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VISION BASED CONTROL OF GANTRY CRANE SYSTEM

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ABSTRACT

Heavy materials handling requires a sophisticated tool for efficient and optimum operations. In recent times, gantry cranes are considered as a dependable choice in terms of handling capacity, effectiveness, timeliness and safety. However, positioning of a trolley to the desired set point as fast as possible within minimum time without overshoot and payload induced oscillation have remained obstacles in crane dynamic control. Several control algorithms have been proposed, tested and implemented based on classical control. Recently, vision control has been introduced in the field of mechatronics as a bridging gap with little or no impact. In this paper, a vision based software control model is proposed such that webcam serves as a capturing sensor and the National Instrument LabVIEW is used as a programming tool for both image processing and crane control. Subsequently, the results of the proposed algorithm are experimentally validated by step increase in the trolley position. According to the results analysis, it is evident that the webcam performance is at an optimum level when compared with the installed sensor in positioning the trolley and minimizing the payload oscillation.

Keywords: Webcam, LabVIEW, Gantry crane, Vision control and algorithm

1. INTRODUCTION

A gantry crane system (GCS) is considered as one of the most crucial equipment in handling heavy load materials in industries because of the dominant advantages of high payload capacity, excellent flexible operation and time–saving capability. These had made it an indispensable tool in industries such as shipyards, manufacturing , automotive, construction sites, warehouses, steel mills, nuclear power, and waste storage services[1–3]. Recently, there is demand to improve productivity in cargo seaport due to large increase in volume of goods and heavy materials handling. Inherently, crane systems are under-actuated with a complex dynamics which are nonlinear [4]. Hence, the dynamics of the GCS is prone to disturbances such as wind, wave and environmental distortion when propel to motion. Some of these challenges are excessive load swing due to crane motion and difficulty in trolley positioning to the desired trajectory with a fast response time[5]. However, it takes an experienced operator to maneuver the uncontrollable swing of the load as the acceleration increases and to maintain safety of both cargo/payload and environment. Hence, it is imperative to automate the system such that exact trolley positioning is achieved and payload swing angle is minimized so as to transport the load in a minimum time to the desired destination with minimal swing. In many published works, several position and anti-swing control algorithms of gantry crane have been proposed and implemented. A model predictive control in [6]Fuzzy control in[7], combination of NCTF and Fuzzy logic control in [2], backstepping controller proposed in[8], linear quadratic regulator control in[9], PID controller in[10], bang-bang controller in[11], feedback and input shaping approach in[12], genetic algorithm technique in[13], wireless microelectromechanical system is proposed in[14] and Firefly Algorithm (FA) in[15]. In the work of[16], an optimal control scheme with LQR are implemented for prompt suppression of the load swing and accurate crane positioning in spite of large initial swing and collision. A performance analysis

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was performed between proposed optimal, linear quadratic regulator controls and conventional PD and PID controllers in the work of [9]. The authors concluded that stable control was achieved through optimal control despite of external disturbances. In addition, the problems of induced motion, induced oscillation and environmental disturbances were addressed with both feedback and input shaping controllers to minimize position error, reject induced oscillation and mitigate the disturbances[17]. The author in [18]compared four control algorithms based on simplicity, stability and robustness and found out that fuzzy controller outweighs others in terms of the stated characteristics. Recently, image processing is significantly gaining tremendous attention in the field of mechatronics, especially, in vision control. Remarkably, a template matching algorithms in [19]was developed for payload position measurement vision-based system, also, a camera was used in lieu of angle sensor in controlling crane angle in [20]. Hekman et al [21] employed the use of computer vision in measuring swing angle of the payload for switching operations of the motors. Crane obstacles detections and minimization through the use of vision system and image processing approach has be proven to be efficient and reliable for a standalone measurement of crane parameters [22]. Authors Lee *et al* [23] presented a vision-based approach to extract both trolley position and load swing information for effective tracking control of the crane.

The objectives of this research are to investigate the possibility of using a webcam as image capturing sensor and computer vision software to control the process of moving payload of a gantry crane.

