TEACHING ROBOTICS IN BUILDING

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1. Introduction

The possible applications of robotics to building activities has been receiving growing attention over the last few years. A number of robot prototypes, which have been already developed and successfully used in construction sites, were described in (2),(3), and other sources. A growing effort is expended, in several countries, on research and development of new and more extensive applications. It seems that this trend towards an increased automation in building will have an evident effect on the nature of construction operations and their management in future years. It is, therefore, appropriate to seriously consider an introduction of orderly automation courses into the curricula of civil engineering education at its various levels.

Such studies should include two types of subjects: one - the general knowledge in the field of automation and robotics, and the other - its application to the building construction tasks. The instruction, as is customarily done in the teaching of industrial robotics, is divided into lectures and laboratory assignments. A similar approach should be undertaken in teaching of construction robotics.

The following paper will examine the problems of the teaching of this subject. It will focus, in particular, on the laboratory assignments adapted to the special features of the building tasks.

2. The special problems in teaching of building robotics

The teaching of building robotics, as noted before, must include two domains. The first involves the general knowledge of robotics which, of course, forms also the basis for operation of construction robots. This knowledge includes:

a. The various configurations of robots, their dimensions, performance capacity, accuracy, etc.

b. The kinematics and dynamics of the robot arm.

c. The various types of robot effectors.

d. The robot control and intelligence on various levels.

e. The robot sensors and the energy transduction processes associated with it.

f. The robot mobility, and the automated guided vehicles' application.

The second subject - the special needs of teaching in building robotics are derived from the problems of application of robotics to building construction. These problems were explored in (4), and other sources, and can be summarized as follows:

a. The building work consists of a great number of interrelated tasks. Each such task requires a separate attention from the point of view of robotization. Moreover, most of the tasks are specifically adapted to the capacity of the human worker, and must be restructured for efficient performance by a robot.

b. Every building project has some unique features in terms of its purpose, geometry, location, and the composition of building works. Furthermore, this is usually true for the different parts of the same project. The robot must therefore be specifically programmed for each project and its different segments.

c. The location of the work within the project or its part continuously changes, so that the robot must be able to move with the work progress.

d. The robot must operate in a rugged and inaccurate environment; the various building components have considerably larger production tolerances than typical work pieces in other industries. The robot, therefore, in order to do efficient work, must be able to continuously interact with the environment either through human guidance or through built-in sensors.

e. The continuous robot movement, its interaction with the human work, and the complexity of supply of building materials, which the changing nature of tasks and the robot movement create, pose various organizational and managerial problems which do not exist in a well structured work station of an industrial robot.

These specific features must be taken into account when teaching construction robotics.

A very important element in teaching of robotics is the experimentation with robots' employment in simulated building conditions. Consequently, laboratory experiments are included today in most courses on industrial robotics, which are offered in various universities and vocational training schools. These experiments are carried out with small scale and inexpensive "educational" robots. Such robots sometimes include also an optional course-ware kit which allows for realistic representation of typical robotic tasks in a real life industrial environment.

A similar element of simulated real life representation is also of paramount importance in teaching of construction robotics, and it must be adopted to the special problems of building which were already explored before. The experience with planning and execution of such a set of laboratory experiments will be described in the next section.

3. The planning of experiments in construction robotics

The objectives of the laboratory experimentation at the Technion in construction robotics had the following objectives:

a. To acquaint the student with the practical operation of a robotic system.

b. To acquaint the student with the special problems of robotic task design and programming in the building construction.

c. To learn from the experiments about the various specific application problems which could be pertinent to the development effort of construction robotics, carried out in parallel at the Building Research Station.

To attain these objectives, the assignments were designed in two levels: one - the general level of the conceptual robot performance, the selection of the tasks to be executed, and the overall approach to their execution. The other - the specific design of experiments for each selected task.

The family which was selected for experimentation following the classification described in [4] was the general purpose robot, shown schematically in Fig. 1. The reasons for this selection were: the versatility of this robot with respect to the various building tasks that it can perform, and its configuration which was similar to that of common industrial and educational robots and therefore could be enacted in the laboratory without an excessive development effort.

Three building tasks were selected for the first group of experiments - the building of walls/partitions, the painting of walls, and the sealing of joints between walls' elements.

