Standard Components for Construction Robotics

Ronald P. Krom, Leon B.C. de Vos and
Frits P. Tolman

TNO-IBBC, TNO-ITI, TU-Delft
P.O.box 49, 2600 AA Delft, The Netherlands

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Abstract

At TNO we are investigating how a number of recent technologies can provide construction robotics with standard components (reference models, standard interfaces, standard components). Currently we are investigating the following 'standard components': standardised product models, based in the standard STEP, standardised communication and control, based on the standard MAP-MMS and a 'standard' low cost positioning device, called CAPSY. In order to gain experience with these standard components we are developing a prototype construction robot in which all components are integrated.

1 Introduction

At the TNO[1] Building Institute and the TNO Institute of Applied Computer Science, we are investigating the use of standard components in construction robotics. We think that the use of standard components as building blocks for construction robots, is essential for the large-scale acceptation of construction robots in the building and construction industry.

We are investigating how a number of recent technologies can provide us with standard components for construction robotics. In particular we are investigating the following technologies:

- standardised product models and data exchange based on the standard STEP[2]
- standardised robot control based on the standard MMS[3], a part of the MAP[4] standard.
- a low-cost positioning device called CAPSY[5]

The first two of the above technologies provide us with standard components for the integration of construction robots into a CIM[6] system for the construction industry. The CAPSY positioning device is one of our 'bottom up' developments which can provide us with a standard device for positioning.

The standard components mentioned are described in more detail in the chapters 2, 3 and 4 of this paper. In chapter 5 we will describe our prototype construction robot under development in which we are integrating these standard components.

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[1]Netherlands Organisation for Applied Scientific Research
[2]STandard for Exchange of Product definition data
[3]Manufacturing Message Specification
[4]Manufacturing Automation Protocol
[5]Computer Aided Positioning SYstem
[6]Computer Integrated Manufacturing

2 Standardised product models; The standard STEP

After the first introduction of computers as support tools in the construction industry it became clear that information needed to be exchanged in a multi vendor environment. Traditional means of information exchange (such as technical drawings and text) are not suitable for information exchange between different computer (application)s. To enable the exchange of high level information the concept of 'product models' has been introduced.

A product model is a computerised model of a product, storing all relevant information. A product model does not only contain the desired topology and geometry, but also contains functional specifications, material properties, process planning information and manufacturing information.

A product model contains a model of the product in different life cycle stages. For instance: As Required, As Designed, As Planned and As Built. The As Built stage describes the current state of the construction (what is in place and what not). The As Planned stage describes what should be done (either by humans or robots) and in what order. The As Designed stage describes the expected result.

Standardised information exchange (STEP)

Currently an ISO[7] standard for product model data exchange is being developed. This standard is called STEP [1]. STEP supports the exchange of product model data in a multi vendor environment.

In the field of construction robotics there are two mayor benefits of standardised product models:

- *integration of information throughout the product life-cycle*
  Information entered in the CAD system of the architect/designer can be used by the process planner, or contractor to develop his process plans. A construction robot can use the product model information as his work assignment. The product model also provides a construction robot with information about its work environment. When a construction robot has finished its assignment, the construction robot can update the product model. Integration throughout the life-cycle enables flexibility and reduction of robot programming.

- *integration of information between different vendor construction robots*
  There are several reasons why it is desirable to use standardised product models that include construction knowledge. First, contractors will not be restricted in the choice of construction robot, as more than one type of robot will be able to do the job. Second, it might be desirable to use more than one robot at the time for some construction job. This kind of integration will help to reduce the operational costs, because more extensive use of construction robots is possible.

The economical feasibility of construction robots is thus highly influenced by the existence of standards for information exchange in a multi vendor environment.

3 Standardised robot control; The standard MAP-MMS

In the previous chapter it was explained why standardised information exchange is important for the economic feasibility of construction robots. However the availability of a standard for the exchange of information is not enough. In order to communicate successfully it is also necessary to have a standardised information channel with a standardised

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[7] International Standards Organisation

communication protocol. We are investigating how the standard MAP[8] [2] can provide construction robotics with a standard component.

The MAP standard defines high-level and low-level protocols for communication and control within manufacturing environments. MAP is based upon the OSI[9] model for data communication. MAP uses standard ISO protocols in all seven layers of the OSI communications model. At layer seven, manufacturing oriented communication and control services are offered by MMS[10] [3].

MMS itself is a general specification. As an extension of MMS there are so called Companion Standards. There are companion standards for NC-machines, PLC's and robots. We are investigating the robot companion standard [4] as a standard component for communication with construction robots.

An implementation of the robot companion standard is not yet commercially available, therefore we implemented the robot companion standard ourselves using the MMS-EASE software from SISCO. We have a small MAP-network which consists of two IBM compatible PC's.

