Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)
© 1994 Elsevier Science B.V. All rights reserved.

Development of a Multi-Purpose Mobile Robot for Concrete Surface Processing

Rolf Berlin

Department of Production Engineering, Robotics Laboratory
Chalmers University of Technology, Gothenburg, Sweden

Abstract
This paper reports on the design and evaluation of an autonomous multipurpose mobile robot for concrete finishing, grinding, and cleaning at construction sites.

The common characteristics of those three applications are rotating tools in contact with the floor. Combined in one machine, they can perform recurrent tasks on a construction site.

In Phase 1, an experimental vehicle was built for tests of navigational concepts including Path Planning, Location Measurement, and Path Following.

Steering and locomotion of the experimental vehicle was provided by two independently steered and powered wheels, enabling the vehicle to perform complex manoeuvres as required by the application selected.

Two navigational methods have been tested: A novel detector for locating rebars embedded in the concrete floor to serve as possible references. A scanning laser sensor, LADAR, providing a digitalized image of the surroundings, used for locating reference walls, columns, and obstacles.

In Phase 2, a full-scale robot prototype equipped with tools was developed. The navigational concept used is LADAR and dead-reckoning.

Different vehicle/tool configurations have been modelled and simulated in order to find the optimal solution for mobility and surface coverage. Steering and locomotion of the full-scale robot is based on a steered and powered multiple wheel roller either pushing or pulling the vehicle, depending on type of application. This design, together with specific rotating tools, gives a well-balanced vehicle in all three applications.

The tool unit consists of two counterrotating and overlapping rotors. Depending on application, the rotors can be fitted with different tool blades/discs. The robot is powered via an electric cable, automatically handled by the machine itself. The robot controls position and pull of the cable to avoid running over it or generating undesirable patterns in the concrete.

Keywords:
Autonomous Mobile Robot, Concrete Surface Processing, Path Planning, Location Measurement, Laser Navigation, Path Following, Vehicle-Surface Interaction.

1. INTRODUCTION

Within the Swedish Construction Federation in Gothenburg, a group of ten Swedish contractors, called "FoU-Väst", has been managing, since 1987, a project concerned with the use of automation and robotics in the construction industry. Also involved in the project are equipment manufacturers, the Labour Union, the Construction Industry's Organisation for Work Environment Safety and Health, and the Robotics Laboratory at Chalmers University of Technology.

The group has made a thorough analysis of current methods used in Sweden. It showed that improvements, in the form of automation or use of robotics, were desirable in, for example, concrete-work, cleaning, masonry, and work at great heights. More R&D work has to be done, however, before the intentions can be realized.

Besides indicating the need for automation, the analysis also pointed at the occasionally long idle periods for a machine on a construction site. To increase the utilization of the robot, a multipurpose machine is desirable. However, the multipurpose use of the robot increases demands on mobility and compact design.

As a pilot project, construction of a mobile robot for concrete surface finishing, such as slab finishing, grinding, and cleaning, was started in 1990. In phase 1, those three applications were studied and a specification of the robot was defined. To evaluate navigational concepts and the onboard motion control system, a laboratory prototype was developed. In phase 2, a field prototype with multitool capability now has been developed; see fig. 1.

