A Sway Reduction Controller For Construction Crane

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ABSTRACT

A tower crane can be reduced the sway oscillation easily by controlling the rotation acceleration. With the proposed open-loop fast control method which is operated by controlling acceleration, the sway angle of suspended load can be maintained during the movement as well as reduced oscillation during and at the end of movement. In this paper, we design and produce a scaled tower crane with a servo control mechanism which can be used to control crane rotation precisely. Also, we do experiments with our scaled tower crane to validate the proposed fast control method. Experiment results demonstrate the effectiveness of maintaining fixed angle during the movement and reducing oscillation.

Keywords –
Tower crane; Sway reduction; Controller

1 Introduction

Crane is one of the most important equipment in the construction industry. Especially in the prosperity sociality, Crane is heavily used to build significant and challenging buildings. However, the efficient and safety of the crane is always a big problem. For instance, the oscillation of the rigging beam may cause deadly accident or delay the progress. Therefore, a skilled and experienced crane operator is required to maintain the safety and efficiency during the construction schedule.

Many researches have proposed various control method to reduce the oscillation. These methods can be categorized into two types: open-loop system and closed-loop system.

The closed-loop requires feedback mechanism to control the oscillation and minimize the sway [1]. On the contrary, the open-loop system can reduce the sway without feedback sensor. Input shaping is one of the open-loop system and it is verified to be an effective way of controlling the sway [2].

This paper focuses on controlling the sway angle of the tower crane with an open-loop system. We try to validate the control of fast crane operation proposed by Kuo and Kang [3]. Kuo and Kang's method contain three main stages: piecewise acceleration stage, constant speed stage and piecewise deceleration stage. With these three stages, we can maintain the sway angle and reduce the oscillation during the whole movement.

2 Methodology

The control method was introduced by Kuo and Kang [3]. This control method contains three-stage procedure shown in Figure 1.

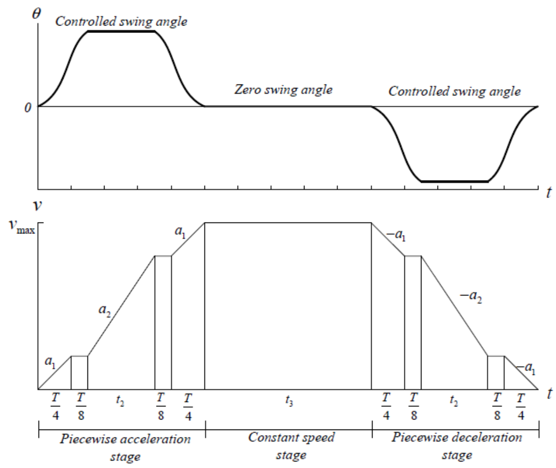

Figure 1. Schematic control diagram of sway angle (upper) and velocity (lower) as a function of operation time.

Piecewise acceleration stage including two acceleration a_1 and a_2 is operated by the following step and pendulum period $\mathrm{T} = 2\pi\sqrt{\frac{L}{g}}$.

Step1:

a_1 is an arbitrary value which is proportional to sway angle. We apply a_1 for $T/_4$ and then maintain constant speed $a_1 \cdot T/_4$ for $T/_8$. In step1, maximum height is reached at $3T/_8$.

Step2:

a_2 is determined by the relation of

$a_2 = g \cdot \tan(\sqrt{2} \cdot \tan^{-1}(^{a_1}/_g))$ and it is used to maintain a fix sway angle. a_2 is applied from $^{3T}/_8$ to $^{3T}/_8 + t_2$ and during this time, sway angle is fixed.

Step3:

In this step, constant speed $a_1 \cdot \mathrm{T}/4 + a_2 \cdot t_2$ will be applied for $^T/_8$ and then a_1 will be applied for $^T/_4$. During step 3, the sway angle will reverse back to zero.

Step4:

From time $^{3T}/_4 + t_2$ to $^{3T}/_4 + t_2 + t_3$, constant speed will be applied without sway angle.

