DEVELOPMENT OF A ROBOT FOR INTERIOR FINISHING WORKS

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1. Introduction

The implementation of robotics in the execution of building construction works has been receiving considerable attention over the last few years. Several prototypes have been developed, almost all of them in Japan for specific purposes, mainly for exterior building works - materials' handling, finishing of facades and floors. These prototypes are described in various publications - among them in (2),(3).

A classification of these and future building robots into 4 generic types was suggested in (5). The building construction robots were divided accordingly into these families:

a. Robots for assembling of large components - beams, columns, precast elements, etc., which usually constitute the "shell" of a building.

b. Robots for finishing of large vertical surfaces - mainly building facades.

c. Robots for finishing of large horizontal surfaces - mainly building floors.

d. Robots for execution of various interior finishing tasks, after the shell - framing exterior envelope and horizontal space dividers have been erected.

The basic configuration and the mode of operation for each of these generic types have been also examined in (5).

The last type - the interior general purpose robot seems to be of particular interest for building construction. It is designated to perform the tasks which complement the prefabrication and erection of building "shell" elements - vertical walls, slabs and columns. The production of these elements and their assembling on site have evolved over the last 2-3 decades into a fairly efficient industrialized process while their finishing on site remained very much a manual craft highly vulnerable to environmental conditions and the skills of the site labor.

The following paper deals with the methodology of the development of a general purpose robot which is intended to perform these complementary finishing works in residential and similar buildings - hospices, nursing homes, resthouses, etc. Those buildings constitute, in most countries, 60-80% of the total building volume.

The development process may include the following stages:

a. Performance specifications for the robot.
b. Its preliminary design.
c. Simulation of the robot employment.
d. Detailed design and construction of a prototype.
e. Experimentation with the prototype.

The following sections will describe items a,b,c in this process, applied to the development process of an interior general purpose robot at the Building Research Station of the Technion, I.I.T.

2. Performance specifications

The purpose of the specifications was to define the required robot performance in the execution of tasks assigned to it.

The robot was intended to perform the following groups of activities:

a. Building of partitions - i.e. interior non-bearing space dividers. The same activity could be used for building of exterior walls.

b. Finishing of interior vertical surfaces - i.e. plastering or painting of the interior.

c. Finishing of the structural floor slab surface.

d. Connecting between erected structural components.

e. Jointing between space dividing elements - walls, partitions and horizontal slabs.

As noted earlier, the robot was to be employed in residential and similar building. The characteristic features of these buildings are - their interior height - 2.60-2.70m and the size of their interior room spaces. Three types of such spaces must be distinguished:

- medium size spaces like bedrooms, small living rooms, kitchens, etc., with an area of $8\text{-}15m^2$.

- small spaces - toilets, bathrooms, corridors, small kitchens, etc.

- large spaces - living rooms, public areas (in non-residential buildings).

It was intended that a robot will be able to perform its whole designated task in each medium and small space from a single work station, without changing its initial location.

The partitions were to be erected by the robot with blocks, the weight of which was not to exceed 10 kg. Using cellular concrete blocks with a specific density of about 500 kg/m^3, their maximum dimensions could be 10x400x500mm. Two methods of blocks erection were considered: one - the conventional "wet" method - where blocks' layers were attached. The limitation of this method was that the robot had to perform two different activities - to lay the blocks and to spread the adhesive, which required a double pass over each layer of blocks; it also required a special adaptation of the effector. The alternative "dry" method consisted of laying the blocks (especially adapted for this purpose) without an adhesive, and subsequently strengthening the wall or a portion of it with a fiber reinforced plaster or with concrete poured into the joints between blocks. Both technological alternatives are described in (1). The partitions were to include two types of openings - for doors and for windows.

The purpose of the robot was, therefore, to identify the location of the wall, to identify the location of the block in a pallet, to place it as needed and, if required, to spread the adhesive substance on the top of the layer.

The plastering of walls was to be performed with one 10mm thick layer of plaster (instead of two layers in the conventional plastering). Two alternatives of plastering were considered - one where the final finish was to be accomplished with a single pass spraying of the plaster, and the other where additional smoothing was required.

The task of the robot was, therefore, to identify the location of the work starting point on the wall, to spray the plaster over a specified trajectory with due attention to various edges and openings in the wall, and to smooth it if required.

The jointing involved the spaces between the following elements:

- different partition segments - perpendicular or continuous.
- partitions and perpendicular exterior walls.
- partitions or walls and concrete columns.
- partitions or walls and top floors or beams.
- partitions or walls and bottom slabs.