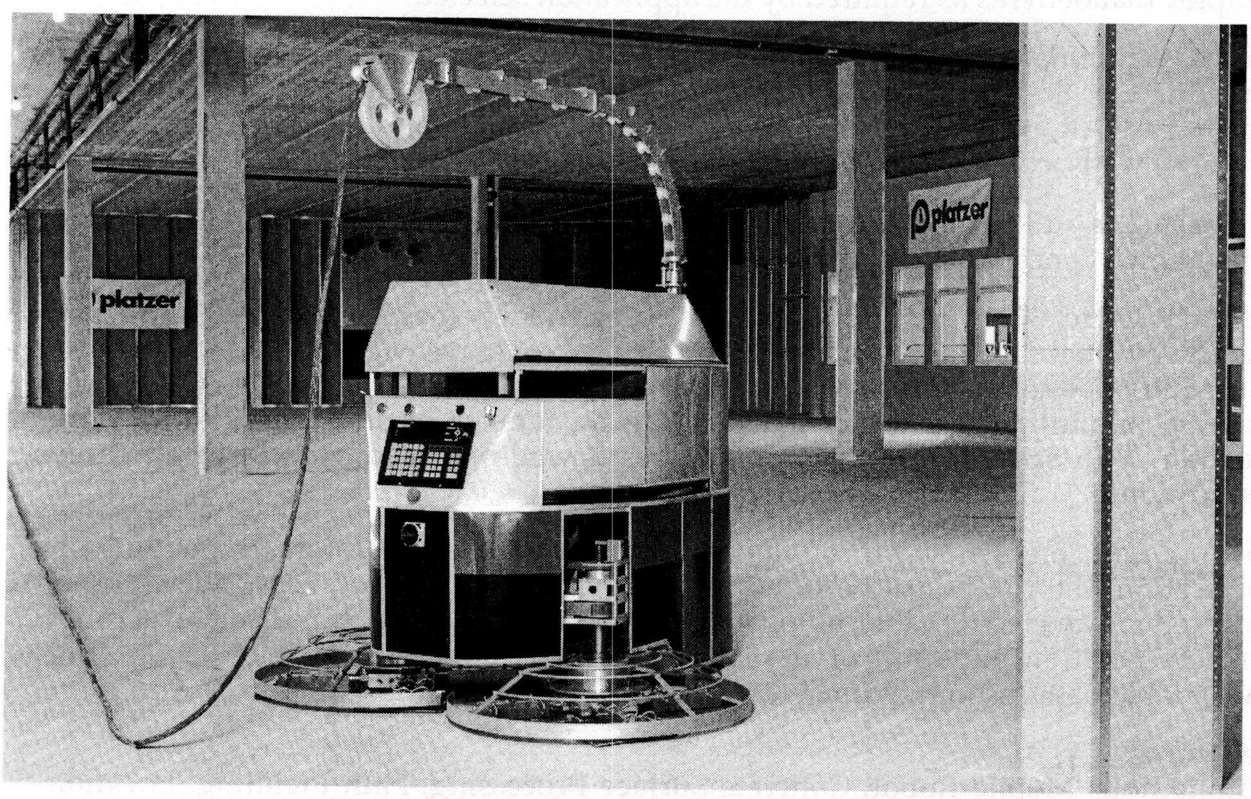

Fig. 1 Photo of the robot with slab-finishing tool on a construction site.

During phase 2, a co-operation with Dynapac, a large producer of construction machines, was started. One result is the know-how and proven design on which the tools for slab-finishing and grinding are based.

The following chapters present an overview of ideas and solutions, as well as a summary of the results so far. In chapter two, the architecture of the vehicle is presented. In the third chapter, the vehicle/tool configurations are outlined. The fourth chapter describes the basic principles for locomotion and steering. In chapter five, handling of the power cable is explained. Finally, the operation of the robot is described.

2. VEHICLE CONCEPT

The purpose of the field test vehicle is to act as a test-bed for evaluation of the chosen vehicle/tool configuration as well as for the general processing performance on different work-sites.

The design criteria for the vehicle were to carry all equipment onboard; no extra arrangements with navigational beacons or a power cable hanging from the ceiling were desirable.

There are subsystems for control, navigation, locomotion/steering, power, tools, and safety; see fig. 2.

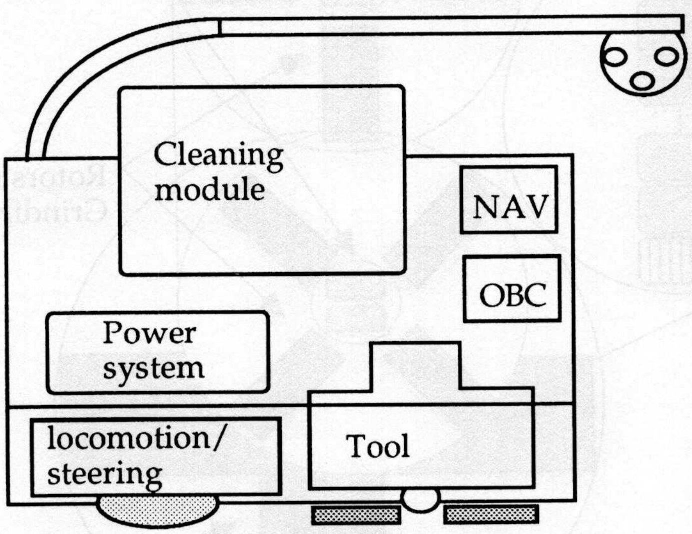

Fig. 2 Different subsystems in the robot.

