Motion Control and Supervision of a Drill Rig for Underground Mining

W. Risse*, H. Krölls*, F. Weissbuch* and M. Hiller#
* IMECH GmbH, Eurotec-Ring 15, 47445 Moers, Germany, w.risse@imech.com
# Gerhard-Mercator-Universität Duisburg, Dept. of Mech. Eng., Inst. of Mechatronics

Abstract

The efficient and precise operation of heavy machines with coordinated motion in multiple axes requires advanced computer-based control approaches. Furthermore, the increasing complexity of such systems demands for comprehensive user assistance as well as for extensive monitoring. This paper presents a Cartesian control system of a drilling boom for blasting and bolting operation in tunneling and underground mining. By means of an advanced human-machine-interface easy manual and automatic operation leading to a higher system performance could be achieved. Since the system architecture is based on standard internet technologies, this approach can be used to build up distributed control systems, e.g. to establish telemanipulation of the drill rig. In addition, system supervision applications can easily be realized from authorized remote clients via common web browsers. Special attention will be given to the use of modern teleservice techniques to support starting up, system diagnosis, maintenance and repair of the system.

1. Introduction

Complex drilling systems with up to three and more booms are widely used for simultaneous and efficient drilling of blastholes in the field of mining and tunnel construction. The system under investigation is part of a twin boom multi-purpose drill rig which can be used for blasthole drilling and bolting. One of the booms has been built up in a full-scale test-bed at the IMECH laboratory to investigate advanced control and monitoring approaches (figure 1). The boom is driven by eight hydraulic actuators and is mounted on a platform that can be swiveled by an additional cylinder to simulate sloping positions of the carrier vehicle.

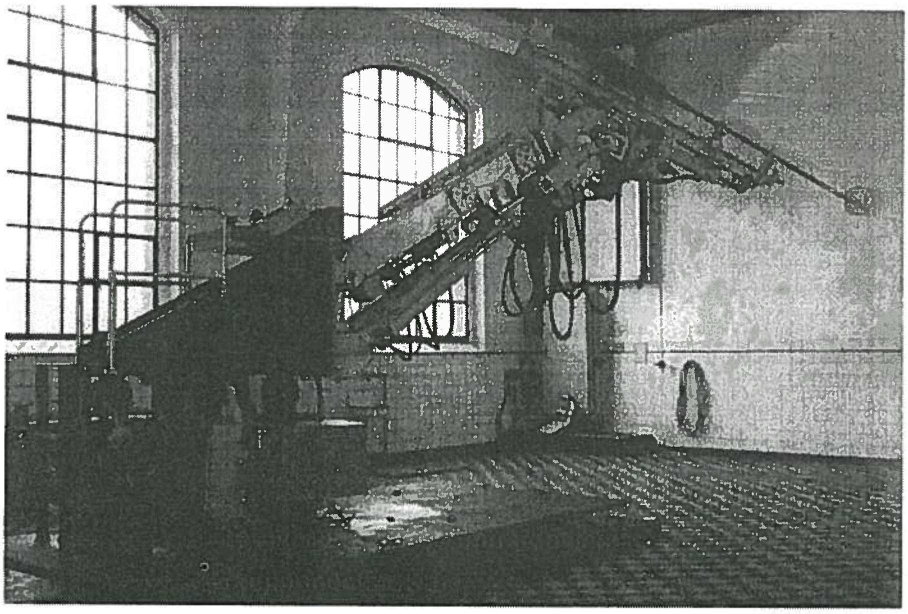


Figure 1: Full-scale drilling boom test-bed at IMECH laboratory

The costs for tunneling are closely related to the efficiency and accuracy of the blasting and bolting operation and can noticeably be reduced by applying advanced control approaches. Conventional drill rigs require enormous coordination skills of the operator for the drill tip positioning through iterative motion of single actuators. A Cartesian control system not only simplifies this task and thus relieves the operator, but also leads to a considerable speed-up even without accelerating the actual boom motion. With the help of position sensors the cycle times can drastically be reduced by programming and repetition of drill tip position sequences. This technique enables subsequent drilling and bolting operation and thus avoids time-consuming and cost-intensive tool changes after each step. However, it must be emphasized that the intention is not to replace the operator by an autonomous control system, but to support him in manual operation [1].