It was assumed that the space between connected elements will be not less than 10mm and not more than 30mm wide. It was to be filled by an elastomeric substance which was to attach itself firmly to the edges of the connected elements. The joint, after being filled, was to be smoothed or taped over.

The robot's task was, therefore, to identify the joint location, to fill it as required and, if decided so, to smooth it or tape it over at the same or a different pass.

The connecting between precast elements involved attaching to each other special fixtures embedded in the connected elements, so that specified forces could be transmitted from one element to another. Two alternatives were considered: one involved welding one fixture to another, and the other - their attachment with an adhesive substance. The robot's task was, therefore, to identify the connection and apply the required process with a suitable effector.

The floor finishing included spreading a self-levelling liquid substance and subsequently smoothing or grinding the surface if required. The robot task was to identify the starting key point and the trajectory to be followed for the finishing activities.

The permitted tolerances were specified for each activity.

The performance specifications included the description of a typical environment within which the robot was to operate. This included the dimensions of medium and small spaces and their special features, such as sizes of doors and windows.

3. The preliminary design

The basic features of the robot were determined in a preliminary design described in [4]. They involved the principal configuration of the robot, its main dimensions, the required capacity of the joints, its weight, locomotion mode, and sensing capacity.

Two main configurations were considered, which were shown in Fig. 1. The maximum horizontal reach of the robot arm in both configurations was determined as 3.00m. This reach was considered sufficient for operation from a fixed location in medium size spaces. Each configuration was designed with 7 degrees of freedom to ascertain sufficient maneuverability of the robot in the typical spaces. This number was later reduced as a result of the simulation process to 6.

The robot arm was designed for a static live load of 20 kgf, which was to include the gripper and the block - for the building tasks - or the necessary tools for other tasks. The power supply necessary for the performance of the specified tasks was to be received from an on board generator.

The sensors considered for performance of the various tasks included on board CDC cameras, ultrasons, and microswitches. The purpose of these sensors was to guide the robot's effector to its destination, and to protect the robot arm, body and effector from a collision with the environment. They are presented in more detail in (6).

The robot is to be mounted on a carriage 0.90m wide, which could allow it to move through 1.00m wide doors. The carriage hosts also an onboard computer, a generator, a cannister with materials' supply and is mounted on 4 skid wheels.

The total weight of the robot system, including the carriage, the arm, the actuators and the onboard motor, was estimated at about 480 kg. This weight was considered excessive for a typical residential floor, and could be reduced to about 350 kg by using lighter materials for the arm, an exterior power supply and a lighter cannister for materials. The performance capacity for the main tasks was estimated, based on the designated velocity of its joints, the orientation and the waiting times as by 100-300% faster than that of a manual worker.

4. The simulation of robot performance

Before the detailed design and testing of a prototype, there was a need to evaluate the basic configuration described above, with respect to some assumptions made during the preliminary design process.

In several terms the simulation process had these main objectives:

- To test the functional feasibility of selected configurations, i.e. their capacity to physically perform the required tasks.

- To determine the optimal value of several parameters which could not be determined in the preliminary design.

- To compare the performance of the robot with the performance of a manual worker in the conventional construction process.

The system parameters specifically addressed in this process included:

- The configuration of the robot arm. Two basic configurations, with 7 degrees of freedom each, were offered during the preliminary design process. The purpose of the simulation was to determine which configuration was preferable. An effort was also made to reduce the number of the degrees of freedom to 6. The two configurations - one cylindrical, and one jointed, are shown in figures 1,2 respectively.

- The optimal dimensions of the individual links in the preferred configuration.

- The maximum dimensions of the carriage which could ascertain the necessary maneuverability in small and medium spaces. This problem is illustrated in figure 3.

- The tradeoff between robot arm length and the necessity to move the robot between different work stations in the same space. The two alternatives - one with a longer arm operating from one work station, and the other with a shorter arm, operation from two stations, are shown in figure 4.

- The velocity of the various joints and their effect on the final work performance of the robot.

- The effect of the construction technologies employed on the productivity of the robot. In particular, it was intended to explore the dry method (masonry without water) vs. the wet method (masonry with water) in building, and the one path plastering (one layer without levelling) vs. two path plastering (two layers with levelling) in walls' finishing. Those technologies are described in (1).

- The effect of the various materials' supply methods, mainly with respect to building blocks.