We are currently working on the integration of the MMS robot companion standard control into the prototype robot.

4 The positioning device CAPSY

One of the important differences between the construction industry and other branches of industry, is the working environment. In the traditional use of robots the environment of the robot is structured. In the construction industry this is not the case. A construction robot must be able to move through the product under construction. This requires it to have knowledge about its current position (accurately).

Positioning systems can be divided into the following categories:

- wide-range: 1m to ∞; accuracy: $\pm$ 0.1 m (E.g. satellite navigation)
- mid-range: 1 to 100 m; accuracy: $\pm$ 0.01m
- close-range: < 1m; accuracy: < 0.001m

Most applications in the construction industry demand a positioning system of the mid-range category. Until now only stereo vision systems existed for positioning application in the mid-range category. Drawbacks of stereo vision are its price, relative poor accuracy and its low speed which can be a problem in moving situations.

We have developed a new Computer Aided Positioning SYstem called CAPSY which can determine its current position in a work space up to 50x50m with an accuracy of $\pm$ 3 mm.

The positioning of CAPSY is based on a rotating laser-beam. This laser beam hits a number of reflecting bar-code labels which are attached to the walls or poles surrounding the work-site. The current position (relative to the bar-code labels) is determined via the principle of triangulation. The bar-code labels are covered with a retro-reflecting material which reflects (laser) light in the same direction from which the light came. The Bar-codes stripes are necessary to recognise the labels and to be able to distinguish between different labels. Figure 2 shows the principle op CAPSY.

The angle of rotation of the laser-beam is measured very accurately. Every time the laser beam is reflected by a label the current angle of rotation is measured. This very accurate measurement (0.01 - 0.001°) enables the calculation of the current position with an accuracy of $\pm$3 mm (depending on the distance,position and size of the labels).

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[8] Manufacturing Automation Protocol

[9] Open Systems Interconnecting

[10] Manufacturing Message Specification

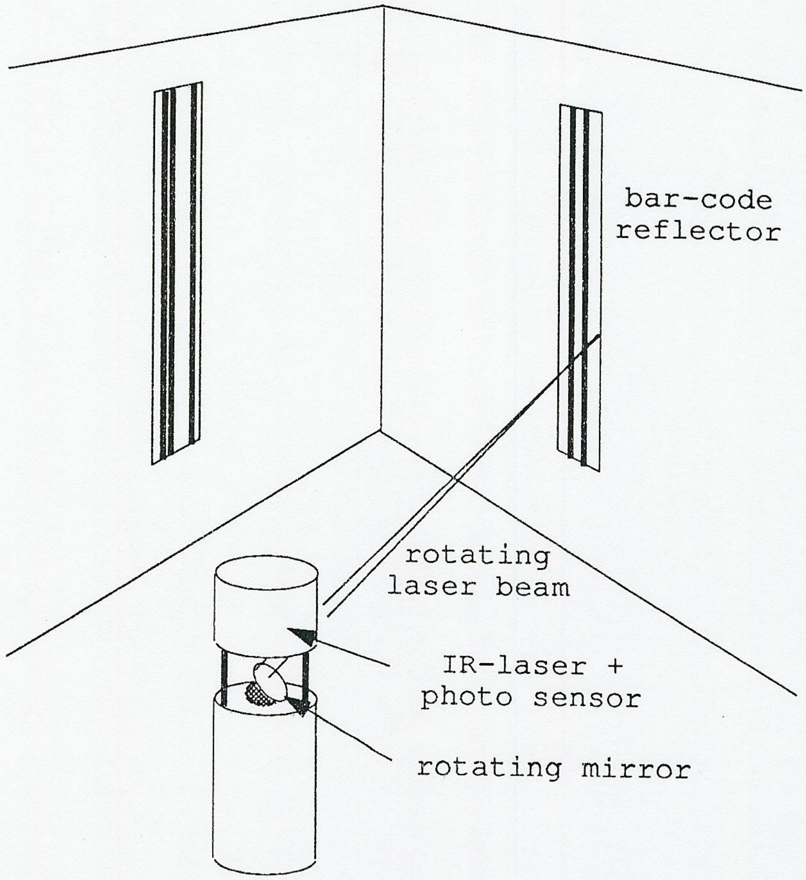

figure 1: principle of CAPSY

The positions of the bar-code labels do not have to be measured in advance. CAPSY is able to learn the positions of the bar-code labels. Therefore two known positions must be entered in the CAPSY computer during a calibration session. At these known positions the angles of reflecting bar-code labels are measured. From these measurements the positions of the bar-code labels are calculated and stored.

CAPSY determines the current position about 50 times per second. This is plenty for a mobile robot to check their route while they are moving.

The design of CAPSY is a typical example of 'mechatronics'. In the design of CAPSY we tried to minimize the amount of mechanical and optical components and implement as much as possible in software in the on-board micro computer. As a result CAPSY is a low-cost and flexible instrument which can determine the current position accurately.