2. System Modifications

In order to establish a computer-based control system the actuators of the conventional drill rig had to be modified and extended by additional sensor components. To determine the current piston positions for the feedback joint controllers all of the seven hydraulic cylinders have been equipped with linear magnetorestrictive position sensors. For the same purpose the hydraulic motor of the rotational joint has been supplemented by a multi-turn sensor. An additional inclinometer measures the slope of the platform relative to the horizontal plane. The original direct switching valves that were mounted on one central block have been replaced by high precision feedback valves located on three blocks distributed over the boom. The integration of these devices into the controller has been realized by a sensor/actuator bus in order to decrease the costs for cabling and software development. With this technique supplementary sensor signals (e.g. from pressure, temperature or flow measurement) can easily be integrated into the control system. Through the fieldbus gateway module all system data is available for both the motion controller and the monitoring system.

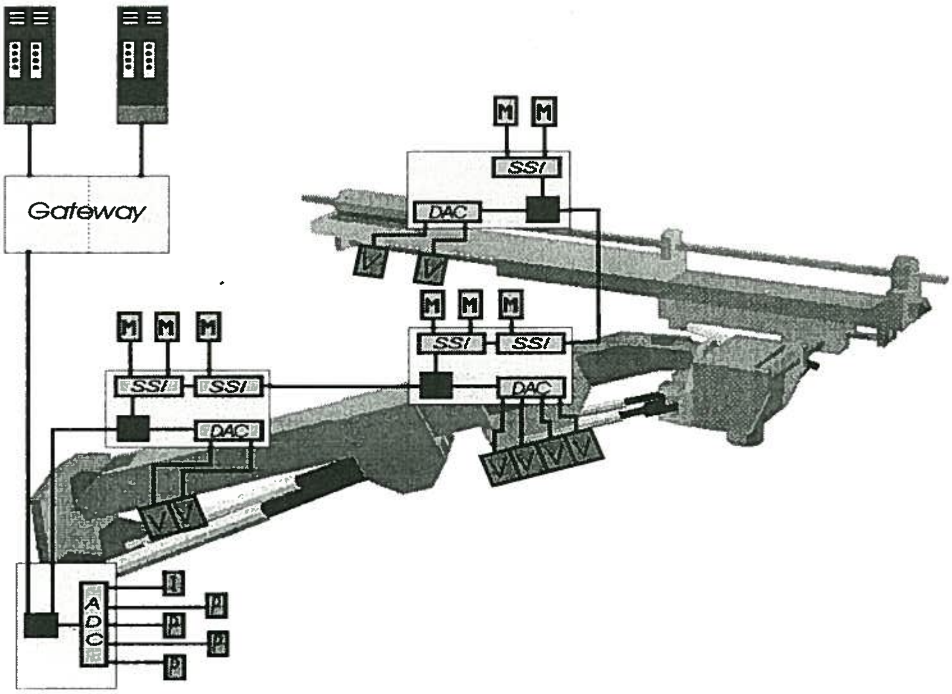


Figure 2: Extended Configuration of sensors and actuators

In contrast to the modifications of the sensor/actuator components, the mechanical design of the drilling boom remained unchanged. The kinematic structure initially had been made up by eight joints, mostly indirectly driven via transmission linkages, in order to make manual operation of the conventionally controlled boom bearable for the operator. Although the degrees of freedom (DOF) can actually be reduced when applying the Cartesian control concept, the original structure has been adopted to the test-bed system. However, only a subset of the kinematically redundant system is used for the Cartesian motion, whereas the two outermost actuators are activated merely during the actual drilling and bolting process or to switch between these operations. The position of the tool-center-point (TCP) can be selected depending on the current task. While blast hole drilling requires drill tip positioning in a vertical plane made up by the tunnel cross-section, bolting operation needs radial alignment of the drill axis perpendicular with respect to the tunnel walls.