- The different modes of man-machine work assignments in the main tasks performed by the robot, e.g. employment of the human operator on identification of key points, moving the robot between work stations, assisting the robot in finish works near corners and openings, etc.

- The effect on the robot's performance of inaccuracies in the dimensions of the shell elements.

The performance of the robot has been simulated with an aid of a program named ROBCAD on a SILICON GRAPHICS computer. The evaluated configurations of the robot have been tested in the simulated scaled environment of typical large, medium and small spaces. The program has simulated the real time performance of the robot under different assumptions of arm configuration, dimensions, joints' velocity and work method. Thus varying these decision parameters, it has been possible to assess their effect on the robot's productivity.

The variation of the above-mentioned parameters of geometry, capacity and employment method, resulted also in cost difference associated with the change in appropriate system components. Thus, for example, higher joint velocity resulted in larger work output of the arm and its effector, but were associated with an extra investment in more intensive activities; a reduction in the arm length could result in more frequent resource consuming robot movements between work stations, but allowed for use of a lighter and therefore less expensive arm. The cost of an alternative was selected, therefore, as the second evaluation criteria.

The third criterion involved the convenience of the robot operation in a given alternative. The convenience could be evaluated only in qualitative terms and involved such parameters as:

- The maneuverability of the robot, i.e. the capacity to execute its tasks in a simple and reliable manner.

- The sensitivity of robot's work to various malfunctions and innacuracies.

- Its dependability on the human intervention.

- Its effect on the complexity of the organization on site.

Conclusions

A development process of a building robot should include, before the actual construction of a prototype, a precise definition of its performance requirements, a preliminary design of its major components and a controlled simulation of its operation. The performance specifications should precisely define the tasks that the robot is to perform, the environment within which it will operate, the work method and its desired quality. The preliminary design should produce the basic robot configuration, the geometry of its components, the capacity of its actuators, and the nature of its sensors. The computer simulation of the robot performance should evaluate the changes in performance, cost and operational convenience for the different alternatives of configuration, components' geometry, actuators' capacity, and work method.

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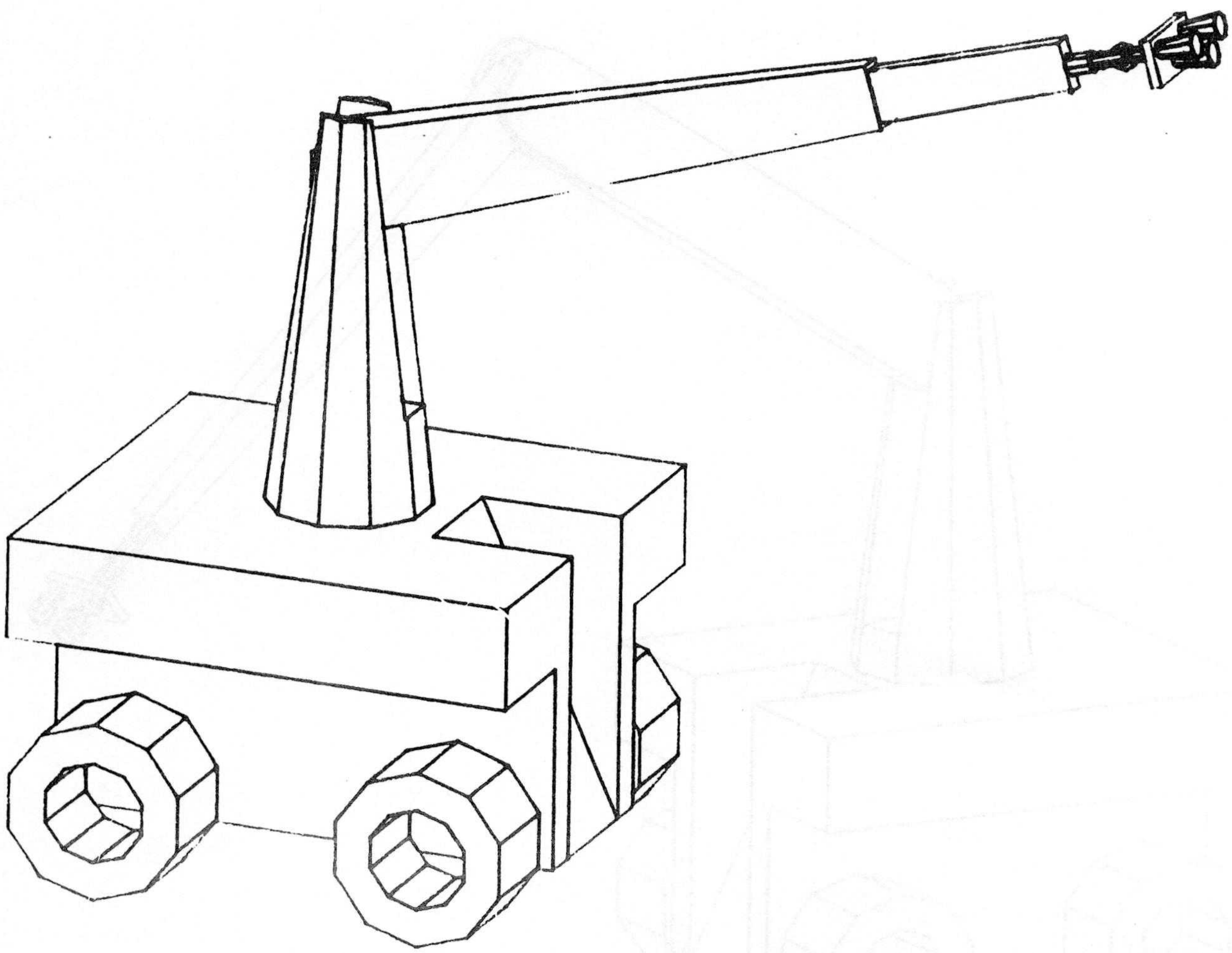

