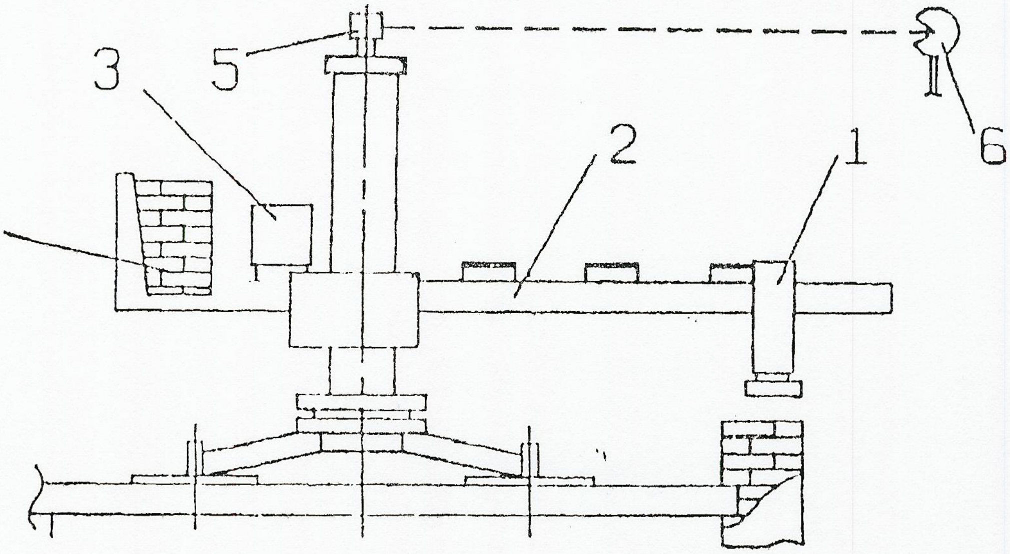

Fig. 2. General schematic of a theoretical building robot Layer. 1 - working member, 2 - feeder; 3 - extruder, 4 - supply of bricks, 5 - laser source of navigation system, 6 - reflector.

The extruder and all feeders should be placed on the working surface of the Layer. The position of the supply of bricks will be a question that cannot be answered until special calculations are completed.

If the supply of bricks is mounted on the Layer, the loaded machine will be too heavy (at the limit of the load bearing capacity of the floor) but the needed organizational self-sufficiency and reliability will be achieved. If bricks are placed on a separate device - a Loader - all weight restrictions will be removed but it will be difficult in terms of organization and control to ensure reliable operation of two complex machines at once. The navigation system which is a must for the operation of the Layer also deserves close attention. A review of technical details of its functioning is far beyond the scope of this presentation. We will just point out that this system uses a laser source and reflectors referred geodetically to the absolute system of axes. It should enable the control system of the Layer to register its coordinates at any moment of time with required accuracy.

Understandably, the development and design of the building robot Layer described here only theoretically is quite a job but as for its philosophy the implementation of this task is within the usual scope of robotics.

5. Robotic Complex

Obviously, the Layer by itself cannot ensure automatic performance of all operations required to erect a wall. Fig. 3 shows a schematic diagram of a minimum set of machines needed for the job.

The diagram of the complex is given for the case when the robot Layer carries the supply of bricks.

The general idea of saving manual labour as much as possible dictates the configuration of a crane loader to be used as a crane manipulator that does not need a slinger. Also important is the natural requirement that bricks should be delivered to the site in specially arranged blocks without any containers by special brick carrier trucks to be moved by the manipulator using only a special gripper.

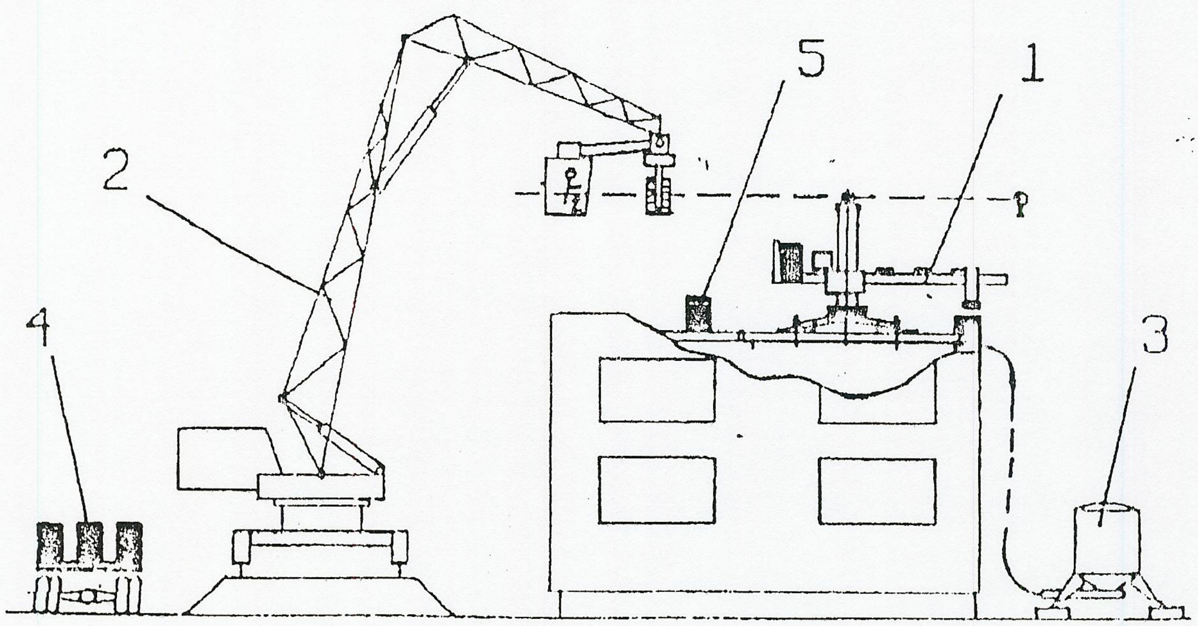

Fig. 3. Robotic complex 1-robot Layer, 2 - crane loader; 3 - mortar generator, 4 - - brick carrier truck, 5 - intermediate supply of bricks.

An analysis has shown that only then it will be possible to solve the problem of dismantling a block of bricks on the robot Layer. It is of no small importance too that the transportation without containers eliminates environmental and management problems of opening packs and disposal of the packing material. Mortar of a composition whose accuracy is strictly maintained should be provided by a nearby mortar generator from dry mix. It goes without saying that the whole complex should be controlled and managed by an on-board computer installed on the robot Layer. A sufficiently conservative estimate has shown that the complex would need 2 operators and 1 or 2 auxiliary workers and so increase the labour productivity 7 to 15 times.

The control software of the complex can (and must) be interfaced with an architect's CAD and so opens up the prospect of paperless process of design and erection of buildings of any desired architecture. And remembering that the modern house, alas, does not consist of brick walls alone, we may suppose that this complex in future can serve as a bridge for generating a new construction culture.

To conclude we will say that the development and experimental debugging of the complex will need a lot of research and thus large investments. But considering its importance for humanity and great promise it holds, it appears that appropriate funds should be searched at the international level.

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