The control is based on a multiprocessor system with advanced servo algorithms [1].

Navigation is performed with a laser scanner, LADAR. The laser unit uses eye-safe laser pulses to measure distance with the time-of-flight method [2],[4].

Locomotion and steering of the vehicle is accomplished with a multiple wheel roller either pushing or pulling the vehicle, depending on type of application. This configuration of partly tricycle and partly differential type cart enables the vehicle to perform manoeuvres that result in excellent surface coverage, [5],[6],[7],[11].

The tool unit consists of two counterrotating and overlapping rotors. Depending on application, the rotors can be fitted with various tool blades/discs. To minimize the weight of the vehicle while slab-finishing, the dust collection system, used while grinding and cleaning, is designed as an add-on module.

The robot is powered via an electric cable, automatically handled by the robot itself. The robot controls position and pull on the cable to avoid running over it. Total power consumption may reach 17 kW in the grinding application.

3. VEHICLE/TOOL CONFIGURATION

The locomotion and steering system consists of an axle on which are mounted two sets of three wheels each. The wheel axle can be held (and locked) in three positions that respectively correspond to driving straight, turning left or right. The outer wheel in each set is driving , while the two inner ones can be either locked or free relative to the driving wheel.

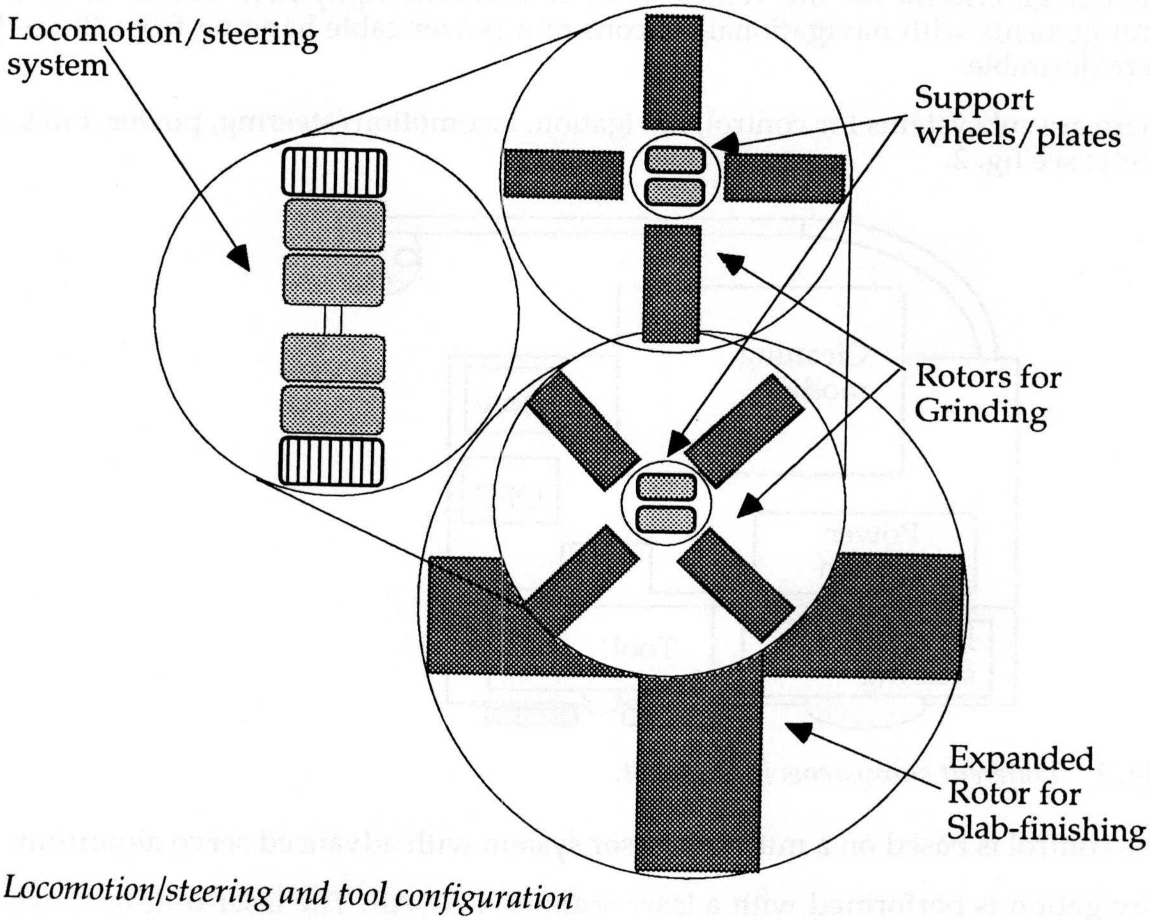

Fig. 3 Locomotion/steering and tool configuration

In the centre of the counterrotating rotors a pair of support wheels or support plates are mounted. The support wheels (alternatively plates) can be lowered or lifted with an electric actuator. In the lowered position they can either partly or completely unload the tool blades/disc from the floor.

In application "slab-finishing" the tool dimensionally exceeds the geometric limitation of the vehicle. It is therefore retractable to be able to pass through door frames and obstacles. When slab finishing, the vehicle moves in the "tool-following-wheel" fashion, in order not to damage the surface that has been finished. To lower the surface pressure enough for proper slab-finishing, the tool rotor diameter and the distance between the rotor axles have dimensions exceeding those of the other applications.

