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First Results of the Development of the Masonry Robot System ROCCO: a Fault Tolerant Assembly Tool

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Abstract

In the article a concept and first prototype realisations will be presented for a fault tolerant assembly tool and the effects to the other subsystems of the ROCCO robotic system. The tool integrates active and passive complient elements, gripping devices and sensor systems. The features of the other subsystems such as the necessary kinematic and vehicle accuracy, which should be as low as possible due to the high payload and reach, the necessary kinematic and vehicle sensor systems, which should be as easy as possible due to the environmental conditions, the features of the control, which are dependent on the integrated sensors, all is dependent on the range of positioning faults, which are tolerated by the assembly tool. Additionally the off-line programming system is dependent on the gripping features: tool changes, gripping points, approach strategies must be considered and developed depending on the tool design. The different requirements and flexibilities concerning the masonry systems, used pallets, wall configurations, fault tolerance in all DOFs and quality checks will be matched by the presented assembly tool, which was developed under the approach of minimising the needed usage of sensor systems and simultaneously maximising the flexibility of use.

1. MOTIVATION

The increasing construction demand in the next years cannot be covered by the construction capacities available today neither in quantity nor in quality without rationalisation.

The share of the building construction in respect to the total construction activities in Germany is 86%, where half of the building construction is residential buildings. The machinery usage rate in this field lies at the same time only between four and eight percent of the total activities performed, through which a big potential of rationalisation exists. However, the unstructured construction site environment and the customised design of buildings makes it more difficult to introduce automated systems.

Essential reasons for a stronger rationalisation in residential building construction to increase the medium term capacities are on the one hand the higher predicted demand and on the other hand the adverse development of fewer skilled workers available over time. No young people want to join the construction industry and many of the construction workers migrate to other industries. As the main cause of this development one can regard the bad working conditions on the construction site. One possibility to approach the identified problems is a flexible automation in masonry construction.

2. ARCHITECTURE OF THE TOTAL SYSTEM

In the framework of the European R&D initiative ESPRIT III, the research project ROCCO was launched to demonstrate the possibilities of a flexible automation of masonry work. The main emphasis of the project lies in the realisation of a mobile robot system for operation on the construction site and in the integration of a computer based system for work preparation and quality control.

In the work preparation phase all relevant data for the pre-fabrication of the non-standard blocks, the construction-site layout and the robot programming is generated. Based on a CAD-representation of the building, the walls are divided into single blocks, the next step is the calculation of the optimum robot working points, pallet positions and block-on-pallet locations. With this information the standard and non-standard blocks can be pre-fabricated and palletised. Finally the robot programs are generated.

Compared to a factory environment one must take into account considerably higher inaccuracies and positioning faults of a mobile robot system on the construction site. This is the reason for developing assembly tools, which are able to compensate the inaccuracies of the total mechanic robot system through suitable sensor systems, passive complient elements and active positioning devices. These assembly tools are a key element of the robot system, which enable the off-line programming and computer integration.

The assembly tool consists of the positioning device for fault compensation and the actual gripper. For the development of assembly tools one has to pay attention to following requirements: Standard and non-standard blocks should be grippable from different positions on different pallets and assemblable at different positions in the walls (i.e. beside columns or at wall corners).