The bar-code labels can also be used to mark moving objects, such as other construction robots. This way 'obstacle' detection for mobile robots can distinguish between identified (moving) obstacles and unidentified obstacles. The bar-code labels are very low-cost, can be sticked on every object, and can be made disposable. For most applications in the construction industry the use of bar-code labels is acceptable. However there may be applications where the use of bar-code labels is impossible.

The navigation of mobile robots is not solved with CAPSY alone. Beside accurate positioning an algorithm for routing is also needed. We do not yet have an intelligent navigation system. We will in the future work on the integration of CAPSY with a motion planning system such as described in [5].

In our efforts to develop 'standard components' for construction robots we have found an industrial partner who is going to produce CAPSY as a low-cost, multi purpose positioning device.

5 Our prototype construction robot

We are currently working on a first prototype of a small-scale construction robot which is based on the standard components described in the previous chapters. In this this first prototype we are integrating all the component systems into one system. In this integration process we try to develop a strategy which can be used with the integration of other standard components in construction robots.

We have chosen a simple application to demonstrate the first prototype. We would like our construction robot to draw mark-lines and -signes. For instance to mark where inner walls have to be placed, or to mark where holes have to be drilled for the installation of ceiling systems, or other systems.

ProMod

At TNO we have implemented an experimental product modeller based of the GARM (General AEC[11] Reference Model) [6]. The GARM is a part of STEP.This experimental product modeller is called 'ProMod' and is described in [7] and [8]. With ProMod we have implemented several product models. The product model we use in our research program is one of the building of our department. We use this product model in a simple simulation system. In this simulation we investigate the control of a mobile robot. We also want to use such a simulation to investigate different robot configurations. Figure 2 shows a ray-trace visualisation of a solid model representation of the building that we occupy together with a simple test vehicle with CAPSY and a video camera.

Our host computer contains a product model of the complete office building containing for instance the information where inner walls have to be placed. These product models can be exchanged with other computer systems using the standard STEP. At our institute we have demonstrated data exchange of product model data between systems of different vendors (e.g. Calma, AutoCad) [9]. Of course there is no need to exchange the product model of the *complete* building. Therefore a certain subset of the product model can be exchanged to the construction robot at the time.

The construction robot has a small product modeller of its own. This product modeller is of course specially oriented towards the applications the robot can perform. It provides the construction robot with information about:

- the current state of the building; what is ready and what not.
- where to do what and in which order.

Only the data of the product to be built is not enough for a construction robot to perform its 'job', also process-planning information is required. The current version of STEP does not (yet) define standardised process-plans. We are working on a reference model for process-planning information for construction robots.

Of course product model information about the work environment does not prevent unexpected situations. Therefore sensors such as for instance close range vision, will be needed. In the future we will look at the integration of such sensors in our prototype construction robot.