2. MATERIAL AND METHOD

In gantry crane system, mounted position and angle sensors are commonly employed to track and detect the gantry crane system was built on the HAN University of Applied Sciences laboratory stand with physical model of an overhead crane. The measurement system is made up of incremental encoders that measure the positions and speeds of the crane's motion dynamics and a high resolution IP camera was installed under the trolley of a crane to capture the pair of images of a crane workspace as shown in Figure 1. An intelligent camera is incorporated into the trolley system configuration to detect the sway of a rope due to crane motion and the vision software (National Instrument image processing toolkit) allows to extract the itemized region of snapshot with full width resolution and part of height resolution to reduce the number of processing pixels in each recorded frame. The cameras are set to measure along x-y planes such that the payload sway angle of a rope information $\left(\theta_x, \theta_y\right)$is determined based on the rectangular coordinate of the images with isolated rope edge and the parallel line of the image height. The pair of images is acquired as the sequence of snapshots of functioning workspace during crane/trolley movement, while the current location of the camera is identified through measuring the crane or trolley position evaluated based on the trolley geometry in rectangular coordinate. This is obtained by locating the centroid of the trolley/payload such that the position coordinates is evaluated in x-y plane. Despite the fact that there are changes on the position of the trolley when subjected on motion, the centroid still remain on the trolley to ensure accurate position coordinates estimation. The algorithm for the gantry crane system consists of vision software, conversion process and the controller.

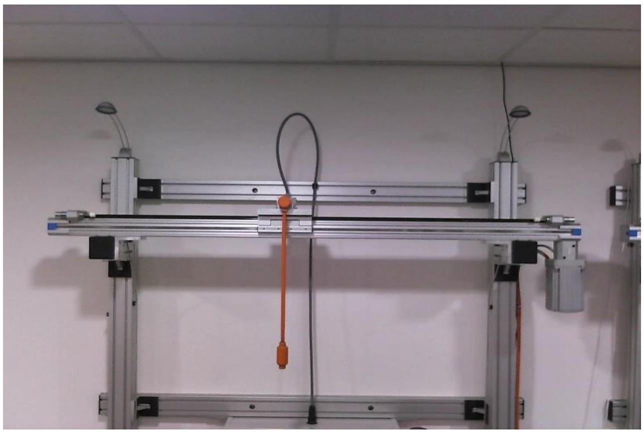

Figure 1: Webcam Gantry Crane image

2.1. VISION SOFTWARE AND CONVERSION PROCESS

The main task of the vision software is to locate and track the payload. In this paper the payload is represented by a colored bob as seen in Figure1.The first idea was to simply analyze each image to find all the corners and then figure out the payload and payload sway angle coordinates for effective gantry crane control. This section includes camera unit, edges/corners detection, color threshold/contracts setting, locating the centroid, filtering, smoothing and lookup table. The process begins by detecting the camera and then find some edges or corners by setting values of contract, filter width and sharpness so as to make the payload visible for positions and sway angles estimation as shown in Figure 2 and then used a smoothing local average filter for blurring and noise reduction. Contrast parameter specifies the threshold for the edge contrast and is the ability to resolve intensity difference. So, an obvious method is to choose a proper threshold to make the difference gray-scale image and background separated. Hence, this paper adopts automatic threshold segmentation function for processing. With the aids of LabVIEW National Instrument Vision Assistant , there were experimentally established the RGB optimum threshold levels for the studied crane object: $R = [124,127], R = [124,127], B = [3,90]$. Thus, the binary image in Figure 2 is obtained and to ensure high image resolution for further image processing of the payload , a wand extraction method that creates an image mask by extracting a region surrounding a reference pixel, using a tolerance of intensity variation based on this reference pixel (payload). Furthermore, the VI searches for its neighbors with an intensity that equals or falls within the tolerance value of the point of reference (payload). So, when click on the region of a gray-scale image after thresholding operation, the result is displayed in a binary image and shown the selected payload. More so, this paper adopts the IMAQ magic wand and VI to realize the payload (target) and background separation in the LabVIEW. The tolerance wiring terminal at the front panel interface can set difference pixel value. The pixel value (X) is obtained and a range of values centered around X with tolerance T (X-T, X+T) is selected. The tolerance is a user specified parameter. However, the tolerance is set-up to 20 and the extracted result is shown in figure2. However, if the tolerance is set more than 20, the extracted payload will appear background. After filtering process, the horizontal area of the cart is searched for a round object (payload) to obtain the axis of the payload/trolley and subsequently obtained the x and y position of the cart. This is further extracted and evaluated to obtain the position of the center of mass (centroid) of the payload as shown in Figure 4. The centroid axis position is further converted and implemented in the LabVIEW with the tangent function to determine the payload sway angles as shown in Figure 7.