The specific design of experiments is affected by the type of robot selected for this purpose - its work envelope, payload and the number of degrees of freedom. The envelope of the robot's work determines the scale of the experiment. A distinction has to be made, in this context, between the nominal and the effective work envelope. The nominal work envelope indicates all the points in space which the end effector of the robot can reach from its central work station. The effective work envelope includes only those points in space which the robot cannot only reach, but approach at an orientation necessary to perform its prescribed task. Both envelopes coincide if the robot has 6 or more degrees of freedom. Otherwise the work envelope for operations which require a specified angle of access of effector, such as, for example, joint sealing, may be considerably smaller for robots with a lesser number of the degrees of freedom.

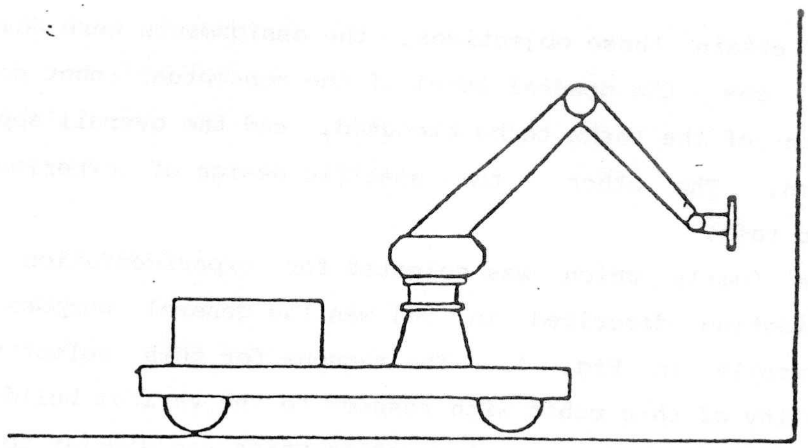

Fig. 1 - The scheme of the interior finishing robot

Another robot feature which determines the experiment's environment, is the payload of the manipulator. It will affect the selection of the effectors which can be used in the experiment - whether they can be "off shelf", or specifically developed for this purpose. It will also determine the nature of the work pieces which are to simulate the pertinent building components - bricks, blocks, beams, etc.

Still another feature is the control ability of the robot in terms of its programming flexibility, potential interaction with sensors, and reliability in execution. The ability of the robot to be controlled in a continuous path fashion vs. point to point, to accept parameter values vs. absolute coordinates and dimensions, and condition its performance on the input from sensors determines very much the type and complexity of the experiments which can be designed with the system. Finally, the resolution of the robot internal measurement system determines if certain composite positioning activities like block building can be executed with the system without substantial adaptations of the simulated work environment.

Other features which determine the nature of experiments are the various effectors and the feeding systems which can be used with the robot. Theoretically, it is possible to develop, for every task, the specific tools which will perform in a satisfactory manner exactly the same operations designed for execution of the task in practice. In reality one must prefer, for economy reasons, the "off shelf" available equipment, even if it does not represent, in an identical fashion, the full scale expected performance of such tools in practice. This, in turn, may affect the shape, weight, etc., of the building components which are easier to produce, as needed, than mechanical work tools.

Finally, one must remember that most small industrial or educational robots are designated to work from a static work station which, again, does not allow, without acquiring this capacity, to express all the specific features of the mobile construction robotics.

The robot which was eventually selected as the basis of the experimental system, was an educational robot of the SCORBOT type, produced by the ESHED ROBOTEC CO. in Israel. The robot, shown in Fig. 2, has a jointed arm with a reach of 600mm and 5 degrees of freedom. Its payload is 1 kg. The robot can be programmed with a computer or with a teach box. Its repeatability is 0.5mm and it has a Point to Point control.

As noted before, three types of experiments were executed, which will be described in the next section.

4. The robotic assignments

Three types of robotic assignments were included in the first stage of the laboratory experiments. They were performed with the robot described in the former section and specially adopted effectors and work components.