3. Control System

In order to increase the accuracy of the manual positioning as well as the efficiency of the overall blasting and bolting process the drill rig has been equipped with a computer based motion control system that provides a wide range of functions from high level human-machine-interface (HMI) to base level single joint control [2]. The hierarchical structure of the real-time control software embraces several processes running at specific cycle-times and priorities (figure 3). The bi-directional data exchange between the HMI and the controller is managed via an internet-based client/server structure that provides information on the current machine state and handles motion commands from the operator. In the latter case a path planner prepares smooth trajectories with appropriate acceleration ramps, that are evaluated by a path generator at discrete sampling rates to obtain continuous reference values for the drill tip position and orientation. In order to control the motion of the mechanism an inverse kinematics module converts this representation into the corresponding positions of the hydraulic actuators. To allow high sampling rates of the joint controllers despite the complex kinematics transformation, a multi-rate system has been established. However, this technique requires the introduction of an additional interpolator to achieve smooth reference quantities for the controller.

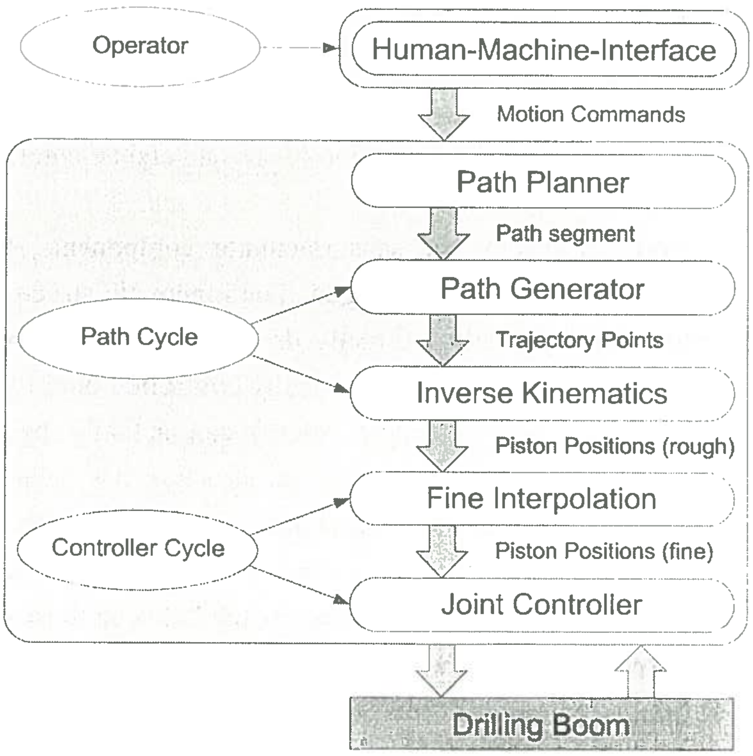


Figure 3: Structure of the drill boom motion control system

The above improvements enable the Cartesian drill tip positioning with an absolute accuracy smaller than 20 mm at a reach of 8 meters. However, the repeatable relative accuracy is even below 10 mm in the plane perpendicular to the drill axis. Figure 4 shows the position error of the drill tip for a sequence of blasthole positions. The static accuracy is an important prerequisite for the efficiency of the bolting process, since previously drilled holes now can exactly be matched again for bolt insertion. Thus time-consuming tool changes can be reduced by subsequent drilling and bolting of hole patterns.