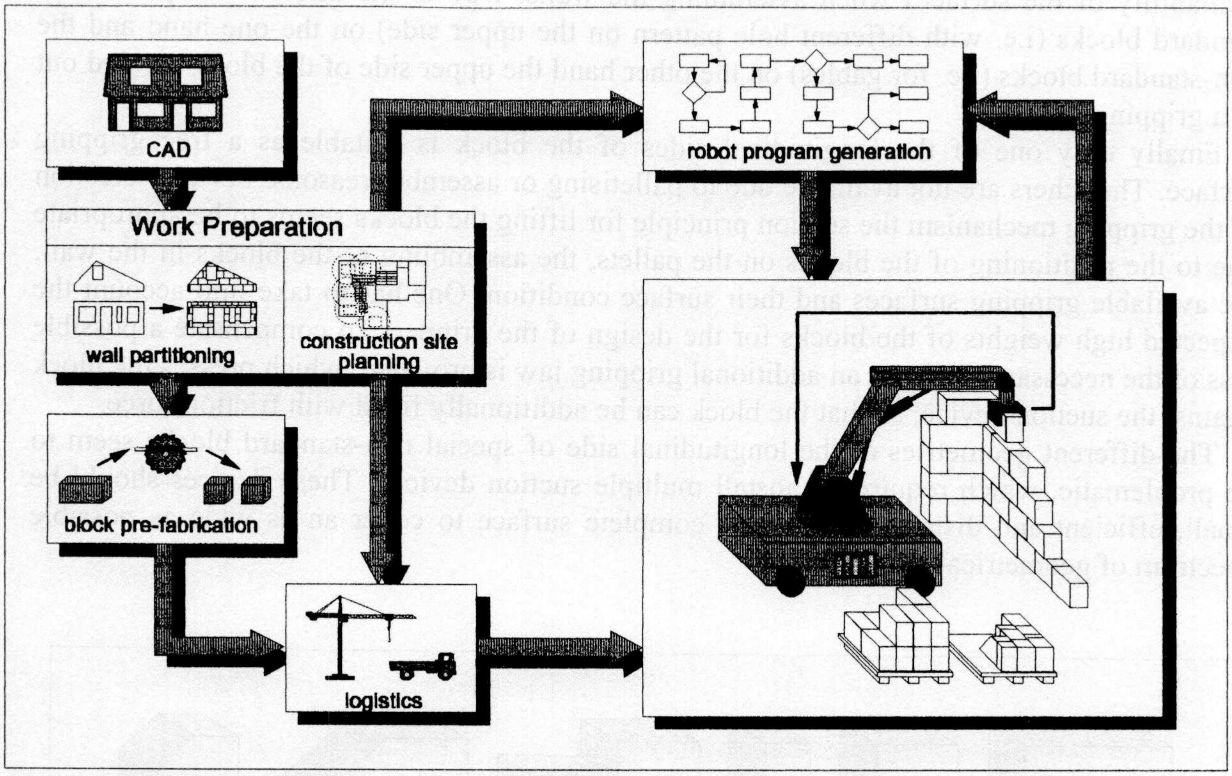

Fig. 1: schematic automated masonry process

3. CONCEPTUAL STRUCTURE OF THE ASSEMBLY TOOL

The requirements for the assembly tool, which consists of the two parts positioning and gripping device, result directly from the expected inaccuracies of the mobile robot system and the prevailing environmental conditions. System immanent faults are among others the calibrating faults of the vehicle and the deformation of the robot arms under load. Faults through the environmental conditions result for example from high surface temperatures of the manipulator during intensive sun radiation, which cause a not neglectable extension of the robot arms. In the following chapters, requirements and possible solutions concerning the gripping principle and the positioning procedure will be presented.

3.1 Selection of the Gripping Principle

The assembly tool to be developed should be able to handle sand-lime, cellular concrete and clay bricks. Different formats as well as different shapes must be considered for the three materials.

In the first approach the maximum dimensions of the blocks are 50 cm x 25 cm x 25 cm. For this concept the most important requirement is that both standard and non-standard blocks should be handable with one tool, so that unnecessary tool changes are avoided, which has a negative impact on the economic efficiency. For the development of the gripper mechanism it is important to consider that the masonry blocks usually come on pallets. Thus, not all surfaces of the blocks are available for gripping, which poses a problem similar to the availability of the surfaces when assembling the walls. Due to the different shapes of the standard blocks (i.e. with different hole pattern on the upper side) on the one hand and the non-standard blocks (i.e. for gables) on the other hand the upper side of the block is ruled out as a gripping surface.

Finally only one of the longitudinal sides of the block is suitable as a free gripping surface. The others are not available due to palletising or assembly reasons. For the selection of the gripping mechanism the suction principle for lifting the blocks seems to be appropriate due to the positioning of the blocks on the pallets, the assembling of the blocks in the wall, the available gripping surfaces and their surface condition. One has to take into account the expected high weights of the blocks for the design of the gripper. To compensate a possible loss of the necessary vacuum, an additional gripping jaw is provided, which presses the block against the suction device, so that the block can be additionally fixed with friction force.

The different geometries of the longitudinal side of special non-standard blocks seem to be problematic, which requires to install multiple suction devices. These devices should be small, efficient and distributed over the complete surface to cover an as wide as possible spectrum of geometrical shapes.