Step5:

Piecewise deceleration stage, from 3T/4+$t_2 + t_3$ to the end, is a mirror image of Piecewise acceleration stage, namely, it is a combination of $-a_1$ and $-a_2$.

To transfer the control method into a practical test, we use an Arduinoboard uno as a microcontroller unit which can output the PWM (pulse width modulation) signal to control servo motor. We use the open-source Arduino environment to write code to output PWM signal range from $900\mu_s$ to $2100\mu_s$, such that $1500\mu_s$ requests 50% duty cycle and $2100\mu_s$ requests 100% duty cycle. So if we output $2100\mu_s$, the servo will spin at maximum speed which is 13.4rad/s and if we output $1500\mu_s$ servo will stop.

To manipulate the servo at the acceleration as the Figure 1, we change the angular speed every tiny unit time. For example, we need $a_1 = 0.8\ ^m/_{s^2}$ with a 1.15 meter rotation radius and it means we need angular acceleration $\alpha = {}^{0.8}/_{1.15}\ ^{rad}/_{s^2}$, so we increase $0.1^{rad}/_s$ per 0.026 second from $0^{rad}/_s$ to $1.925^{rad}/_s$. The following is the pseudo code of our control logic:

d← assign moving distance
L← assign length of rope
a_1← assign acceleration1
a_2← assign acceleration1,f(a_1)= $g \cdot \tan(\sqrt{2} \cdot \tan^{-1}(^{a_1}/_g))$
t_2 and t_3← adjust t_2 and t_3 to reach d
T← pendulum period, f(L)= $2\pi\sqrt{\frac{L}{g}}$.
N← gear ratio
R← rotation radium of jib
α_1←servo angular acceleration1, f(a_1,N,R)= a_1*N/R
α_2←servo angular acceleration2, f(a_2,N,R)= a_2*N/R
$\omega_0 = 0$←start angular speed=0
ω_1←first angular speed, f(α_1,T)= α_1*(T/4)
ω_2←second angular speed, f(α_2, t_2, ω_1)= ω_1+α_2*t_2
ω_3←third angular speed, f(α_1,T, ω_2)= ω_2+α_1*(T/4)
s_1← delaytime for angular speed to form α_1,
f(ω_1, ω_0,T)= (T/4) /(ω_1- ω_0)
s_2← delaytime for angular speed to form α_2,
f(ω_2, ω_1, t_2)= t_2/(ω_2- ω_1)
FOR ServoSpeed=ω_0
Servo rotate at rate of ServoSpeed for s_1/10 second
ServoSpeed +0.1
ENDFOR ServoSpeed =ω_1
Servo rotate at rate of ServoSpeed for T/8 second
FOR ServoSpeed =ω_1
Servo rotate at rate of ServoSpeed for s_2/10 second
ServoSpeed +0.1
ENDFOR ServoSpeed =ω_2
Servo rotate at rate of ServoSpeed for T/8 second
FOR ServoSpeed =ω_2
Servo rotate at rate of ServoSpeed for s_1/10 second
ServoSpeed +0.1
ENDFOR ServoSpeed =ω_3

Servo rotate at rate of ServoSpeed for t_3 second

FOR ServoSpeed =ω_3
Servo rotate at rate of ServoSpeed for s_1/10 second
ServoSpeed -0.1
ENDFOR ServoSpeed =ω_2
Servo rotate at rate of ServoSpeed for T/8 second
FOR ServoSpeed =ω_2
Servo rotate at rate of ServoSpeed for s_2/10 second
ServoSpeed -0.1
ENDFOR ServoSpeed =ω_1
Servo rotate at rate of ServoSpeed for T/8 second
FOR ServoSpeed =ω_1
Servo rotate at rate of ServoSpeed for s_1/10 second
ServoSpeed -0.1
ENDFOR ServoSpeed =ω_0

3 Implementation

The validation test is operated with a 1.7 meter height scaled tower crane. The tower crane consists of a base section and a 2 meter long jib driven by a high torque servo motor. First, we design the assembled scaled tower crane by Google Sketchup and then cut aluminium plate by OMAX water jet cutting machine to form each component of the tower crane. Figure 2 shows the process of assembling the scaled tower crane. After finishing cutting all unit parts, we assemble these parts into jib and base section. Finally, we connect the jib with servo and base section.