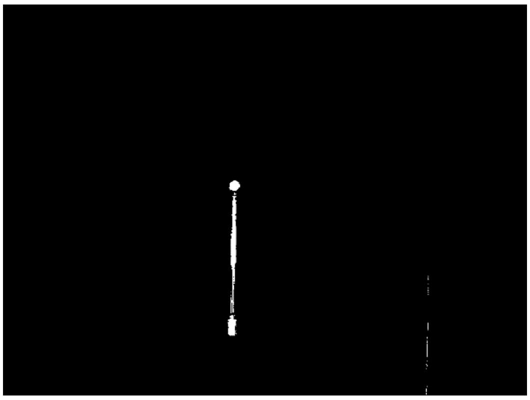

Figure 3. Effect of color threshold on the image

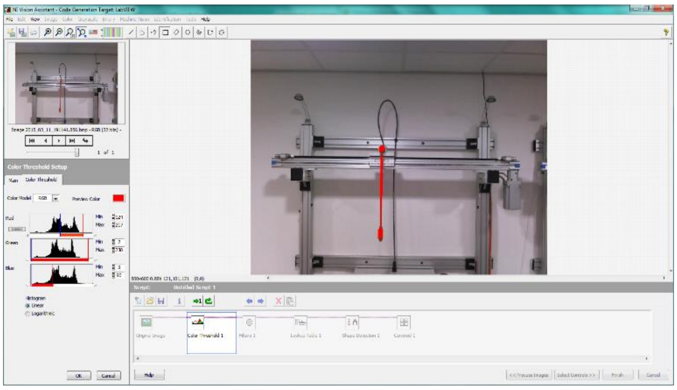

Figure 2. Color threshold setting of the image

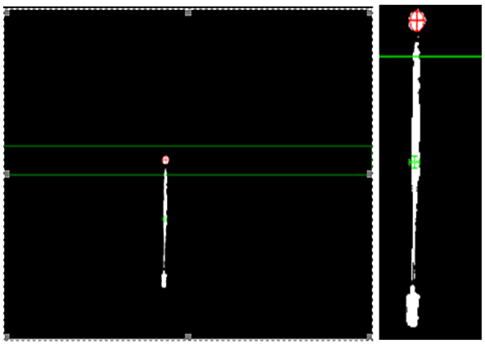

Figure 4. Centroid location of the image

2.1.1. CONTROLLER

Proportional Integral derivative (PID) controller is widely used in control and mechatronics applications due to its robustness, simplicity in control configuration and suitability for linear system. The control goals of the PID controller are for positioning control of trolley displacement and payload oscillation reduction. The PID controller algorithm combines the P-action, I-action and D-action to eliminate the process disturbance and model error such that a control signal $u(t)$ is based on the error discrepancy between the reference input signal and the output measure in conformity with generic time domain description of PD controller, given as:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_D \frac{de(t)}{dt}$$

Where u (t) is the control signal, the error signal e (t) is defined as e (t) = r (t)-y (t), and r (t) is the reference input signal. With an input voltage, two system responses namely trolley displacement, x and payload oscillation, $\boldsymbol{\theta}$ are studied.