Fig. 1 - The cylindrical configuration

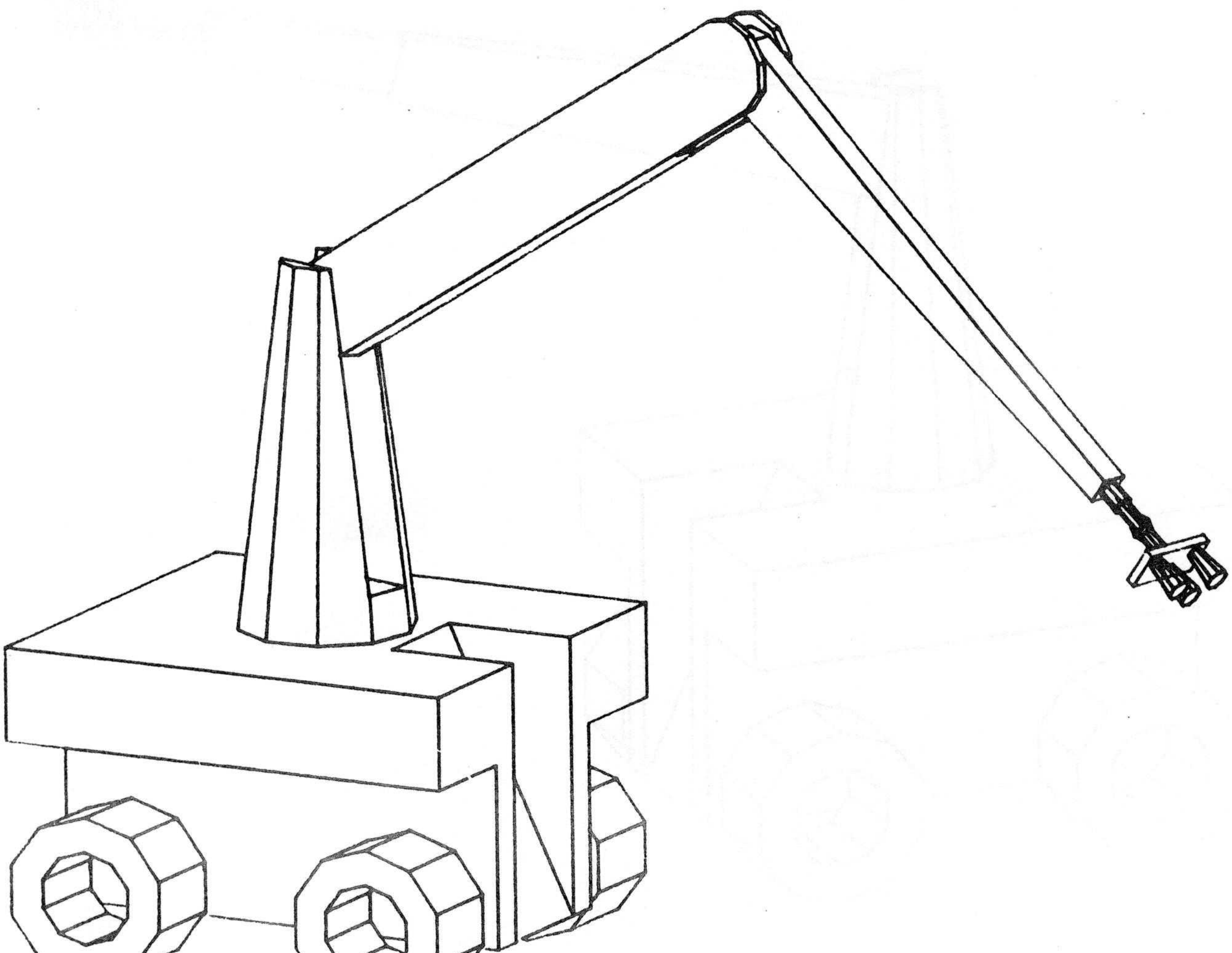

Fig. 2 - The jointed configuration