In applications "grinding" and "cleaning" the vehicle moves in the "wheel -following-tool" fashion, so as not to be affected by obstacles or roughness on surfaces not yet ground or cleaned. Support wheels are lowered in the centre of both tool rotors to control the contact force between tool and floor.

Since all grinding is performed under dry conditions a dust separator is used. Two types of grinding shall be performable: *deep grinding*, with heavy cutting (200kg dust/h) using diamond tools, and *surface grinding*, with moderate cutting using Carborundum or tungsten carbide tools.

The dust collecting system consists of an industrial vacuum cleaner having dual filters with automatic cleaning. The collected dust is sealed in bags and dropped behind the moving vehicle.

4. LOCOMOTION/STEERING

The vehicle has two modes of movement: the tool-following-wheel, in slab-finishing and the opposite, wheel-following-tool, in grinding and cleaning.

All paths are divided in segments of straight lines and curves. When moving along straight paths, steering is carried out through differential speed control of the driving wheels (right and left wheel sets).

When slab-finishing the wheel axle is locked in the straight position relative to the chassis since the torque induced by the tools must be taken care of with forces from the wheels. Path correction is made by differential steering of the two wheel sets.

Before a turn is made, the vehicle decelerates to a stop of very short duration. The turn (see fig. 4) is performed in four steps:

1 Prior to the turning manoeuvre the steering axle is unlocked. The wheel sets are rotated until the wheel axis intersects the inner rotor axis. This turning is performed by driving the outer wheels (left and right) in a differential mode (inner wheels free rolling). At the same time a support plate in the centre of the inner rotor axis is lowered to slightly unload this rotor and create a point around which to rotate.

   The steering axle is locked in the turning position. Now the driving wheels are driven in a forward mode and the entire vehicle is turning around the inner rotor axis.

2 After another quick stop, the steering axle is unlocked and turned to the standard forward position, the support plate in the centre of the inner rotor axis is raised, returning *both* rotors to the normal working condition.

Now the vehicle is driving forward a distance corresponding to one tool rotor diameter minus the desired lateral overlap.

3 After yet another quick stop the driving wheel unit is turned for the second time as in step 1.

The vehicle is turning again to take a parallel path adjacent to the earlier one.