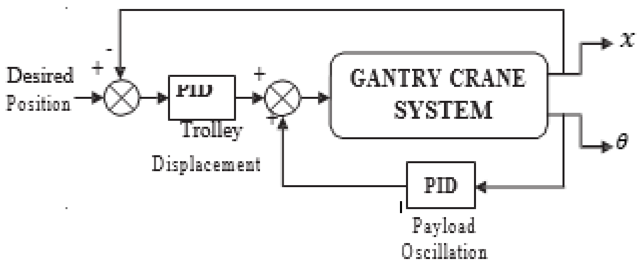

Figure 6. PID Control Structure for the Crane System

The tracking control law for the overhead gantry crane system based on PID law as depicted in Figure 6. The outer-loop PID controller allows the trolley to track the refernce while the inner-loop PID controller has the control goal of ensuring velocity stability and minimizing the force that causes the load swinging. The controllers design is further implemented in the LabView using NI vision image procesing toolkit. The overhead crane is a nonlinear system with uncertainty. The turning of control parameters is done using Ziegler-Nichols method method and the parameter values for the outer-loop PID and inner-loop PID are $K_{P_1} = 10, K_{i_1} = 0.3, K_{d_1} = 0.0012$ and $K_{P_2} = 10, K_{i_2} = -10, K_{d_1} = 0.1$ respectively.

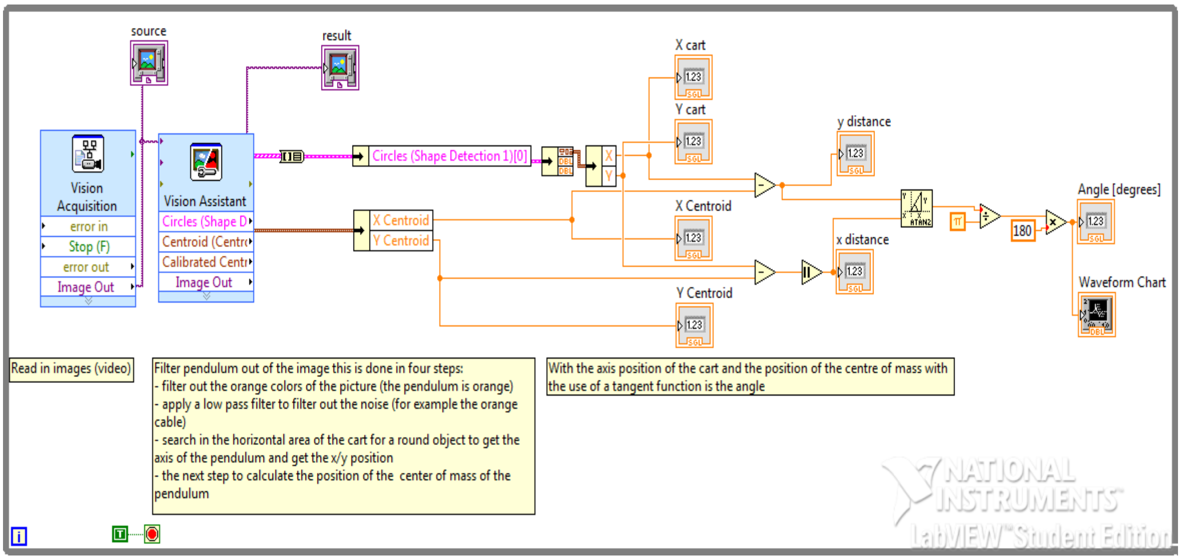

Figure 7. Implementation of angle and position coordinates in LabVIEW

NI vision image processing toolkit in the LabVIEW is utilized for angle and position control of the gantry crane. A proportional integral derivative controller is developed based on the crane dynamic model and real-time image data obtained from the cart and trolley position and angles. Figure 4 shows the LabVIEW vi implementation of the webcam angle. The controlling scheme is designed such that there is the possibility of switching between mounted sensor mode and webcam sensor mode and the positioning of cart could be achieved either with a slider or PID controller as shown in the control scheme and the front panel of the GUI in figure 8 and 9 respectively.