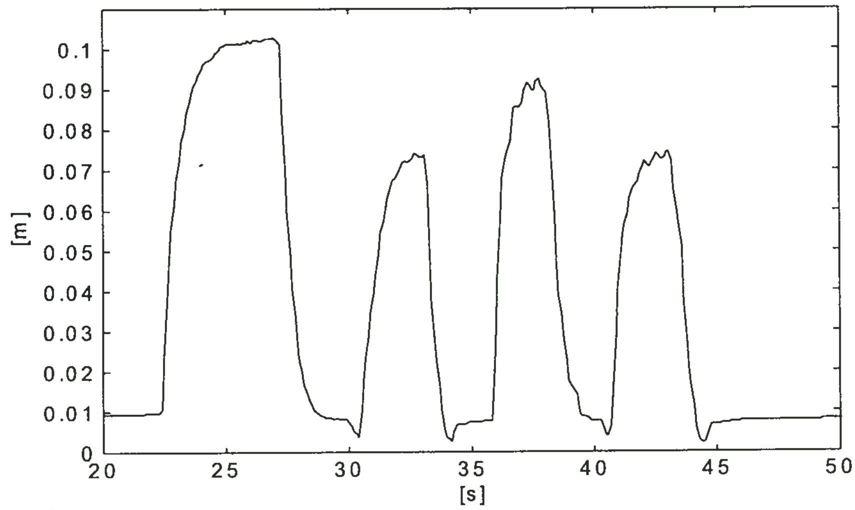


Figure 4: Positioning accuracy of the drill tip

4. Human-Machine-Interface

The interaction between human operators and the machine control system is a crucial point regarding the system productivity. The challenge in the drill rig HMI design was to provide easy to handle tools by offering intuitive methods for motion input and the programming of automatic functions. Moreover, the interface is onboard the machine, so the design must meet the rough conditions of the working environment. Hence two robust joysticks (three DOF each) are used for positioning and orientating the boom in Cartesian or joint space. For standard actions (e.g. boring mill on/off) and programmable functions two sets of push-buttons have been arranged next to a flat panel monitor which provides essential information on the current machine state (e.g status, current mode, drill tip position). In addition, the graphical user interface provides a number of dialogs to configure motion or process parameters, to recall previously stored positions or to switch between different positioning modes.

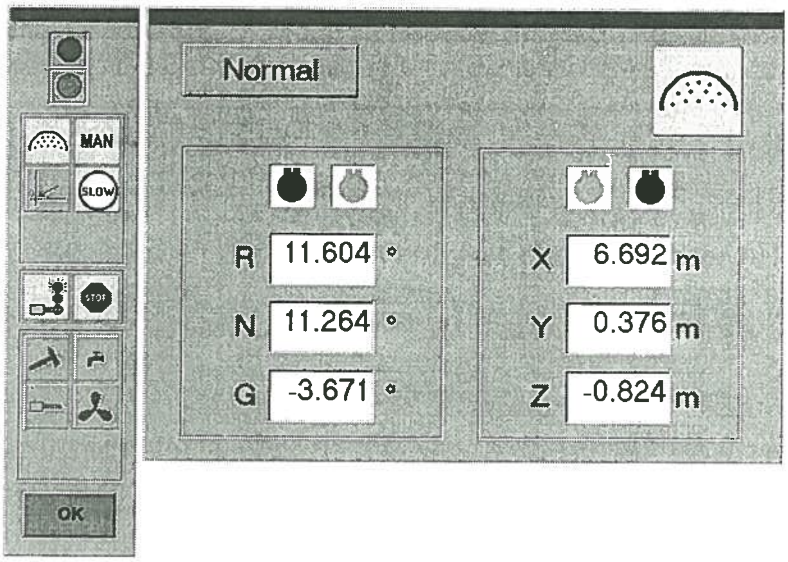


Figure 5: Graphical user interface for manual positioning of the drilling boom

To support the user in the positioning of the drill tip a three-dimensional graphical model of the boom can optionally be displayed to illustrate the current mapping of the joy-stick directions. A more detailed description of the interface and the underlying design principles can be found in [1] and [3].