4 Step 2 is repeated, and the vehicle now has turned 180 degrees and is ready for a straight path return.

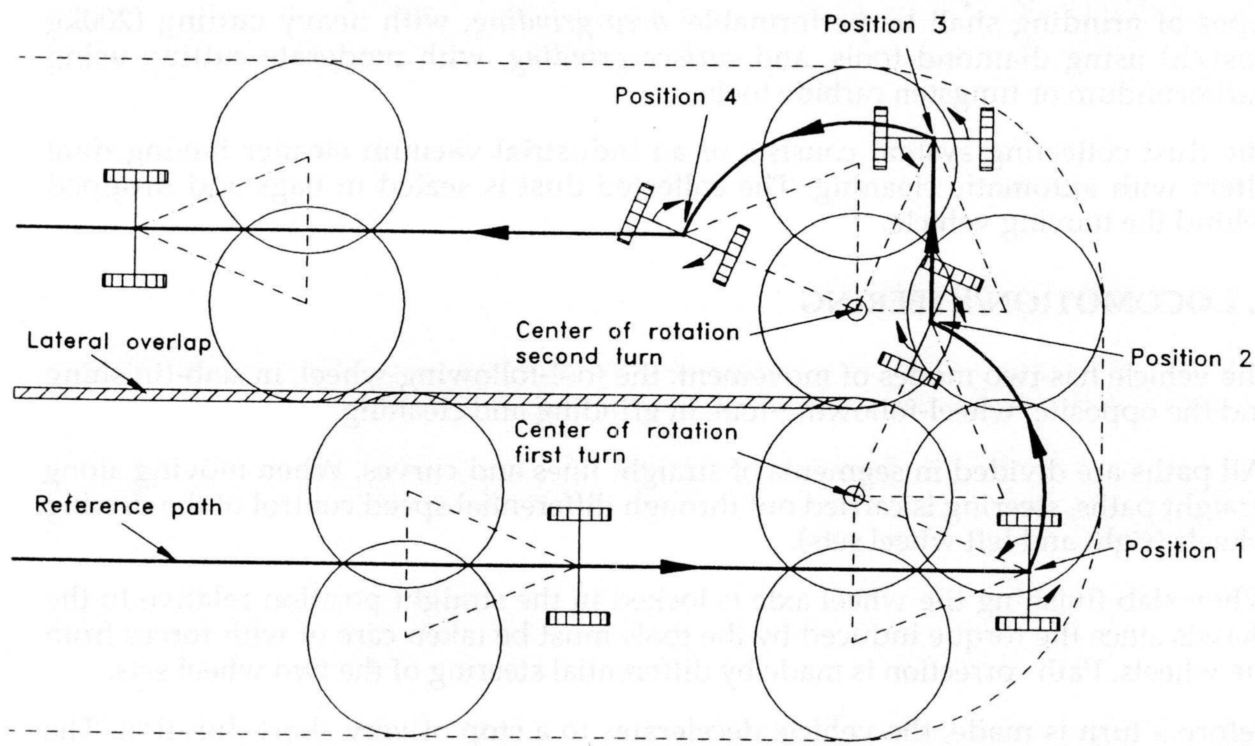

Fig. 4 Illustration of the steps resulting in an U-turn of the robot.

When grinding and cleaning the wheel axle is free relative to the chassis, since side forces will be taken care of by the support wheels. Thus, steering is that of a reversing tricycle type of vehicle. The turn is performed as explained in steps 1-4 except that, instead of lowering a plate in the centre of the inner rotor axis to create a point around which to rotate, the existing support wheel is lowered.

5. CABLE HANDLING

Power is supplied via an electric cable to the electric motors onboard the vehicle.

Onboard the robot is a cable drum equipped with 70 meters of three-phase cable. The cable is guided by an arm with runners. The arm is freely to turn around the robot. From the end of the arm the cable is hanging down to the floor where it is lying without ever being pulled. This arrangement constantly will control the position of the cable ensuring that it will not be run over by the vehicle.

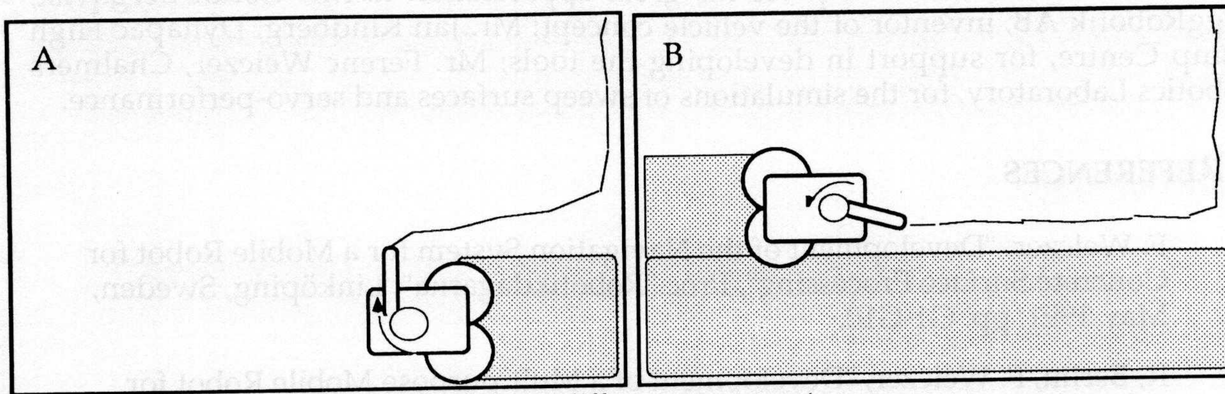

Fig. 5 Position of cable and arm during different movements.