We use Arduino as a microcontroller unit to output the pulse width modulation signal controlling servo speed. We increase the speed linearly to create tangential acceleration.

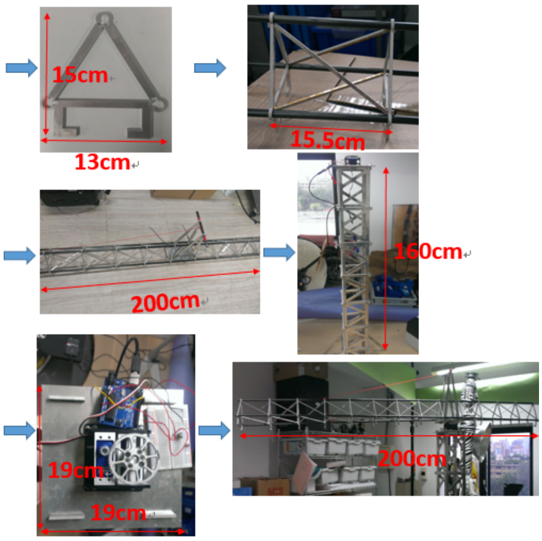

Figure 2. Scheme of the process of assembling scaled tower crane.

The experiment is operated with a 1.15 meter rotation radius and a 1 meter long cable which is used to hook an object. Additionally, we install a camera on the end of jib in order to observe and record the motion of the object during the experiment. The camera take pictures with 30 frame rate and the resolution of the camera is 544x960 pixels.

To analyze the motion of the hooked object effectively, we arrange a circle black cardboard above the object and several white paper on the ground which is in a sharp contrast to the circle black cardboard. After the experiment, we analyze the record videos by Opencv (Open Source Computer Vision Library) which was designed for computational efficiency and with a strong focus on real-time applications. First, we transform the experiment video into a sequence of photo. Second, we analyze the pixel of these photos. Each picture in the computer displays color by a combination of red, green and blue which have value from 0 to 255. If the value of red, green, blue of one pixel are all smaller than 60, we will define this pixel as a black point and record the position of this pixel. After collecting all position of the recorded pixels, we calculate their average position which will be regarded as the center of circle black cardboard. With this analysis procedure, we can precisely gain the object position and portrait the diagram of x component of position as a function of time.

4 Experiment Step

This validation test is divided into four parts, A-plan, B-plan, C-plan and Uncontrolled plan. A-plan contains all stages of the acceleration model including acceleration a_1, acceleration a_2 and constant velocity. B-plan only includes acceleration a_1 and constant velocity. C-plan only includes acceleration a_1 and acceleration a_2. Uncontrolled plan is operated purely at constant velocity. And three different plans are operated with the same moving distance.

Before the experiment, we have to assign a_1, t_2, t_3, distance, T and a_2. T is decided by the length of pendulum and a_2 is derived from relation $a_2 = g \cdot \tan(\sqrt{2} \cdot \tan^{-1}({a_1}/{g}))$. For A-plan, $a_1 = 0.8\ {m}/{s^2}$, T = 2 sec, distance = 3.5 m, a_2=1.13 $a_2 = 1.13\ {m}/{s^2}$, $t_2 = 0.5$ sec and in order to reach moving distance, $t_3 = 0.56$ sec is required. For B-plan, $a_1 = 0.8\ {m}/{s^2}$, T = 2 sec, distance = 3.5 m, $t_2 = 0$ and $t_3 = 2.875$ sec is required to reach moving distance. For C-plan, $a_1 = 0.8\ {m}/{s^2}$, T = 2 sec, distance = 3.5 m , $a_2 = 1.13\ {m}/{s^2}$, $t_3 = 0$ and $t_2 = 0.7$ is required to reach the moving distance.

Additionally, to further validate whether a_2 is effective to maintain the sway angle, we also focus on time from ${3T}/{8}$ to ${3T}/{8} + t_2$ and increase t_2 to 1.7 sec.