The wall-building

The wall building, shown in figure 3, was performed with the "dry" method presented in (1), which does not require spreading of mortar between consecutive block layers and uses interlocking building blocks. The blocks used were made of polyurethene and their dimensions were 60/50/100mm and 60/50/40mm. They were smooth and specifically adapted both for finger and for vacuum gripper. The blocks were packed in special pallets with spaces between adjacent rows of blocks. The space allowed for a convenient picking of blocks with a finger gripper, which was

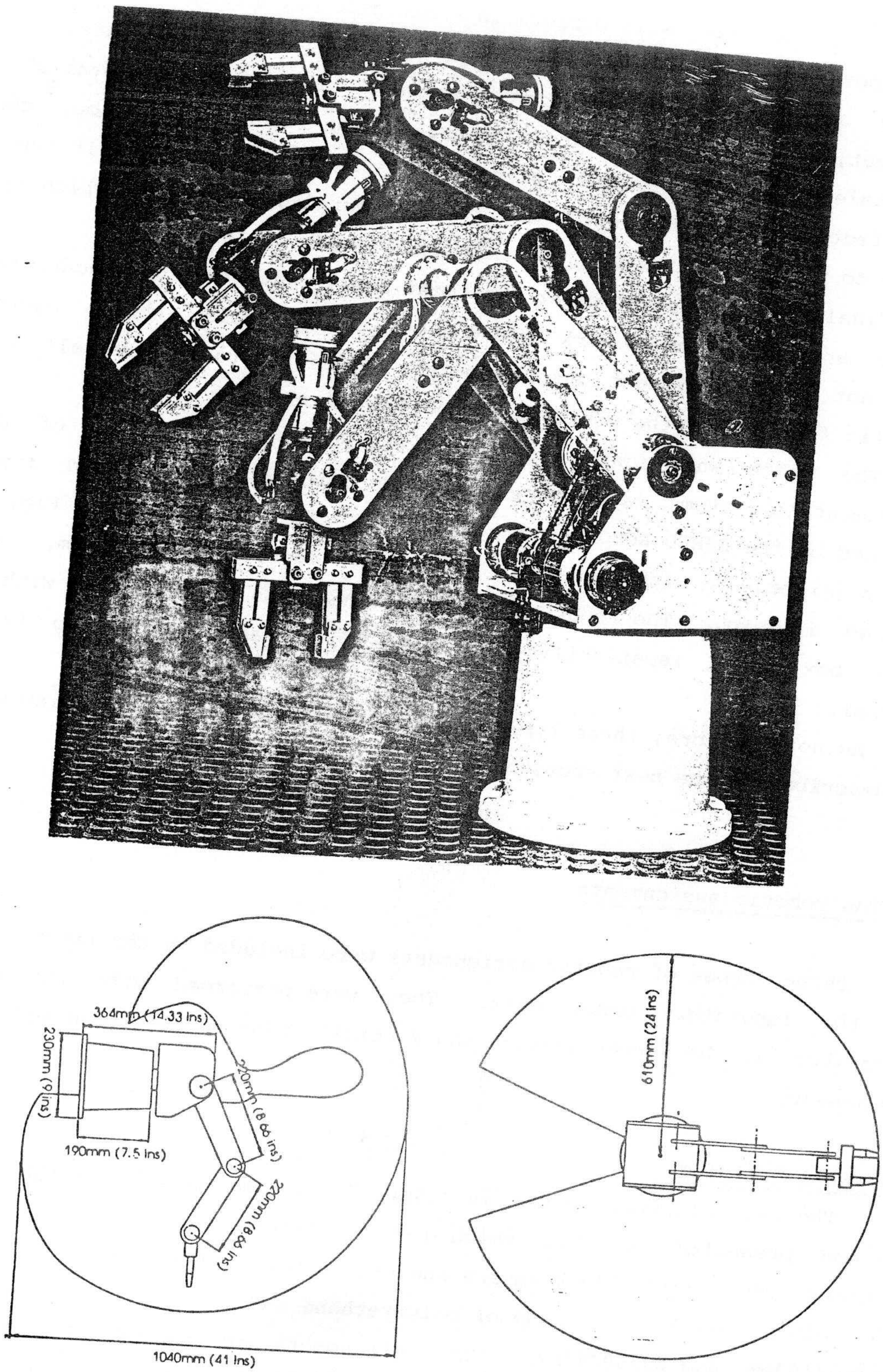

Fig. 2 - The basic robot

eventually selected for the experiment. The walls which were erected with the conventional "running bond" arrangement, included a straight segment, a corner and an opening.