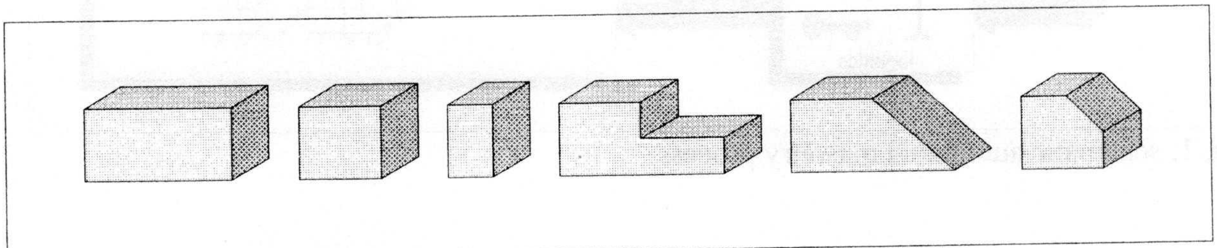

Fig. 2: spectrum of standard and non-standard blocks to be gripped

3.2 Requirements for the Positioning During Wall Assembly

Because of the expected extreme environmental conditions and occurring inaccuracies on the construction-site, the assembly tool will be featured with a positioning system, which consists of several modular sub-systems and which is robustly designed and built up. The intended positioning device should use as few sensors as possible, due to the harsh environment. The intended simplified overall structure is shown in figure 3. It is based on an already constructed and tested prototype, where not all complient mechanisms are realised, but where the basic gripping and positioning principles are already verified.

The upper part consists of a joint plate for fixing at the robot system. For compensating the expected inaccuracies on the construction-site suitable passive complient and active positioning elements are intended as they are already used for other assembly tasks. These elements must be able to compensate deviations in all three dimensions during the assembly of the block on the wall. The expected maximum deviation from the programmed co-ordinates is about 50 mm in each dimension. Here one has to consider that the positioning faults should be compensated independently in every co-ordinate direction, which assumes, that each compensating sub-system has to work independently.

Additional angle faults of all of the three main axises can occur, which are however minor to the linear deviations. The deviation around the Z-axis amounts to 2° maximum. But the tilting errors of the X- and Y-axis can be higher due to foreign bodies laying on the surface of the lower block row.

For the positioning of the block during the lowering on the wall a mechanical solution is foreseen to match the extreme site conditions and to ensure a simple operation and low maintenance of the assembly tool. Principally the deviation compensation is realised through pneumatic active positioning devices combined with passive complient elements.