The decoupling of the motion control system and the human-machine-interface via an ethernet connection allows the implementation of distributed control architectures. Using this technique the system can also be controlled via telemanipulation e.g. when working in hazardous environments. Here, scene visualization by means of a controllable camera and standard teleconferencing software, extended by a supplementary three-dimensional graphics animation of the boom, supports the operator during manual remote control.

5. Supervision

The increasing complexity of machines and plants together with the growing importance of control software requires advanced methods for system supervision. In this context the support of starting-up and maintenance by modern telecommunication techniques within a *teleservice* approach seems very promising. Teleservice actually is no new technology but the bundling of available telecommunication tools such as data transfer, remote functions and teleconferencing [4]. These techniques enable easy and comprehensive access to relevant machine data and thus allows quick state and fault diagnosis by specialists from remote. The exemplary application of this approach to the drilling boom will be outlined in the next section.

Based on preliminary investigations a monitoring concept covering eight relevant measuring points (including pressure, position, acceleration and temperature) has been developed together with the manufacturer of the drill rig. The monitoring system is running on an additional computer that is connected with the control system via the common fieldbus gateway depicted in figure 2. In addition to local monitoring tasks, this computer serves as a data server for intranet or internet access; a platform-independent transmitting medium of increasing importance. Supplementary audio-visual communication interfaces provide further information on the machine state. The monitoring system has been built up within the graphical programming environment LabView® and consists of three layers. These embrace a device server to integrate the process hardware, the actual inspection system together with a logging data base, and the human-machine-interface for user interaction. The latter component displays the current state of the measuring points by means of easily cognizable status lights, varying from 'green = no damage' over 'yellow = first alarm level' to 'red = highest alarm level' (figure 6).

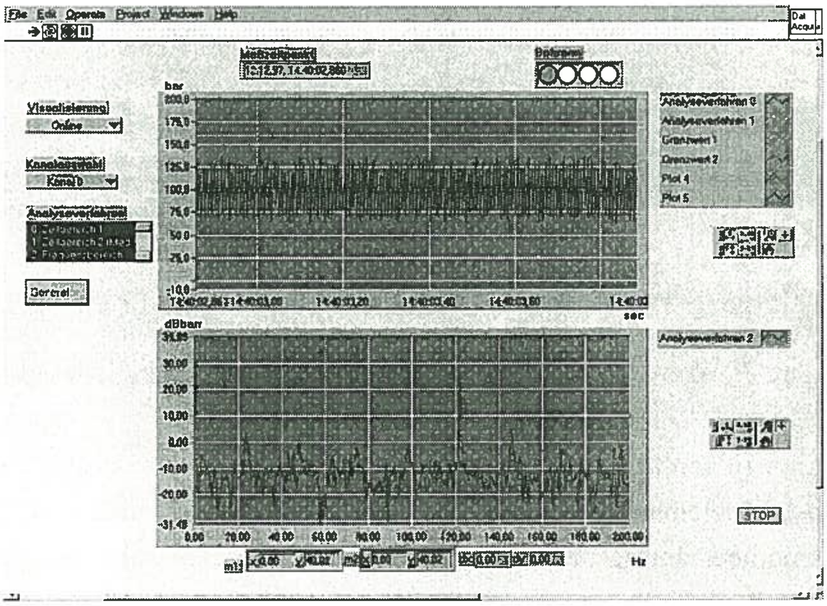


Figure 6: Graphical user interface for local access to monitoring system

With the help of log files stored in the data base the signal history can be visualized and analyzed. In normal operation mode the measuring data is continuously displayed together with the alarm level limits. Furthermore, the parameters for sensors and the analysis and evaluation of the signals can be configured via appropriate menus. To make these functions also available to authorized maintenance personnel from remote computers, the internet-based teleservice approach has been applied to the drilling boom. For this purpose a web-server on the monitoring computer supplies a dynamic

HTML-page which is generated by the LabView® development environment and that can be viewed with any common web-browser (figure 7). From the status lights that are refreshed every second the user can branch to other machine sections and access different measuring points. In addition, a common gateway interface (CGI) provides interactive access to a wide choice of preprocessed system data. These are displayed by a Java applet which is automatically downloaded from the web-server on the monitoring computer.