The size of the simulated wall segments was largely limited by the effective work envelope of the robot determined by the reach of the arm and the "running bond" method of wall building.

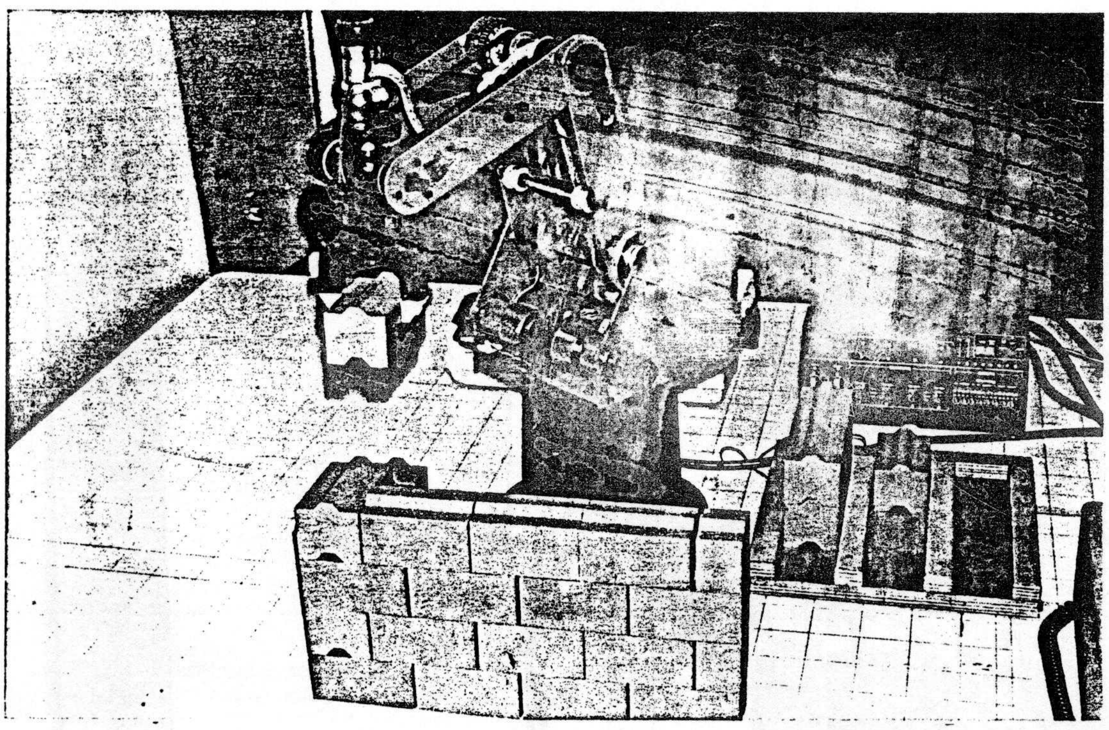

Fig. 3 - The wall building experiment

The general structure of the experiment allowed for formulation of various assignments involving different shapes of walls to be erected. The experiment could be also easily expanded into other types of similar activities, e.g. bricklaying, assembling of precast beams, columns and slabs, and erection of drywalls. All these activities could be performed with similar type of effectors and control programs and required only preparation of appropriate work prices.

The addition of sensors and mobility to the robot in the second development stage allowed both for a considerable increase in the size of the simulated environment, and in the complexity of the tasks to be performed.

The interior walls painting

The walls painting, shown in fig. 4, was performed with a spray gun. The paint was pumped to the arm from a cannister, attached to the robot base with an aid of an air pressure from external compressor. The painting was done in parallel vertical strips and required in order to ensure a uniform thickness of the paint coat, an access of the spray gun