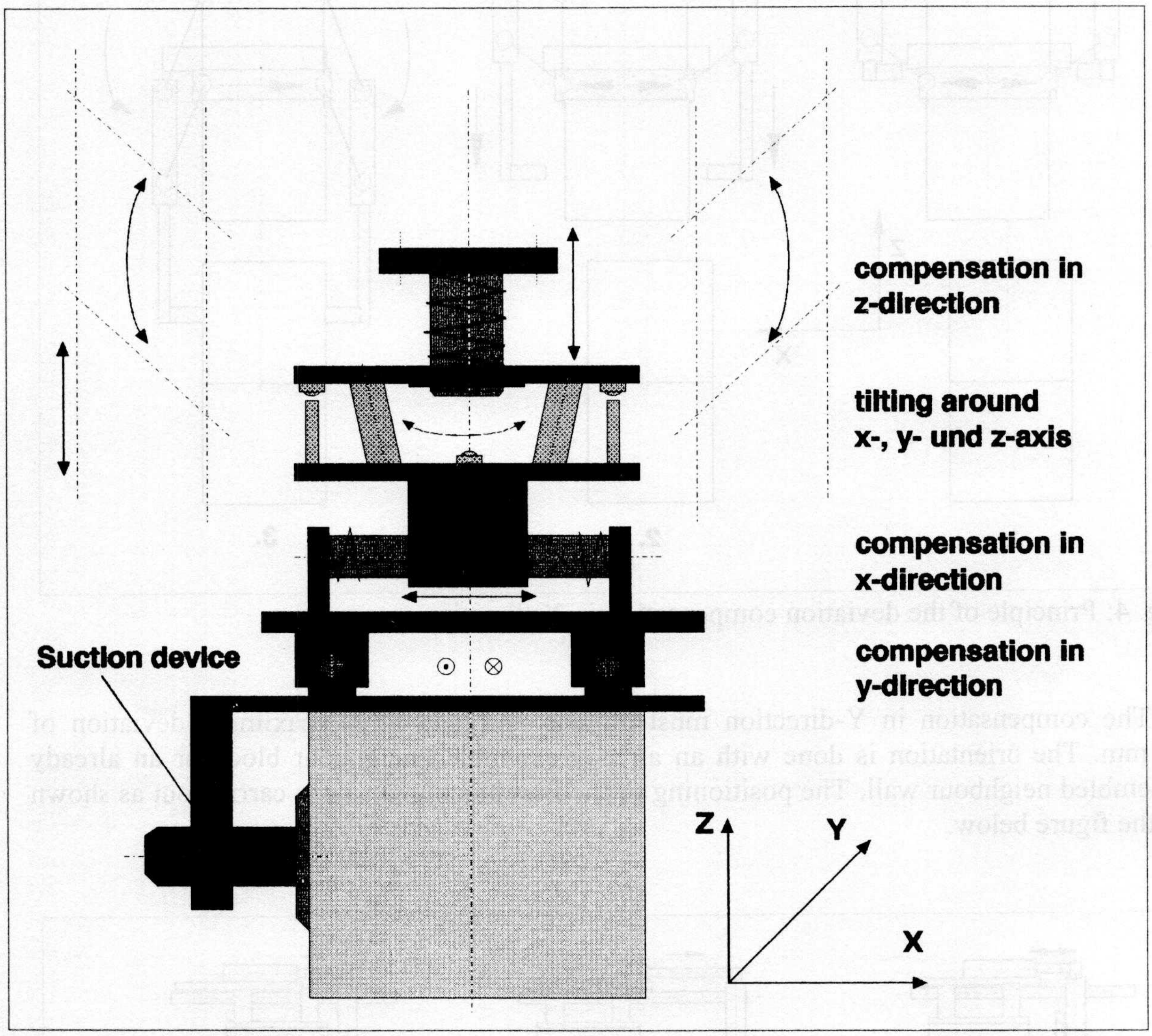

Fig. 3: Concept of the assembly tool

The positioning in X-direction handles a maximum deviation of 50 mm. The compensation is done as shown in the picture below: The pneumatically lowering stud orients itself at the already assembled row of blocks. To minimise the size of the device, a parallelogram construction is integrated, which allows a circular move in Z-direction. With this move, the lowered studs reach the already assembled row of blocks and compensate the X-deviation through a moveable sledge (see figure 4). The circular move is also driven by pneumatic cylinders. Additionally one has to consider, that the studs in the high position must be above the upper surface of the handled block in order to not disturb the gripping process from the pallet.