[11] Architecture, Engineering and Construction

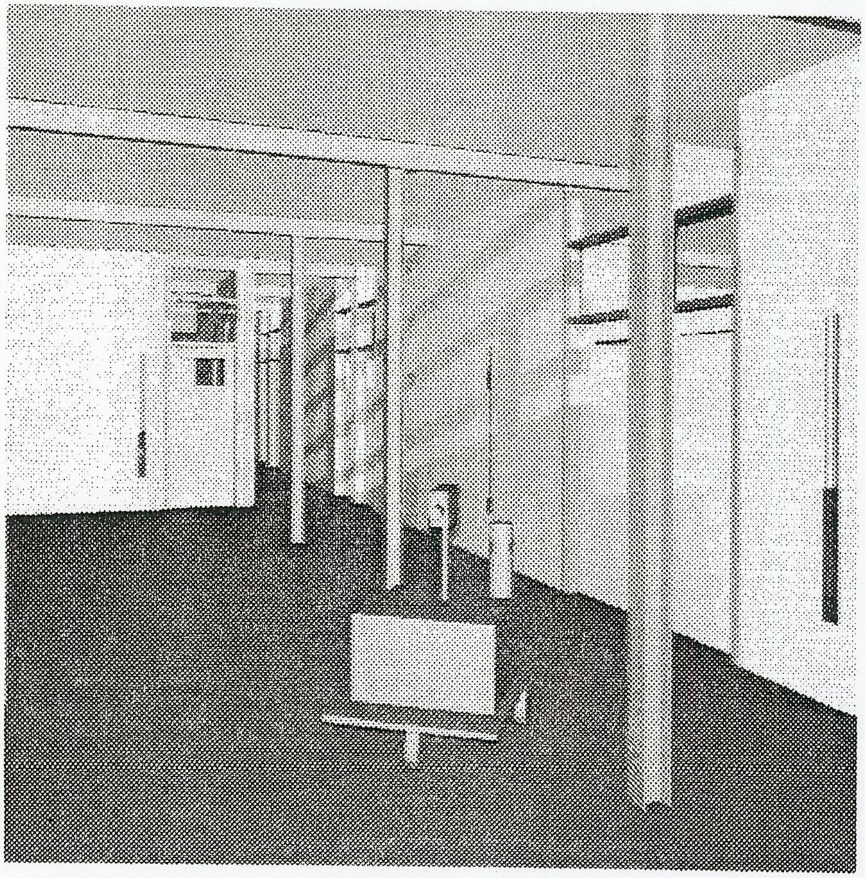

figure 2: Visualisation of solid model representation of product model

In order to achieve robot independent control, there should be a standard to exchange process-planning information in a device independent manner. We think that the control of construction robots is a mapping between a product model and a robot model (in which the abilities of the robot are described).

For instance in the future we could expect very advanced robots which can install ceiling systems. When this robot is used by a company they will have such a robot which knows perfectly what to do when a ceiling system has to be installed. The product model information provides the robot with information about the measurement of the room, the pipes, and other 'obstacles' to take into account during the installation of the ceiling systems. All low level action like drilling holes mounting plates etc. are dealt with in the ceiling systems robot. But what if you do not have a specialised ceiling systems robot, but a general purpose one? In that case you must tell the robot what to do. Otherwise nothing can be done. We are investigating how (high level) robot actions can be expressed in terms of basic resources and operations on these recourses. Therefore we would like to describe all actions in terms of low-level actions such as:

- place
- assemble
- drill hole
- cut

A marking robot

We have a three wheel AGV[12] like vehicle. On the vehicle we mounted a CAPSY system. The on-board computer is a COMPAQ DeskPro PC. This PC communicates via MMS robot companion standard with a similar PC ground station.

The first application we chose is marking robot. This robot extracts the places where for instance place walls are to placed or where holes for the ceiling system are to be drilled. The ground station can extract the relevant information from the product model. Figure 3 shows a view on the building with the places where to mark the holes for the attachment of ceiling system to the concrete above.

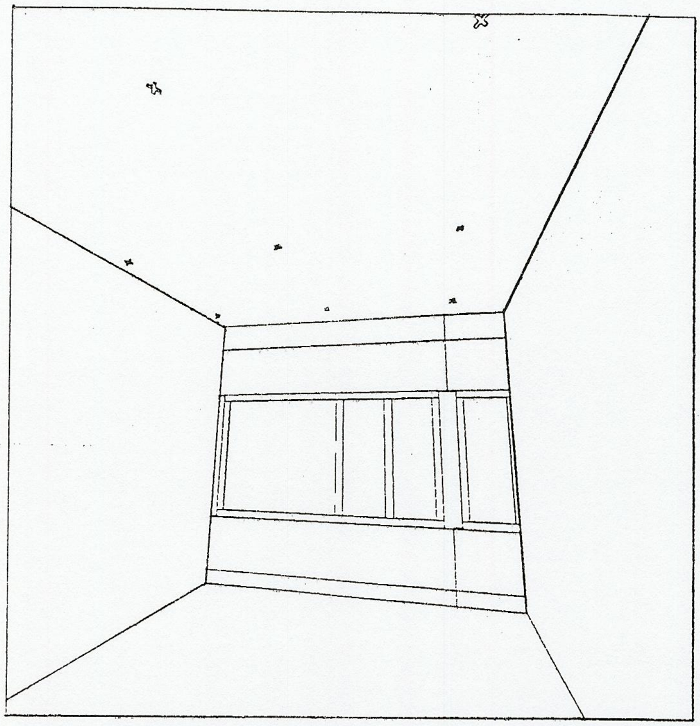

figure 3: marks for places to drill holes for ceiling system

6 Conclusions and future developments

It has taken many years to introduce robots in industry branches such as the automotive industry. With our vendor independent approach we hope to make a contribution to the successful introduction of construction robotics in the building and construction industry.

Standardised product models can provide integration of information throughout the life-cycle stages: design, process planning and manufacturing. This integration of information is necessary for the flexibility required in construction robotics.

Beside information exchange a standardised method of communication is also necessary. MAP-MMS provides us with an industrial standard which can also be used for communication with and control of construction robots.

We believe that standardised product models, standardised communication and control become an essential part for construction robots.

Our CAPSY positioning device will become commercially available in the near future and can provide others with a standard component.

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[12]Automated Guided Vehicle

Based on these standard components it is possible to develop a family of low cost, flexible construction robots. Our first prototype will be a marking robot. Next comes a robot that can drill holes and mill grooves. At that time we will have extended our component library with close range vision sensors. We then will make an autonomous inspection robot, that can check the results of his college. Finally we will develop a robot that can mount ceiling systems.

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