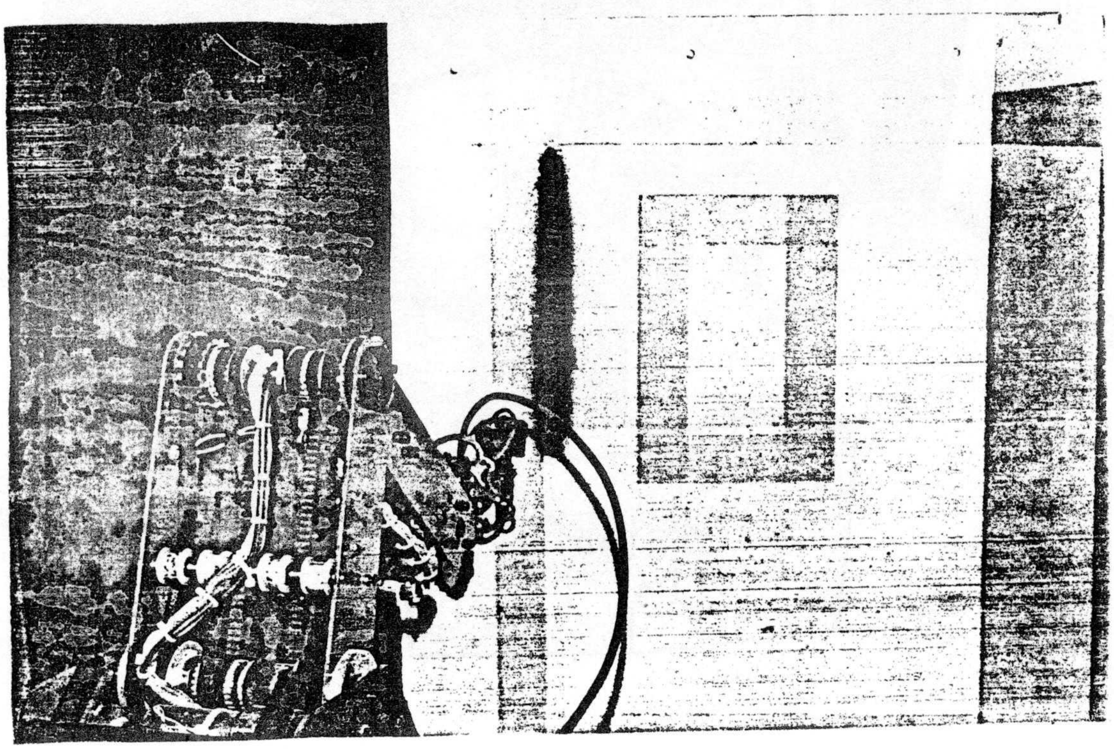

Fig. 4 - The wall painting experiment

at an angle almost perpendicular to the painted surface. This requirement limited very much the size of the simulated work environment which had to be adopted to the thereby reduced work envelope.

The assignments included painting of a straight wall segment, of a corner between two perpendicular walls, and a wall with an opening in it.

The experiment could be expanded into additional building activities, such as one or two layers plastering of walls and ceilings, covering of floor with self-levelling screed (as described in (1)), cleaning and sandblasting of vertical wall panels, etc. These applications could be simulated with minimal adaptation of the spray gun and its feeding mechanism, using similar control algorithms.

The sealing of joints

The third group of assignments, shown in fig. 5, involved sealing of joints between vertical wall elements. The sealant was injected into the joint from an elongated thin tube attached to and activated by the robot gripper. Since an effective injection of the sealant required a perpendicular approach of the effector to the jointed edge, the effective envelope of the robot here was even more limited than in the former cases.

