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Dynamic Anti-Collision System for Hydraulic Cranes

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Abstract: The need for dynamic anti-collision systems is rapidly increasing. The future stopping positions of a crane and its neighbor cranes are predicted, which allows to stop the cranes on time to avoid collision. The brake path calculation includes reaction times and is realized via kinematical transformer. A safety concept is exploited by using two different computational methods. The algorithms were implemented and tested with real cranes.

Keywords: Obstacle Avoidance, Anti-Collision, Cranes, Robotics, Prediction Problems, Robots Manipulators, Mechatronic Systems.

1. INTRODUCTION

This paper presents a dynamic anti-collision system for several rotary cranes with interfering working space, see Fig. 1. The goal is to protect boom and tower of rotary cranes and other fix defined obstacles.

Fig. 1. Three cranes with a dynamic anti-collision system.

1.1 Literature Review

There is a vast literature on collision avoidance, but not so much research has been done if two cranes work partially within the same work-space. A special strategy for collision avoidance of two robots in the same work cell was proposed by P. Alison, M. Gilmartin, P. Urwin (1994). If all start and end positions are known, and a collision is detected a path around, by defining a free space point, is calculated. They also used a virtual arm like Shen and Bien (1989), however they compute only one sample time ahead. The company SMIE (1970) sells anti-collision and zoning systems for more than two tower cranes on construction sites and other obstacles, like buildings, since 1970. They use position and velocity information to avoid collision. Several other works have been done on robotic systems by A. Dirafzoon, M. Menhaj, A. Afshar (2010); M. Defoort (2010), however, their algorithms are not directly applicable to cranes.

In this paper, we utilize actual position and velocity, theoretical deceleration and reaction times of the hydraulics to predict future braking positions and can therefore avoid collisions, without knowing the final destination of the motion.

1.2 The General Idea of Dynamic Anti-Collision Systems with Reaction Time

Real hydraulic cranes always have some reaction time, as soon as this reaction time is finished, we assume a constant deceleration of the crane's motion. Therefore the stopping process needs to occur sooner. The path of the jib is then of first order.

2. BRAKE TIME AND PATH

Each crane computes its brake path position and the brake path positions of its neighbor cranes independently.

The reaction time is non-linear in speed. Hence, we assume a fixed and a variable reaction time, see also Fig. 4,

$$T_{reaction} = T_{fix} + T_{var}. \tag{1}$$

The reaction times are parametrized by using real measurements. The fixed reaction time T_{fix} is taken from braking tests with very low speed. Note, that the variable reaction time T_{var} is a function of the real speed and max. reaction time (taken at max. speed):

$$T_{var}(\dot{s}) = \frac{|\dot{s}_{real}|}{\dot{s}_{max}}(T_{max.reaction} - T_{fix}). \tag{2}$$

The complete brake time $T_{complete}$ is a combination of reaction and brake time:

$$T_{complete} = T_{reaction} + T_{brake} \quad \text{with} \quad T_{brake} = \frac{|\dot{s}|}{\ddot{s}} \tag{3}$$

The reaction time $T_{reaction}$ depends on the hydraulic system. The brake time T_{brake} depends on the actual speed and the desired and possible deceleration. Therefore, the complete brake path consists of a reaction path and the actual brake path:

$$s_{complete} = s_{reaction} + s_{brake} = \dot{s}\,T_{reaction} + \frac{\dot{s}^2}{2\ddot{s}}. \tag{4}$$

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3. BRAKE PATH KINEMATICS

Several different kinematics are possible for rotary cranes. For example, there are cable rope reeving systems for CBB (Cargo Board Bulk) cranes and cylinder actuated systems for LHM (Harbor Mobile) cranes, for more detail, see Liebherr (1949).

