Evaluation of Remote Crane Operation with an Intuitive Tablet Interface and Boom Tip Control

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Cranes are important tools in industry and construction. Usually, a crane driver controls all crane drives (i.e., joints) individually, such as slewing gears, undercarriages or hydraulic cylinders. To achieve the desired load movement as the sum of all joint movements, he has to combine the movement of all joints by simultaneously actuating joysticks, levers or push buttons to a resulting hook movement. Additionally, cranes are often operated remotely using a remote control.

Apart from his/her safety and monitoring tasks, the operator's most important task is to correctly control all drives by using human-machine interface (i.e., remote control) to achieve the desired load movement. In order to determine the required actuation of all control elements, the operator has to mentally break down the desired load movement into the individual joints of the system. To do so, both the characteristics of the drive (permitted movements and speeds) and the direction of movement must be chosen correctly. The driver then has to trigger the correct drive movements by actuating the respective control elements. Consequently, the operator has to carry out two mental recoding operations to ensure correct load movement:

- converting of the desired load movements into the movements of the individual crane joints, and
- assigning the correct actuator input to the corresponding crane movements.

Both operations involve a certain mental effort, and are imply a potential for frustration and error. When using a remote control, the user must also consider his/her own orientation relative to the crane's coordinate in addition to the current position of the crane and the device kinematics. This increases the incompatibility between load movement and operator input even more. These compatibility problems can result in loss of time due to unnecessary crane movements, operator fatigue, or increased error potential.

Research Objective

As solution to this problem, an intuitive app interface is developed and applied on a loader crane with boom tip control. The new control method resolves incompatibilities of present conventional controls. An evaluation study examines the new control system with regard to the basic characteristics of safety and usability: effectiveness, efficiency and satisfaction. Experiments were conducted with 56 test persons from two user groups (novices and experts).

Interface Design

In a first step, we solve the incompatibility between the hook's movement and the user’s input by implementing boom tip control. Secondly, we propose a tablet interface to capture the input of the hook movement from the user.

All research was carried out on a Palfinger PK 7.501 SLD 5 loader crane. [1] presents the crane's boom tip control. The corresponding evaluation shows that the applied boom tip control is suitable for calculating all necessary drive movements in order to achieve a desired hook movement. Consequently, the first incompatibility is resolved.

To capture the desired hook movement, to provide all necessary information to the crane operator, and to control all crane functions, such as power on/off or mounting/demounting, we use a tablet app. In order to provide additional information about the load and the crane's surroundings on the tablet's screen, a camera is located next to the hook (see Fig. 1).

Fig 1.: Camera at boom tip.

Depending on the chosen operating mode, the tablet displays the current operating status and the camera’s view. At the same time, it records the user's input. Via a wireless radio interface, it is connected to the Controller Area Network (CAN) controller interface. The CAN controller acts as a converter between the tablet and the crane-internal CAN communication. Fig. 2 shows the two resulting tablet GUI. Especially inside the intuitive 3D mode (Fig. 2 right), wiping in the direction of the desired load movement leads to the crane’s hook moving in the chosen direction. The operators is not required to perform any calculations to achieve the desired goal, which considerably improves compatibility and intuitiveness.

Fig. 2: Tablet GUI for Crane Operation: manual mode (left) and 3D mode (right).

Evaluation Results

An evaluation study with 56 test persons in two experience groups was used to examine the interface's usability in terms of effectiveness, efficiency, and satisfaction. Within this study, the two app modes were compared to the traditional, joint based manual control with joysticks.

The core results of the evaluation study can be summarized as follows:

- Time Efficiency: The novices needed the least time with the manual mode, with all three modes being very close to each other. Experts needed the least time with the conventional mode. Examining all performance times and time deviations reveals that both experts and novices were able to perform complicated movements comparatively quickly with the 3D mode.
- Error Efficiency: Both experts and novices made fewer mistakes with all app modes than with the conventional control.
- Effectiveness: Novices achieved better placement accuracy with the tablet modes than with conventional control, with the 3D mode performing best. The experts achieved the highest accuracy with the conventional mode.
- Satisfaction: Both experts and novices rated the app modes as usable systems according to the SUS scale. Furthermore, both groups award higher usability scores to the app modes.

The presented solution can therefore be considered as an improved human-machine interface in terms of a crane remote control, that

- solves current compatibility problems between
    - desired load movement and individual crane joints,
    - correct actuator input in order to reach the desired load movement;
- ensures safety of equipment (fewer errors), process (high efficiency), operator (remote operation) and environment (high placement accuracy);
- guarantees high usability.

Consequently, the presented research contributes to the development of improved, more intuitive remote crane control with higher usability. Thereby, it forms a considerable improvement to current human-system interaction during crane operation.

Reference

1. Top, F.; Wagner, M.; Fottner, J.: How to Increase Crane Control Usability: An Intuitive HMI for Remotely Operated Cranes in Industry and Construction. In: Intelligent Human Systems Integration 2019, pp. 293-299, Cham (2019)

Short bio of corresponding author, Felix Top

Felix Top, M.Sc. is currently working as research associate and PhD candidate at the Chair of Materials Handling, Material Flow, Logistics at the Technical University of Munich (TUM). He earned both his B.Sc. (2014) and his M.Sc. (2016) in mechanical engineering at the TUM. His research focuses on human-centered human-machine interfaces for crane teleoperation and the automation of logistics machinery such as cranes and AGV. In October of 2020, he received the Franklin V. Taylor Memorial Award for the best paper at the annual conference of the IEEE Systems, Man and Cybernetics society.