5 Result

We track and record the position of object by analyzing the video which is recorded by a top view. Figure 3 is the result shows the tangential sway angle θ of a function of time during the operation.

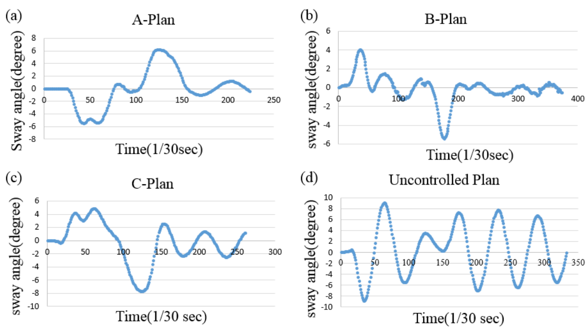

Figure 3. The experiment result of sway angle of a function of time for (a)A-Plan (b) B-Plan (c)C-Plan (d)Uncontrolled Plan.

Figure 3 apparently indicate the fast control, compared to uncontrolled Plan, is effective to control the sway angle during the operation as well as reduce oscillation at the end of operation. Also, the results are roughly corresponding to the proposed schematic diagram, despite some tiny vibration during the operation.

Among the three controlled plans, C-plan is the fast one to finish the operation, but it includes the most obvious vibration. Conversely, B-Plan is the slowest one but it includes least vibration at the end of the operation.

To validate whether a_2 is effective to maintain the sway angle, we focus on time from $^{3T}/_8$ to $^{3T}/_8 + t_2$ and $t_2 = 1.7\ sec$. Figure 4 shows the result of tangential sway angle during the operation. We find applying acceleration a_2 is effective to fix the sway angle. And there is some reasonable sway angle draft caused by radial acceleration. As Figure 5, due to the sway, the position of load object is slightly later than the position of camera, namely, the camera and the load object are not on the same position from top view. So when observing from the viewpoint of camera, radial acceleration will contribute to x component of the sway.

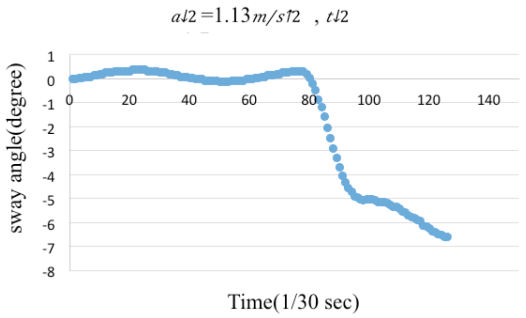

Figure 4. Result of sway angle of a function of time from $^{3T}/_8$ to $^{3T}/_8 + t_2$ with $a_2 = 1.13\ ^m/_{s^2}$, $t_2 = 1.7$ sec.

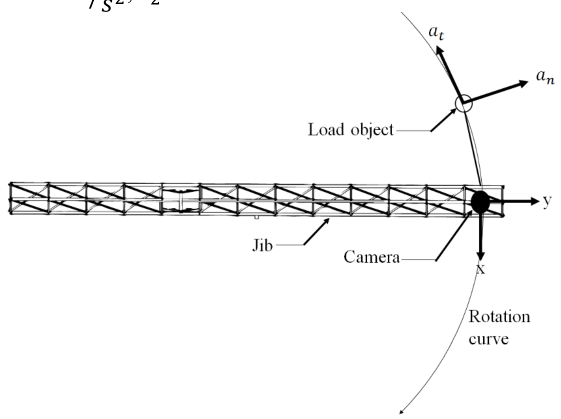

Figure 5. The relative position between object and camera. a_n: radial acceleration a_t: tangential acceleration.

6 Conclusion

Our research, based on the previously proposed fast control method, validates three control plans with our scaled tower crane. We input specific acceleration value to maintain the tangential sway into a fix angle during the movement and reduce the oscillation during and at the end of the movement. Our experiment result indicates the proposed fast control method will be effective to a real tower crane. But this method also contains some limitation. Although using specific acceleration can fix the tangential sway during the movement, radial acceleration still causes the radial sway.

References

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