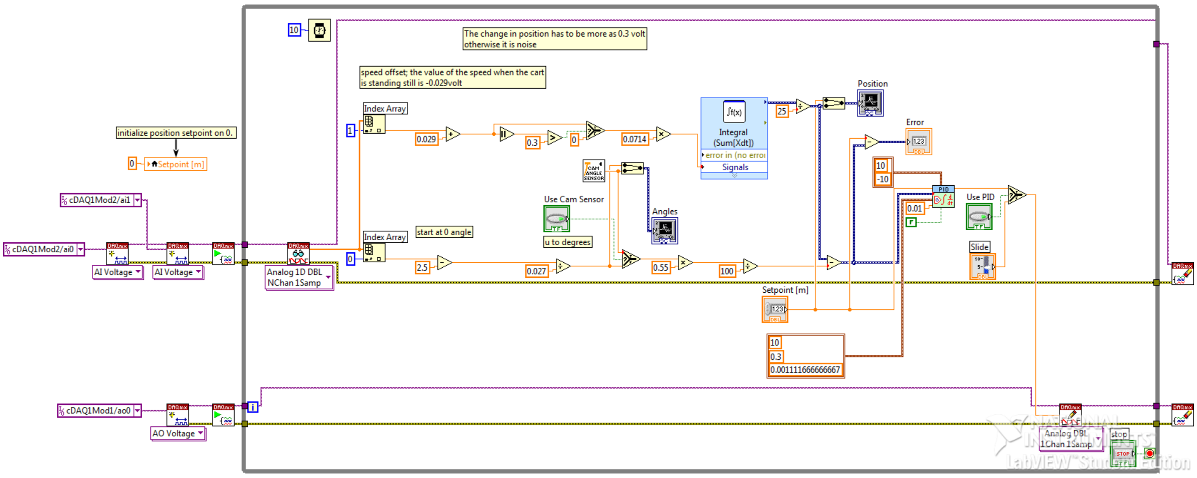

Figure 8. Block diagram control scheme

3 RESULTS AND DISCUSSION

In Figure 10 the validation of the implemented algorithm is tested without the proportional integral derivative action on the proposed webcam sensor and the mounted sensor of the crane system. It is observed from the same graph that, the measured angles of the both sensors are exactly the same over the same period of time expect that there is only a small phase shift of about 100millsecond in the webcam sensor and this is evident in figures 8 and 9. However, this indicated that for timeless capturing of images the webcam might not produce good result. Figure 12 and 13 show the trolley positioning and payload angle control with the blue line indicates the reference input and the red line as the position of the trolley. Similarly, Figure 14 and 15 represent the controller output of the trolley and payload angle with the same legend. Analytical comparison of figure 13,14,15 and 16 reveal that the response of the both sensors are well controlled to minimized the payload oscillation and which also ensure that the trolley position follow the input reference without overshot and within a short settling time. However, it is noted that the payload angle is a bit larger in webcam sensor than the mounted crane sensor in spite of this the positioning of the crane to the desired set point is the same in both sensors. Furthermore, the step responses of the webcam sensor and mounted sensor are step from 0.4m to 0.5m to ascertain the effectiveness of the controller on the designed algorithm. It is observed that in all cases of the incremental step, the system is stable without undue overshot and the settling time for 0.4m step increase in the webcam sensor is 3.7 second while that of the mounted sensor is 3.8 seconds. At the step increase of 0.5m, the settling time is 3.8 and 3.9 seconds for the webcam sensor and mounted sensor respectively. Despite the fact that there is delay in the angle estimation process implemented in the vision software, the system performance for both sensors remain the same. The novel vision approach proposed in this paper addressed the excessive load swing and difficulty in trolley position by designed a vision algorithm and control schemes that minimize the swing angle and stabilized the trolley position to the desired trajectory when subject to crane's motion. The simulation shows that the proposed vision based control scheme works very well in theory. The control signal is not too large and the angle is never greater than one degree. The simulation results revealed that the new scheme has the affinity to enhance the robustness, transients and steady performance than conventional method in the literatures.