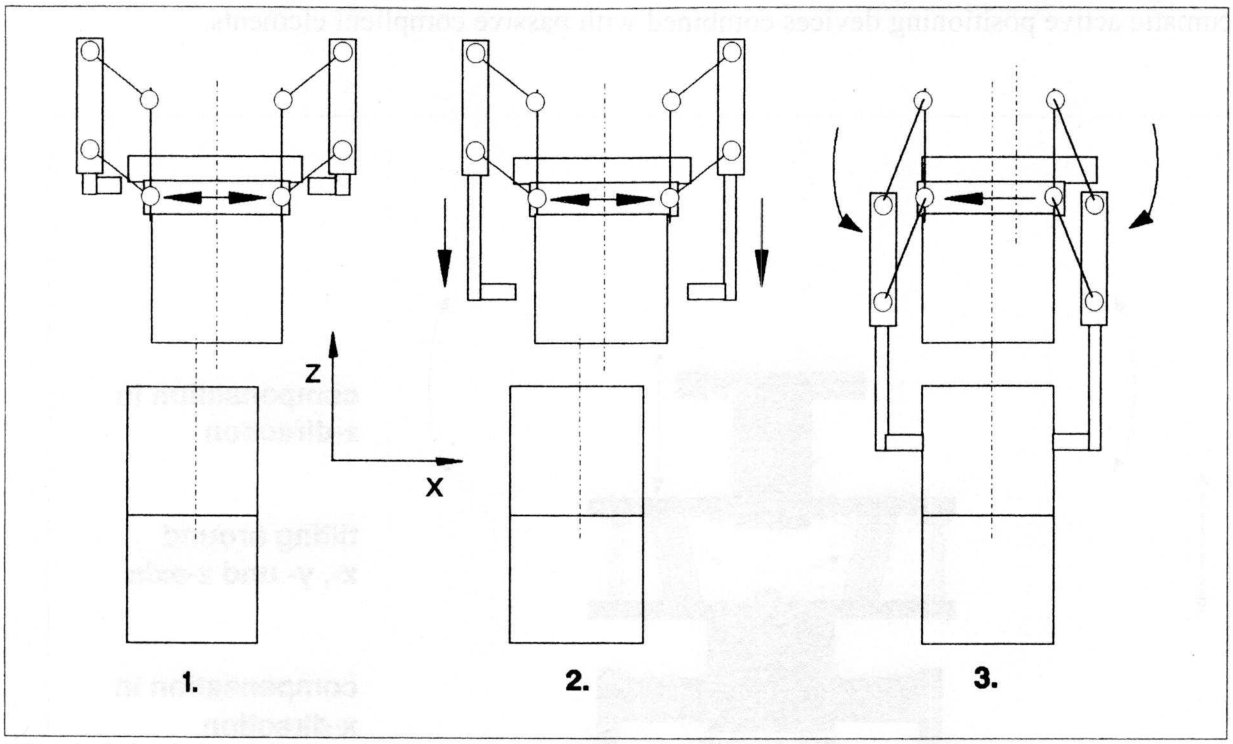

Fig. 4: Principle of the deviation compensation in X-direction

The compensation in Y-direction must be also designed for a maximum deviation of 50 mm. The orientation is done with an already assembled neighbour block or an already assembled neighbour wall. The positioning of the first block in a row is carried out as shown in the figure below.

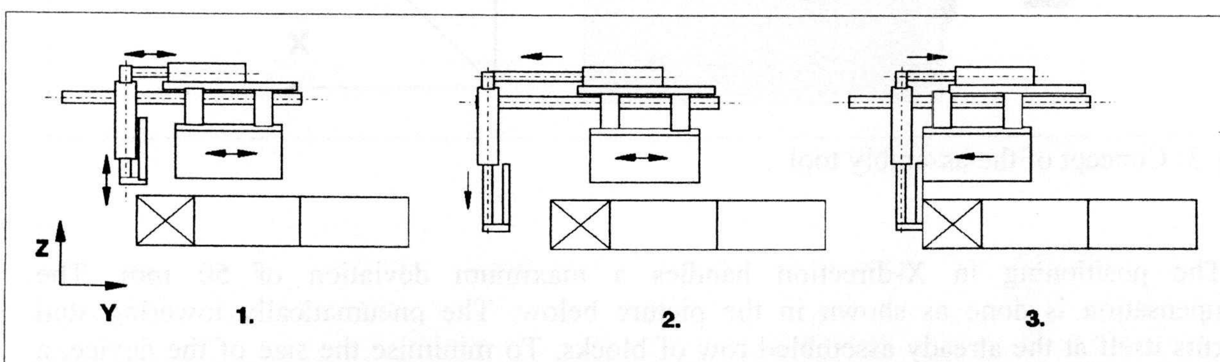

Fig. 5: Alignment of the first block in the row in the Y-direction

The alignment of the following blocks is done in the same way, but the left stud is not necessary, the already assembled blocks can be used as orientation and stud. For the positioning a sledge is used, which is movable in the Y-direction 100 mm to the left and right and which is driven by a pneumatic cylinder.

The force of the pneumatic cylinder must be less then the friction force of the already assembled block, so that the block cannot be moved by the occurring strike. For the positioning of the first block in a row, only one stud is necessary because the hand of the manipulator is 180° turnable and therefore a block can be assembled from the left and from the right.

The compensation in Z-direction is realised with a vertical complient element (see figure 3), which has an integrated switch to observe the spring tension.

To recognise tilting errors in X-, Y- and Z-direction another passive complient element is foreseen with integrated switches. A possible tilting against the horizontal level activates the switch, which causes an error message. A possible reason for this error could be a broken part of the block laying on the assembly surface, which prevents a correct horizontal assembling. The complient elements are also able to compensate deviations around the Z-axis. For an active correction of such deviations the X-direction cylinders can be used.

The design of the complient elements must be in such a way, that during the gripping from the pallet and during the robot move tilting cannot occur through an uneven load distribution. For this, measurements have to be taken to fixate all the complient elements during the robot move and to open the elements only for the assembly task. For the programming of the robot, also one has to move the robot first into a safe pre-position to avoid collisions with the already assembled wall. This means that the prepositioning has to be in such a way, that the block does not touch any sides of the already existing wall due to inaccuracies, when being moved into the position where the fine positioning occurs.

In the laboratory a modular assembly tool is already built up as a first prototype. With the use of pure pneumatic positioning elements and passive assembly aids it is already possible to reach the requested accuracy of ±1mm, so that the implementation of all additional designed compensation elements will be realised as an integration into the existing system.

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