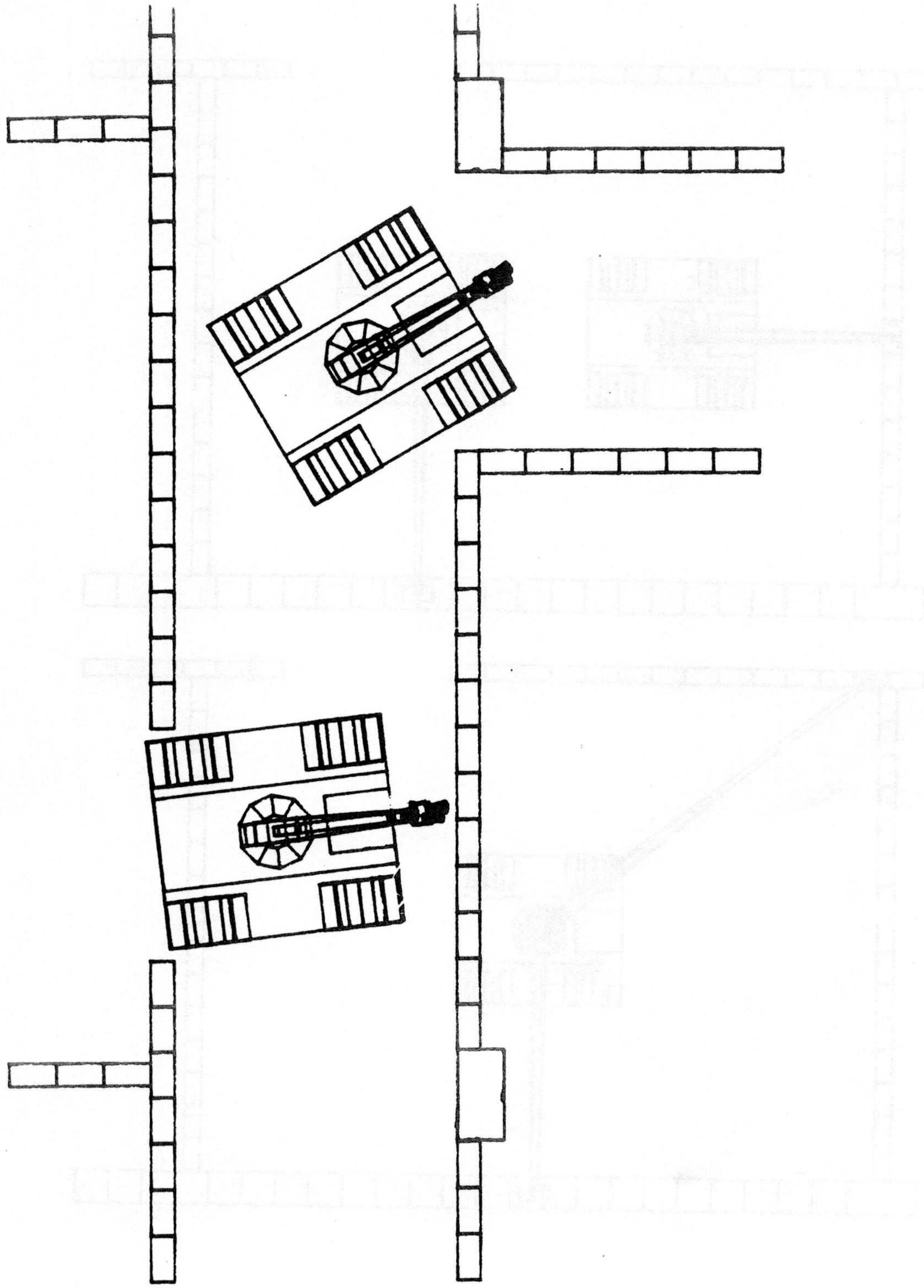

Fig. 3 - The movement of the robot in a restricted space