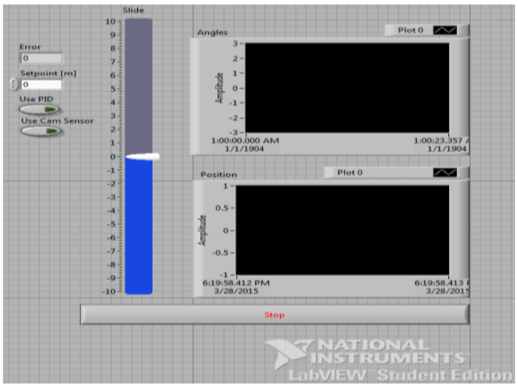

Figure 9. Front Panel of control GUI

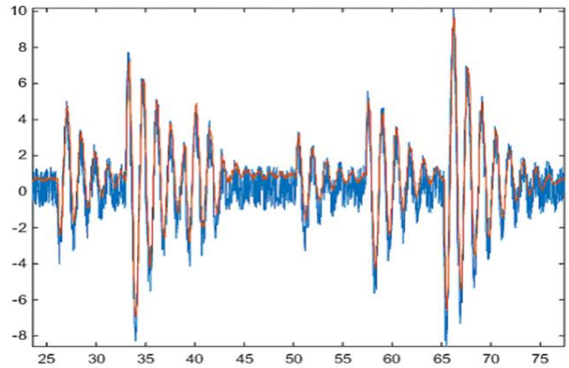

Figure 10. Validation of both mounted webcam sensors

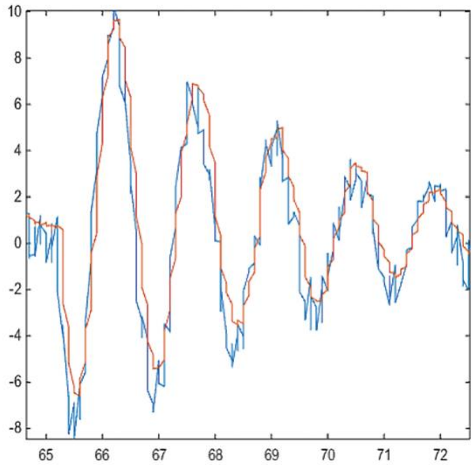

Figure 11. payload angle phase shifts of the sensors

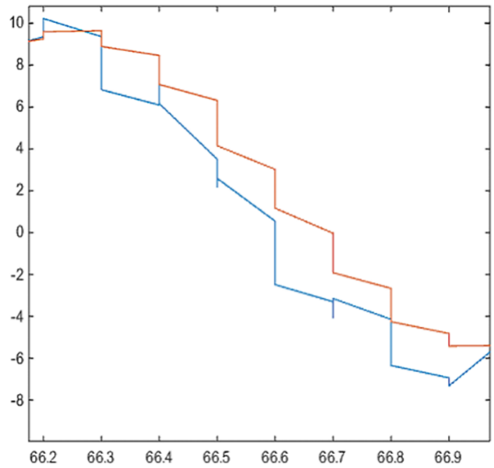

Figure 12. sensors phase shifts

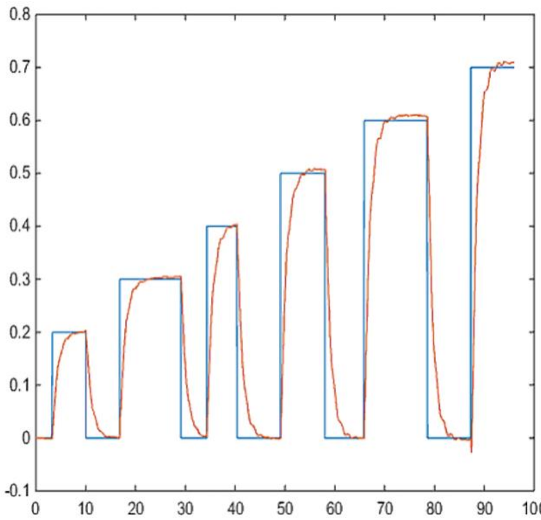

Figure 13. Trolley positioning Position Control with Mounted Sensor

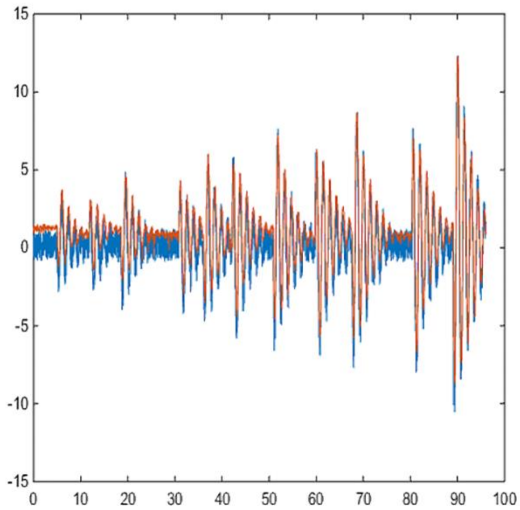

Figure 14: Swing angle Control with Mounted Sensor

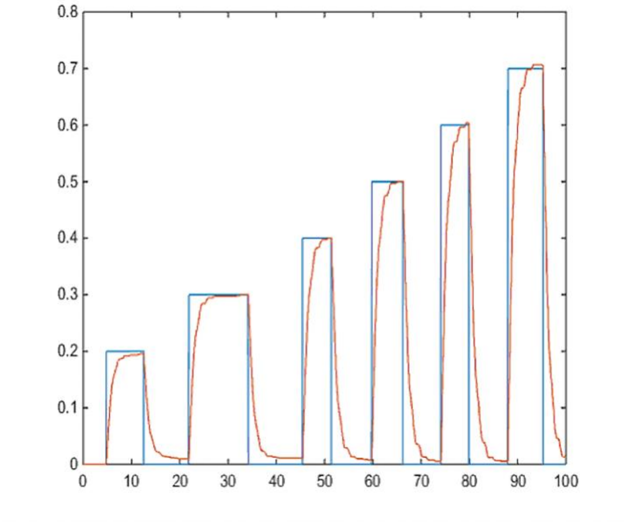

Figure 15. PID control of the trolley positioning with the webcam sensors

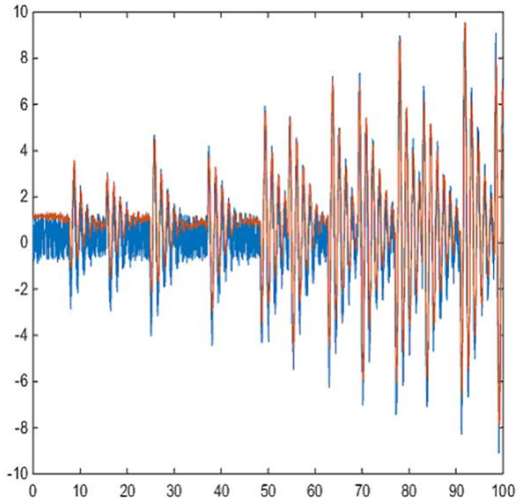

Figure 16. PID control of the mounted swing angle with webcam sensor

The following remarks can be made from the results:

i. The webcam angle estimation is quite robust.
ii. The discrepancies in angle estimation of the webcam sensor are compensated for by the controller action, so there are no differences in the step response of both mounted and mounted sensor when subjected to the same conditions.
iii. The use of filter would help in minimizing the computation error of the webcam sensor.
iv. It is evidence from the laboratory experimental set up that, the performance of the webcam as a sensor is affected by illumination.
v. Several lighting conditions posed serious challenges on the webcam performance, for instance, at low or high light intensities the angle of the webcam is not attainable. Hence, there is need to improvise for this shortfall in future research.
vi. As a result of the robustness of the proposed system, it is suitable for hands-on controlling of the gantry crane.

4 CONCLUSIONS

This paper present a novel vision based scheme of laboratory crane transporting disturbed-mass payload. The vision controller scheme eliminated the payload swing and trolley position instability through effective PID controller that compensated for process disturbances and twisting induced by human operator response. The proposed approach was experimentally validated and the performance of both webcam and mounted sensors was compared. Simulations and experiments were used to verify key dynamic behavior and the effectiveness of the proposed scheme. The simulation results show better performance over the existing methods in terms of robustness and performance. Hence, this relative performance investigation for the crane system substantiates that the proposed vision based control system approach is simple, effective and robust for hands-on controlling of the crane.

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