AUTOMATION OF EXISTING TOWER CRANES – ECONOMIC AND SAFETY EXAMINATION

Y. Rosenfeld and S. Berkovitz
National Building Research Institute
Technion – Israel Institute of Technology
Haifa, ISRAEL

ABSTRACT

The geometric configuration of construction tower cranes – with well defined joints and degrees of freedom – allows to transform them, via robotic technologies, to semi-automatic equipment. We wish to add a fast and accurate navigation option to be used by the operator, mainly for cyclic, routine tasks. We report here on the first completed phase of a project aimed at developing a control system, to be furnished on either existing or newly manufactured cranes. This feasibility study deals with technological, economic and safety aspects of the idea. It identifies major components for a control system, which would be capable to record and play back common paths of the crane hook, as well as automatically navigate between benchmarks at the construction site. The economic evaluation quantifies potential savings in both routine and non-routine tasks, and predicts a minimum of 10–20 percent improvement in the operational efficiency of the crane, and in the productivity of the crews who depend on its services. The safety study highlights typical problems expected from semi-automatic operation of a large crane at a busy construction site, and suggests initial solutions via sensor interaction. The additional safety means should not merely overcome newly created problems, but also enhance the overall safety performance of tower cranes, prevent overloading and reduce maintenance costs. The study concludes with performance specifications for a basic prototype to be built at the next stages.

INTRODUCTION

Despite their key role in determining the efficiency of many operations at construction sites, tower cranes have not substantially developed since their introduction after World War II [7]. It appears that most users enjoy the essential conveying convenience offered by cranes, and do not bother with "minor" improvements of their performance. Nevertheless, today's technologies in the fields of Robotics and Automation permit far reaching improvements in tower cranes as well.

Within this study we examined the technological feasibility of furnishing ordinary tower cranes with robotic properties, analyzed expected costs and benefits of such a system, and dealt with envisaged safety problems.

TECHNOLOGICAL FEASIBILITY

The combination of a favorable geometric configuration for automation on one hand, and the availability of advanced, inexpensive, computer-based devices for motion control on the other, are bound to encourage the transformation of most existing tower cranes (and other equipment too) to semi-automatic giant robots. It is important to emphasize, right from the beginning, that there is no intention, at the present stage, to eliminate the human operator from the cabin of the crane, but rather offering him new options and capabilities, which he may decide to use, or not to use, for any specific task, according to his personal judgement.

Figure 1 schematically describes two common configurations of tower cranes [4]. It can be clearly seen that the position and the path of the hook can be determined singularly by controlling the motions at each degree of freedom of the geometric configuration. This can be done by a relatively simple system, which can compute inverse kinematics by closed control loops.

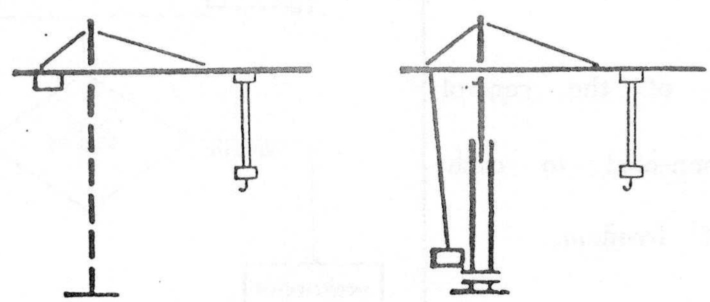

Fig. 1: Two common configurations of tower cranes.

Fortunately, most tower cranes already have an option of remote operation – either through an extention cable or by radio waves – in addition to the common operation from the cabin. Thus it can be viewed as a natural development, to further enhance the operation modes by adding a microcomputer on-board, which will collect information from encoders and sensors, memorize benchmarks and paths of the hook, and send instructions to the motors. All required components can be externally furnished on existing cranes, as well as originally incorporated into newly manufactured cranes. The proposed system is graphically illustrated in Figure 2. The existing manual control box A, has to be replaced by a dual-purpose, MANUAL/AUTOMATIC control box B. The operation principle of the system, including input-output connections, is schematically presented in Figure 3.