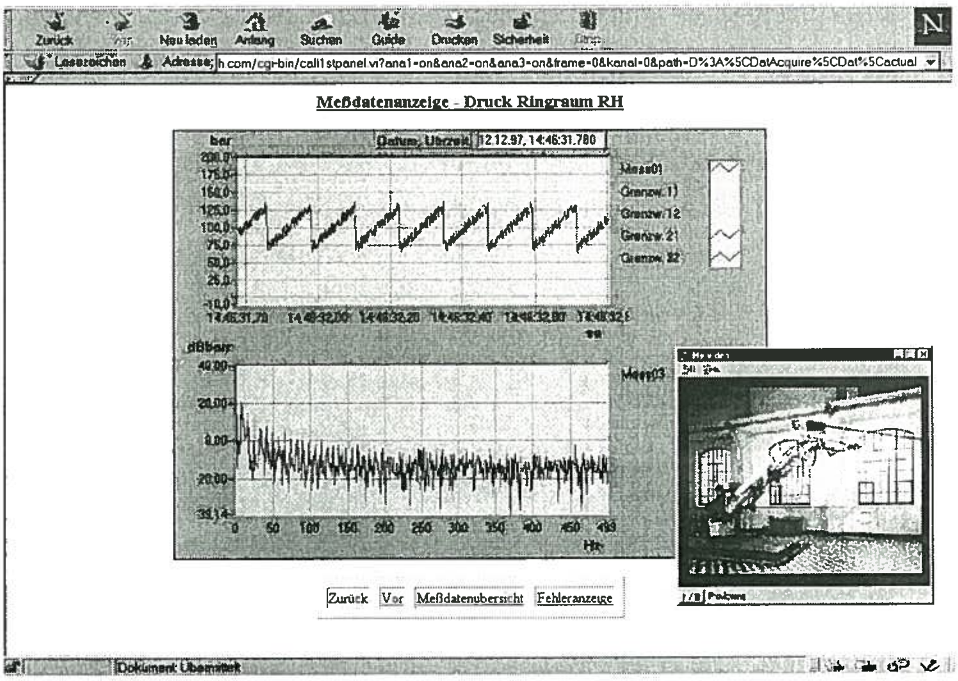


Figure 7: Web-page for drill rig monitoring enhanced by live video

The combination of multimedia techniques like scene visualization and audio transfer together with the telemanipulation of the drill rig can give further support to the maintenance engineer during the analysis of the machine condition. Besides the short-term benefits of flexible system monitoring and fault diagnosis, the stored data can be used for preventive maintenance or even an optimization of the construction.

6. Conclusions

The performance of heavy machines, like the drill rig presented here, can considerably be increased when applying advanced computer-based control concepts. Due to comprehensive support from the control system a higher efficiency and accuracy in manual operation can be achieved. Especially for the bolting process this leads to an enormous speed-up and a considerable cost reduction. Besides, the network-based connection between the controller and the human-machine-interface provides the prerequisite for telemanipulation approaches. This technique has also successfully been used for the system supervision of the drilling boom. By means of powerful data analysis and evaluation methods together with flexible accessibility via platform-independent internet tools the down time in case of failures can be decreased which leads to a higher system availability.

Current activities deal with the design of an explosion proof prototype for underground use. Future work will focus on more complex tele-manipulation applications and the integration of visualization techniques using streaming video from the real system as well as three-dimensional graphical animation from a software model of the device and its working environment.

Acknowledgement

This Project was carried out in cooperation with Deilmann-Haniel, Dortmund, Germany and financially supported by the Ministry of Economics in the Federal State North Rhine-Westphalia.