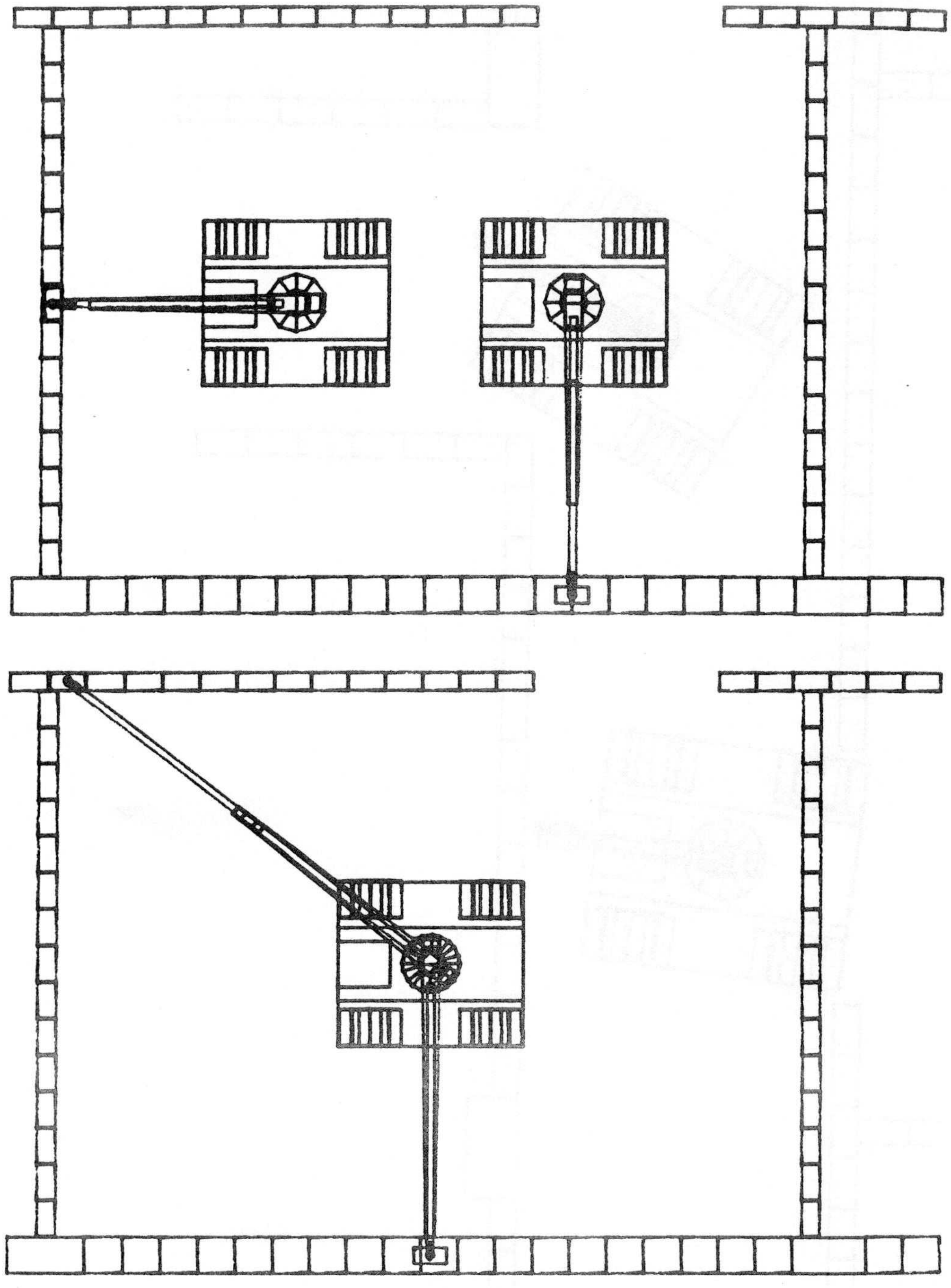

Fig. 4 - The implications of a varying arm reach