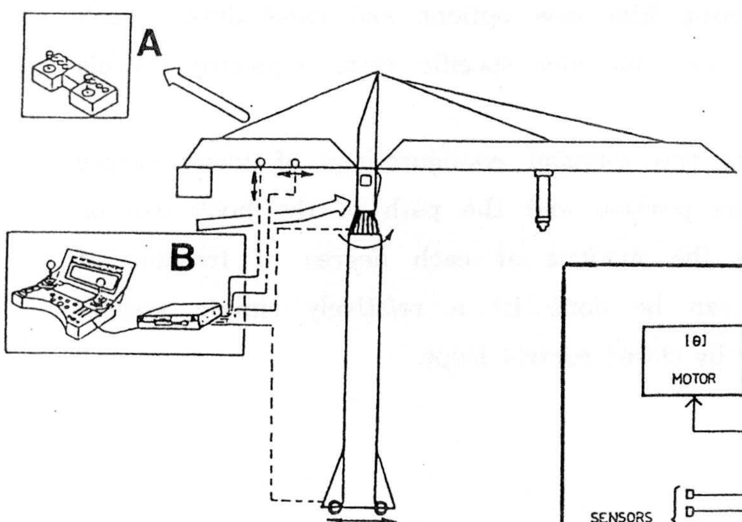

Fig. 2: Illustration of the control system connected to each degree of freedom.

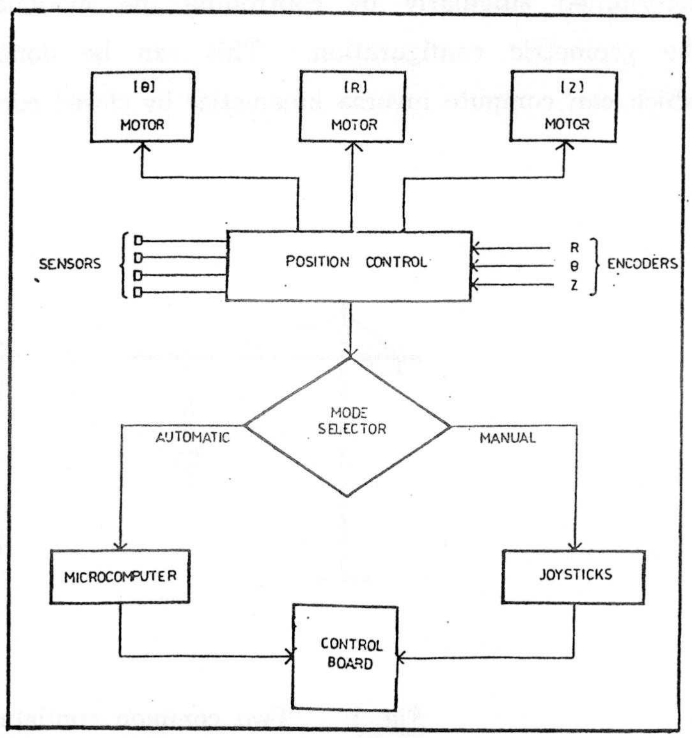

Fig. 3: The operation principle of the system.

ECONOMIC FEASIBILITY

The initiative behind this study was an intuitive expectation, for high benefit to cost ratio. Hence, detailed evaluation of the value of the system to the user, through a method offered in [8] - led to even higher expectations.

The expected cost of a basic, "low-resolution", control system for tower cranes (without charging R&D costs), is estimated within the range of $5,000 to $8,000. A more advanced system, featuring fine navigation by a beacon from the crew at the theater of operation, may cost about $12,000. Considering the many benefits, rigorously quantified below, this kind of one-time investment is going to be very profitable, usually paid back in less than a year.

Most benefits stem, to the user, from shortening cycle times of the crane, mainly consisted from three categories.

a. Long distance navigation or major path of conveying,

b. Fine maneuvering at loading and unloading zones, and

c. Tying and releasing the load.

All these three categories can be substantially improved with existing technologies.

Listed below are the major benefits expected from the proposed system:

Better utilization of the crane

Work studies generally found that tower cranes at construction sites are only utilized 60%-80% of the working hours [e.g. 2,5]. This can lead to a wrong conclusion that shortening of cycle times will merely reduce, even further, this already low rate of utilization, but will not shorten the stay of the crane on site. Such a conclusion is untrue, since cranes usually have waves of busy and non-busy periods on an hourly daily, weekly and even yearly scale. Thus, shortening of cycle times during busy periods definitely results in parallel (though not similar) shortening of the crane's stay on site, as well as of the total project duration.

Our own work studies, at 11 construction sites, was aimed at estimating the potential for time savings due to partial use of an automatic navigation mode, at least for routine tasks. Cycle times, according to our analysis, are expected to drop by about 25% in average, while shortening of the crane's stay on site may reach about 10% only. A typical example for the economic value of this benefit may involve a crane worth $300,000, with a life expectancy of 8 years, interest rate of 10%, and an operator with $30 hourly cost. 10%

improvement in the crane utilization has a direct value of about $9,000 per year.