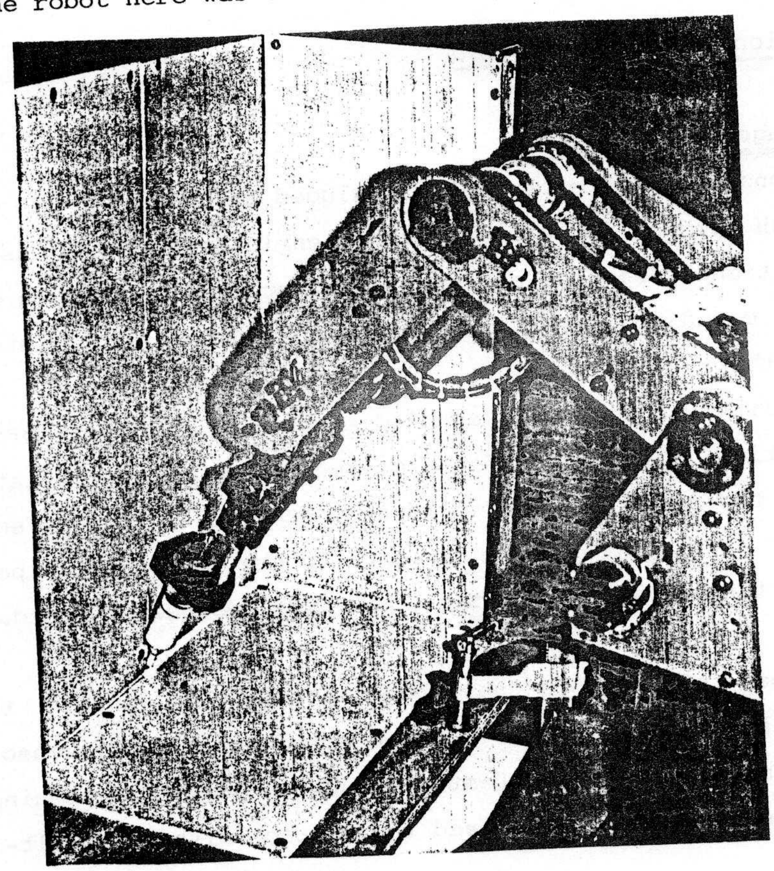

Fig. 5 - The joints sealing experiment

The assignments performed within this group involved sealing of vertical and horizontal joints. It could be expanded to include additional continuous path activities such as welding, taping over joints, etc.

The students' assignments involved the following steps:

a. General planning of the work (for a given work assignment). This included the location of the robot work station with reference to the work location, location of auxiliary equipment, and detrmineation of its progress mode.

b. Detailed task planning. For the wall building, for example, this step included a detailed design of location of blocks within the wall, in the pallet, and the key points for the robot work. For painting it included the width and orientation of the strips to be sprayed with each robot pass.

c. Programming the robot for the work to be executed and monitoring its performance.

d. Documentation of the experiment

The second stage of experiments

The second stage of experiments included an expansion of the robot hardware which allowed for a considerable enrichment of the assignments. The main additional features of the system included a track on which the robot could be moved and several sensors with which he could interact with the environment.

The mobility of the robot enabled execution of a work portion from one work station, an autonomous movement to another station, and completion of the remaining work from that station. It also enabled an easier access, at a desired orientation, to the various work points with the mobility acting as an additional (the sixth) degree of freedom of the arm.

Three types of sensors have been applied to enable the robot interaction with the environment. One electro-optic (LED) sensor allowed for interaction with prominent features such as edges and openings. The other, also electro-optic, was used to interact with the built-in light reflectors. The third one reacted to contact between the effector and the adjacent building part, and guided the modification of the arm or effector movement.

4. Conclusions

The conclusions drawn from planning and execution of the simulated robot tasks described above, can be summarized as follows:

a. A relatively inexpensive laboratory may serve as a very effective tool for teaching of real life applications of building robotics. The assignments performed with the laboratory enable a very good understanding of the operation of a robotic system, and of the specific problems of its employment for building construction.

b. Great care must be exerted in determining the scale and the scope of the building tasks to be performed. The scope will be determined by the main parameters of the robot used - its payload and work envelope. The effective work envelope for each task will be affected by the number of degrees of freedom of the robot and the required orientation of the tool for the task execution. The scale will be determined in such manner that it will bring into focus all the specific features of the simulated work segment, e.g. windows, corners, etc.

c. There is a dependence between the simulated building components and the available effectors of the robot. In reality, as noted elsewhere (4), the building components and the effectors will be developed simultaneously within the system. However, in the laboratory conditions it is often easier to adapt building components to the available effectors of the system. Thus, for example, in the above described experiments the pallets were constructed with spacings between the rows of blocks to enable their easy handling with the existing grippers.

d. Some mobility of the robot is essential to realistically simulate its application to real life construction activity - the operation from different work stations and the movement between them. The mobility can also add to the robot an additional degree of freedom and enable its access to the desired work location from a variety of desired angles.

e. The use of sensors is essential for any type of complex pick and place activity typical to assembling of building components. The robot repeatability tolerance, and the tolerance in the dimensions of assembled work pieces, may cause an accumulated deviation which will prevent an effective assembling process without employment of sensors or some other control device. The use of sensors in the laboratory also enables a realistic interaction between the robot and the environment and its special features such as openings, edges, etc.

6. References

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