References

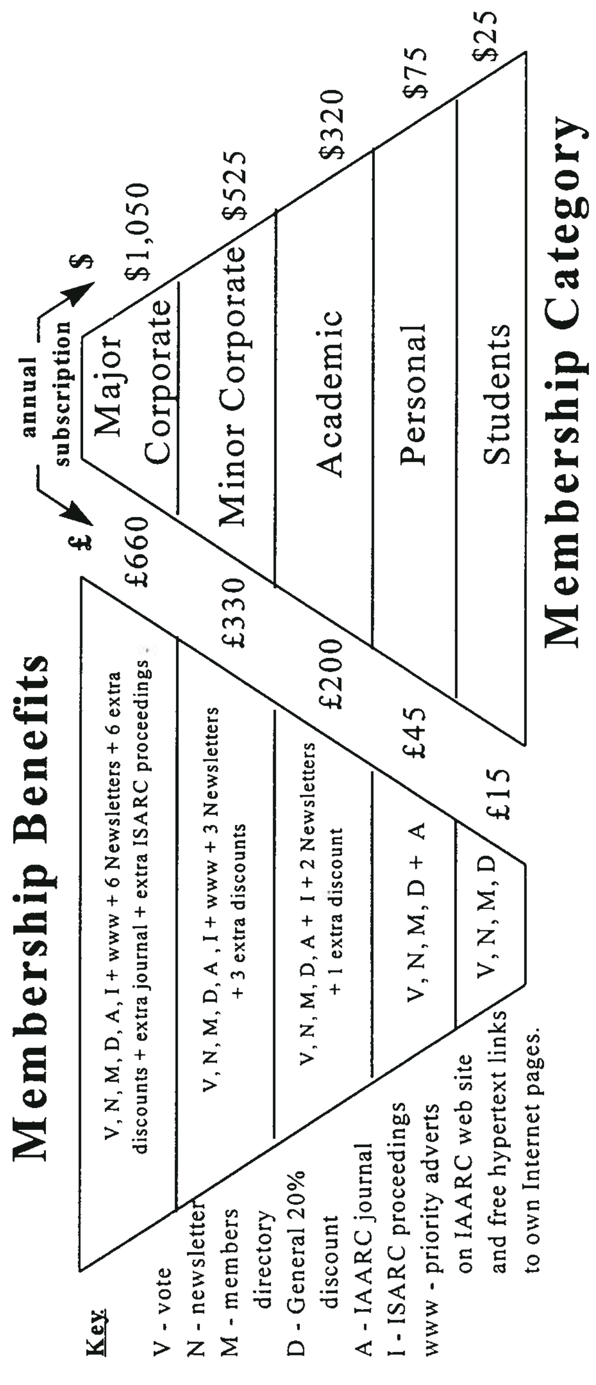
[1] B. Fink, M. Hiller, H. Krölls and S. Schweikart: Concepts of an advanced Cartesian control system for a redundant twin boom drill rig. In *Proc. of the 13th Int. Symp. on Automation and Robotics in Construction (ISARC), Tokyo, Japan*, pp. 103-112, 1996

[2] B. Fink, M. Hiller, H. Krölls, W. Risse and S. Schweikart: Cartesian controlled heavy machines supported by advanced human-machine-interfaces. In *Proc. of the 14th Int. Symp. on Automation and Robotics in Construction (ISARC), Pittsburgh, PA*, pp. 496-501, 1997

[3] R. Roshardt and G. Schweitzer: *Feasability study for operating a sensor-guided heavy manipulator, Technical report (in German), ETH Zürich (IfR), Switzerland,* 1995

[4] W. Hudetz and M. Harnischfeger: *Teleservice introduction and benefits, Report (in German), Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany, 1996*

IAARC membership categories and benefits



Visit our Internet site at : http://www.iaarc.org

to be continued
see page 152