When the robot is following a preprogrammed path, the winding/unwinding of the cable is synchronized with the vehicle motion by control signals from the computer. In figure 5, the robot is laying out cable in picture A and collecting cable again in picture B.

6. OPERATING THE ROBOT

The operator drives the robot in a manual mode between working areas with a joystick. Before starting the robot a map of the navigational area is created either by the operator using a CAD program or by the LADAR scanning the area from a known location. Algorithms generate surface coverage paths, taking into consideration tool overlap, obstacle avoidance, and processing efficiency. The path is presented to the operator, allowing him to modify path or tool parameters.

When path and start position have been decided, the operator drives the robot to the start position, places the cable appropriately and starts the machine.

Changing tools from slab-finishing to grinding or cleaning is quickly done by one person. The support wheels/plates in the centre of the rotors can be further lowered, lifting the rotors from the floor. In this position it is possible to disassemble one rotor at a time.

7. CONCLUSION

Our work to find a feasible vehicle/tool configuration for the chosen applications has resulted in a new concept where no turning overshoot and no isolated missed areas occur on the sweep surface of the twin rotors.

The cable handling for an automatically moving machine like ours, even though simple, is very promising also in other fields of application.

Verification tests with grinding tools have shown good results, but an extended program of field tests must be conducted under various circumstances, before the robot can be finalized and production considered.

7. ACKNOWLEDGEMENT

The author would like to express his great appreciation to Mr. Göran Bergqvist, ByggRobotik AB, inventor of the vehicle concept; Mr. Jan Kindberg, Dynapac High Comp Centre, for support in developing the tools; Mr. Ferenc Weiczer, Chalmers Robotics Laboratory, for the simulations of sweep surfaces and servo-performance.

8. REFERENCES

[1] F. Weiczer, "Development of the Navigation System for a Mobile Robot for Concrete Surface Processing", Proc."Robotikdagarna", Linköping, Sweden, May 1991, pp. G1-G10.

[2] R, Berlin, F. Weiczer, "Development of a Multipurpose Mobile Robot for Concrete Surface Processing, A Status Report", Proc. 9th International Symposium on Robotics in Construction, June 1992, pp. 535-544.

[3] R. Hinkel, T. Knieriemen, E. v. Puttkamer, "MOBOT-III - An Autonomous Mobile Robot for Indoor Applications", Proc. 19th International Symposium on Industrial Robots, 1988, pp. 489-504.

[4] IBEO, Product literature LADAR 2D, IBEO Lasertechnik GmbH, Germany.

[5] M. Saito, N. Tanaka, K. Arai and K. Banno, "The Development of a Mobile Robot for Concrete Slab Finishing", Proc. 15th International Symposium on Industrial Robots, Sept 1985, pp. 71-78.

[6] K. Kikuchi, S. Furuta and T. Imai, "Development and the Result of Practical Works of Concrete Floor Finishing Robot", Proc. 5th International Symposium on Robotics in Construction, June 1988, pp. 561-569.

[7] N. Tanaka, M. Saito, K. Arai, K. Banno, T. Ochi, S. Kikuchi, "The Development of the "Mark II" Mobile Robot for Concrete Slab Finishing", Proc. 5th International Symposium on Robotics in Construction, June 1988, pp. 249-257.

[8] T. Shiokawa and Y. Yamashita, "Navigation/Positioning Control of Mobile Robots for Construction", Proc. 5th International Symposium on Robotics in Construction, June 1988, pp. 589-598.

[9] T. Ueno, Y. Kajioka, H. Sato, J. Maeda, N. Okuyama, "Research & Development on Robotic Systems for Assembly and Finishing Work", Proc. 5th International Symposium on Robotics in Construction, June 1988, pp. 279-287.

[10] Örjan Petersson, Arne Johansson, "Controlling Trowelling Hardness", CBI Report 1:91, ISSN 0346-8240. 1991, (in Swedish).

[11] D. Wright, "Algorithms for All-wheel Steering", Proc. SPIE Vol. 1007 Mobile Robots III, 1988, pp 263-270.