At first, the brake path calculation considers the actuator only. In order to find out what the brake path of the jib in radial direction is, a kinematical transformer, see A. Kecskemthy (1993), is necessary. The predicted angular brake position is computed via e.g. a 3RP transformer, see J. Eberharter, M. Rajek, K. Schneider (2009). From that angle, the radial position of the jib's braking position is determined, see Fig. 2. There is just one last challenge, we do not know the actual speed of the linear actuator; only the position of the boom. Now, the boom angle is derived numerically, then this resulting angular speed is transformed via a 3RP Jacobian transformer, see J. Eberharter, M. Rajek, K. Schneider (2009), to get the actual actuator speed. The block diagram in Fig. 3 depicts the relations again.

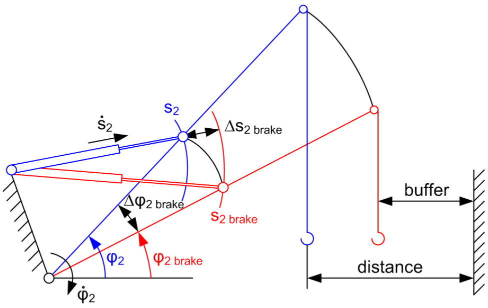

Fig. 2. Kinematics of the luffing brake path.

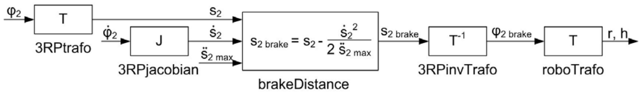

Fig. 3. Block diagram of the luffing brake kinematics.

The brake path of the slewing gear does not need such kinematical transformations, it can be applied directly.

4. SAFETY CONCEPT

To achieve better safety, the brake path is computed twice; once, analytical and once iterative. The deceleration of the iterative method is reduced, the analytical method utilizes the actual maximal possible deceleration, see Fig. 4. The reduction of the deceleration allows a softer stopping. I.e. the hook/load will not sway as much! Note, the hook itself is not protected.

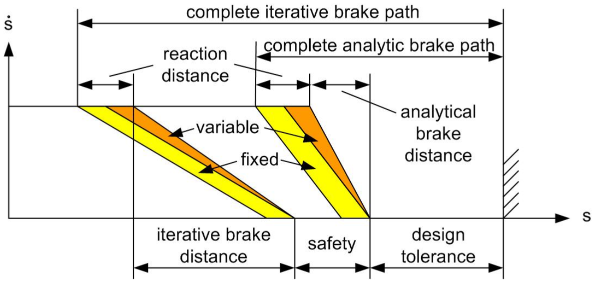

Fig. 4. Safety concept of the brake path.

5. VERIFICATION AND CONCLUSION

The algorithms were implemented and tested with real cranes. Let us take a closer look at the slewing gear. Figure 5 shows clearly that the reduction of the desired speed happens about the amount of reaction time sooner, then the actual crane starts to reduce its speed. In Fig. 6 the predicted brake and actual position is plotted over time for a model and a real crane. We can see a slightly overshoot of the predicted brake path, which is necessary to trigger at its first overshoot the braking manoeuver. The actual error for accurate stopping is the overshoot itself.

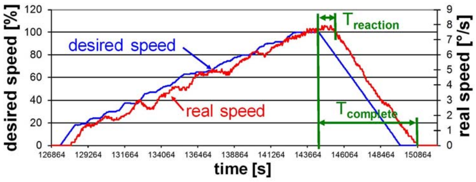

Fig. 5. Desired and real speeds.

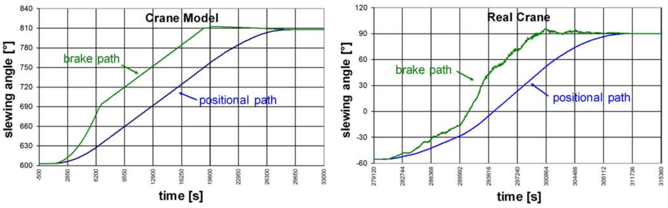

Fig. 6. Position and brake paths.

In conclusion, utilizing kinematical transformers to get the complete brake path from the instantaneous brake and reaction time, it is possible to predict the future stopping position of a hydraulic crane.

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