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Handling uncertainty due to the delay between complex sensing and manipulation in an industrial workcell

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SUMMARY
In this paper, we propose a generic method to model the dynamic intercept and manipulation capability of vision-based industrial robot systems. In order to verify the method, we present experiments using our industrial workcell prototype to dynamically intercept and manipulate semi-randomly moving objects.

KEYWORDS: Industrial robots; Timing model; Dynamic manipulation.

1. INTRODUCTION

Vision-based robotic systems often encounter the time delay problem when they perform real-time grasping or intercept tasks.[1] While using non-trivial visual sensing, there is a significant time gap between when an object is sensed and when a robot can reach the sensed position of the object. Liu *et al.*[2] explicitly depicted this time delay in a timing model.[2] In this case, the system must predict where the object will be by the time the robot arrives at the desired location. This critical time gap is a key factor to determine the intercept capability of vision-based robotic systems. In Section 2, we present a way to model this time gap, which we call object unsensed period.

2. THEORY FOR PREDICTING RANGE OF TASK VARIABILITY

Figure 1 shows how the sensing and interception process evolves in the time domain (see Liu *et al.*[2] for the definitions of Δq, Δc, Δf, and N). m is the number of the last set of control commands before interception. Hence, the object unsensed period Δt is the difference between the last instant when reality is sensed and the final impact time. Therefore, it is clear that the properties of velocity variation during this period decide whether the robot can succeed with the interception or not.

The following equations present an estimate of the range of motion variations within which the robot can succeed. First,

$$\hat{x}_f = x_i + v_i \times \Delta t \quad (1)$$

$$x_f = x_i + \bar{v} \times \Delta t, \quad (2)$$

where $\hat{x}_f$ is the predicted final impact x position for the object, x_f is the actual final impact x position for the object, v_i is the last observed velocity of the object, and $\bar{v}$ is the average velocity of the object over the time interval Δt. Note that x_f is thus an estimate over all average velocities. Combining Eqs. (1) and (2), we obtain:

$$|v_i - \bar{v}| = \frac{|\hat{x}_f - x_f|}{\Delta t}. \quad (3)$$

We know that if $|\hat{x}_f - x_f|$ is less than half of the width (w) of the end-effector, the robot can succeed intercepting in the moving object. Thus, we obtain an estimate for the condition when the robot can succeed:

$$|v_i - \bar{v}| \leq \frac{w}{2 \times \Delta t} \quad (4)$$

3. EXPERIMENTAL VALIDATION AND CONCLUSION

We conducted experiments using three end-effectors, two scoopers and a trapper, under three different interferences, wind, bump, and ramp. We designed 15 sets of experiments

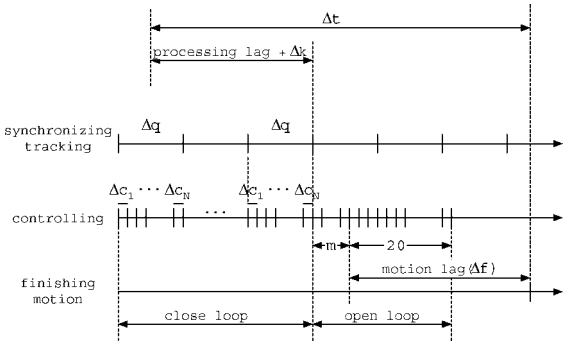


Fig. 1. Timeline description.

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and ran 70 times for each set. The goal of these experiments was to determine if our methods could accurately predict when a manipulation would be successful and when it would fail. Overall, we noticed that out of 1050 experiments, the average success percentage, which is when the theoretical prediction matches the experimental results, is 92.5%.

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