Saving of labor time

Probably the most tangible benefit of faster crane cycles is the resulting savings in labor hours. When a crane is involved in an operation, it usually dictates the pace, thus a faster crane means higher productivity of the whole crew. To rigorously appreciate the economic value of this aspect, we may assume that only 15%, out of the expected 25% reduction of cycle time, will be reflected on the crew, which will count only three workers. If we further assume an hourly cost of $20 per worker, and 1,500 operating hours of the crane per year, we arrive at a typical yearly savings of $13,500.

Reduction of crew sizes

With an improved and accurate navigation system on the crane, the operator will require less guidance, signalling, and involvement of the crew in loading and unloading. If we assume elimination of only one single person for 500 hours (out of the 1,500 working hours of the crane) per year, the savings on this item will accumulate to $10,000.

Reduction of maintenance costs and depreciation

Yearly expenditures on maintenance and repair of cranes (including down-times associated with them) typically ranges around 10% of the initial cost. Installation of an automatic "smooth" navigation system would substantially reduce accelerations and decelerations of all moving parts, while the safety sensors would avoid overloading. This will not merely reduce breakdowns and repair costs, but also prolong the overall economic life of the equipment. The yearly value of this item is estimated at the range of $3,000-$9,000 for midsized tower cranes.

Other indirect benefits

Several other benefits of more efficient cranes are hard to be quantified. They include, inter alia, some shortening of the total project duration, which has a great value for every single day. A faster crane may sometimes save complimentary equipment (such as concrete pumps) otherwise required. It can also save overtime payments on busy days. Last - but not least - safer operation of the crane, which is associated with the system, has also a non-negligible economic value.

Safety aspects

Safety records of tower cranes are quite bad [e.g. 1,3,6]. Human errors usually head the list of causes for accidents, while overloading, low maintenance and fatigue of materials are also quite frequent. Surprisingly enough, an automatic navigation system, combined with sensor-based protection, and a housing system for fine tuning can improve the safety performance of tower cranes, rather than worsening it.

Most severe accidents caused by: untrained operator, hasty operation, doziness of the operator, incorrect estimation of load or distance, misunderstanding of signals or verbal directions, poor visibility, bad weather, etc., can be substantially reduced by the proposed system.

New safety problems may arise from unobserved automatic navigation, which may cause collision of the jib, the cable or the load with unexpected obstacles. To avoid such collisions, we suggested a laser or infrared beam protection besides the jib (illustrated in Figure 4), which can measure its deflection at the same time, and update the system. For protecting the hook, we have prepared a set of four (or more) ultrasonic proximity sensors, which will generate a warning signal whenever it comes closer than a predetermined distance (e.g. 5 meters) to any surrounding object. The system will allow the operator a few seconds for manual intervention, or otherwise perform an emergency stop. We also listed many other optional safety devices.

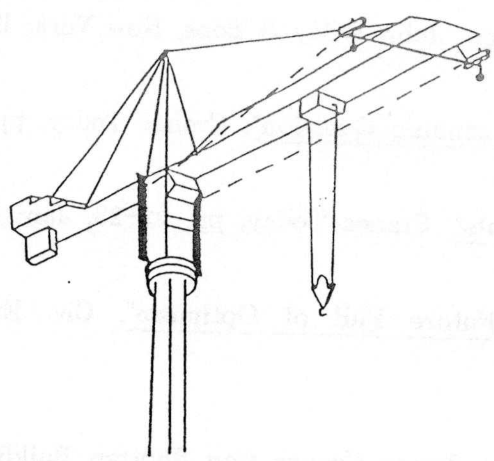

Fig. 4: Protection of the jib against collision.

CONCLUSIONS AND RECOMMENDATIONS

Furnishing tower cranes with the proposed automatic mode of operation, has to be viewed as an evolutionary development, almost as natural as furnishing a standard car with a cruise-control system. The payback period of the investment will usually be less than one year of more efficient operation. Additional R&D are required to build a universal prototype which could be retrofitted on different models of cranes. The promise of this idea mainly lies in the possibility to upgrade the large existing population of cranes, not merely the next generations. Furthermore, similar principles can be applied to other equipment, such as hydraulic cranes, tranchers, loaders, etc., which may require more complicated electro-hydraulic interfaces.

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