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EXPERIMENTAL DESIGN AND DEVELOPMENT OF HEAVE COMPENSATION SYSTEM FOR MARINE CRANE

Yougang Sun, Haiyan Qiang, Kerong Yang, Qinglan Chen, Guowen Dai* and Mian Dong

College of Logistic Engineering, Shanghai Maritime University, Shanghai, China.

Email: ygsun@shmtu.edu.cn

ABSTRACT

In order to analysis the performances of the marine crane and verify the stability of heave compensation control algorithm and examine the actual control effects, an experimental heave compensation system for marine crane had been built according to working principles and composition structure of real marine crane. This system is mainly composed of four parts which includes detecting system, driving system, control system and mechanical executive system. There are two control methods in the design of control system which includes DSP controller and MATLAB/Simulink platforms. The experimenters can pick up one of these controllers according to their demands. DSP controllers can also be used to the learning and development of embedded programming while MATLAB/Simulink platforms can be easily used to experimental tests with different control strategies. The common PID closed-loop control strategy, where the relative velocity between the cargo and the being supplied vessel can be got in the high frequency and low frequency sea conditions, is applied to this experimental system which verified the feasibility of this system effectively.

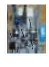
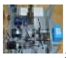
Keywords: Heave compensation, Marine crane, Designing and development of experiments.

1. INTRODUCTION

Marine crane is essential to Marine engineering equipment's [1]. In order to fully exploit the marine resources and obtain sustainable development of marine resource, we should ensure the safety of the working crane at sea. The working marine crane is affected by the wave load which would produce complicated nonlinear dynamic responses for the cargoes and cause accidents [2].For example, due to the wave (ups and downs), the cargoes would crash to the deck and cause safety accidents. Because of the complexity of the working environment, to achieve the safe and efficient control is faced with many difficulties. So, compensation of this kind of control system has become a focus of research. In recent years, many scholars put forward the concept of active heave compensation system [3, 4]. The heave compensation refers to the correction and compensation of the ship's fluctuation caused by the waves. Scholars have put forward various heave compensation control strategy, such as adaptive control, fuzzy PID and sliding-mode control and neural network [5-9]. But considering the nonlinear and coupling phenomenon existing in the actual system, the practical of these control strategies remain to be further tested. Experiment method has become indispensable tool in a system feature analysis, controller design and stability verification. Based on the above reasons, this paper designed and developed an experiment system of heave compensation system, which provides a great convenience for validation and implementation of the related control strategies. The system not only can simulate the real operation of crane system, and is very convenient for all kinds of test and adjustment of the algorithm. In order to verify the feasibility of the system, the basic PID control algorithm is applied to the system, and the experimental results are obtained.

2. BASIC PRINCIPLE OF THE HEAVE COMPENSATION SYSTEM

When marine crane operate with the marine environmental impact, waves, load, hanging system and the hull will produce coupling effect. Hanging system will occur nonlinear dynamic multi body motion. This non-linear dynamic response would pose a great threat to the safe operation. Especially in the heave direction, the collision of the downing object and the sudden rise of the deck tendered by the wave may result major accidents.

When study the so-called "automatic soft landing" controlling strategy (also known as the heave compensation), control the speed of lifting cargo in heave direction to make the speed of the goods relative to the supply ship be constant. Marine crane operate supply work on the sea. As shown in Figure1. The respectively speed of supply ship and the supply ship in heave diction should be  and , Hoists to the rate of decline of the global coordinate should be . Hoist speed with respect to the tendered should be , Rated speed of recharge should be .Crane relative speed with respect to the supply ship in heave direction should be .

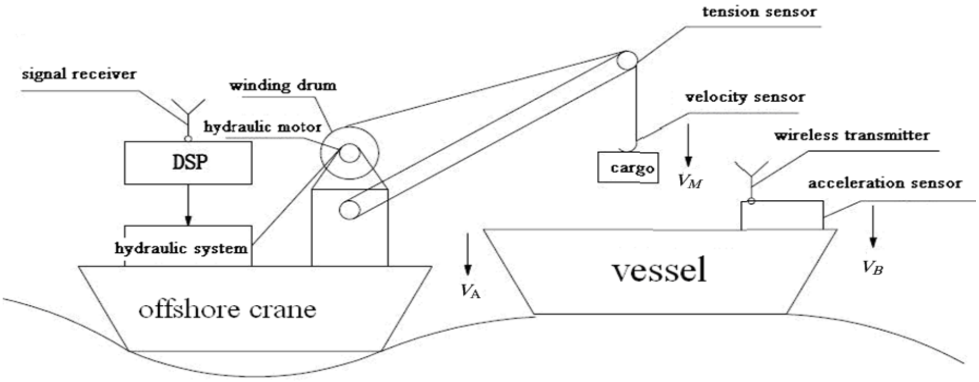


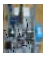
Figure 1. Heave compensation system

When there is no heave compensation:

 (1)

When a heave compensation exist, compensation objectives should be

 (2)

Setting compensation speed be , the speed of weight should be :

 (3)

 (4)

Comparative Formula (1) and (2), the relationship between the compensation speed and the movement of full should be

 (5)

Introduce the compensate speed  to make the speed of weight relative to the rate of decline tender has nothing to do with the relative motion of two ships that is , the weights can be put down by a crane on a steady supply ship to achieve heave compensation.

3. DESIGN AND IMPLEMENTATION OF HEAVE COMPENSATION EXPERIMENT SYSTEM

According to the actual principle and structure of active heave compensation system in ship cranes, heave compensation experimental system designed in this paper consists of detection systems, drive systems, control systems and mechanical systems, as shown in Figure 2. Where use DSP controller or MATLAB / Simulink software platform for control respectively in the control systems which have better flexibility and agility. DSP controller enables embedded development and be widely used in mature products. MATLAB / Simulink software platform can be easily carried out experiments to test various control strategies which are more suitable for use in the study.

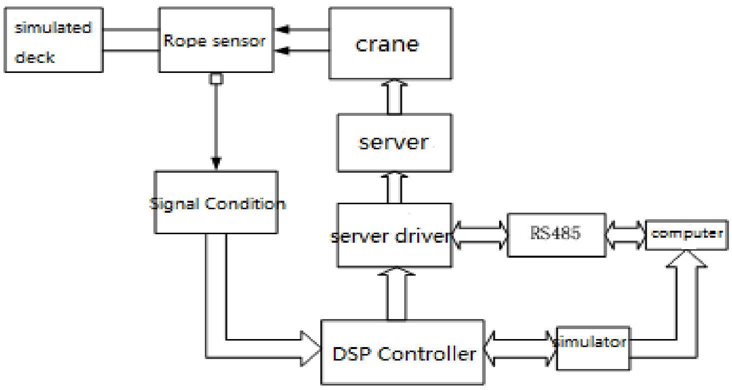
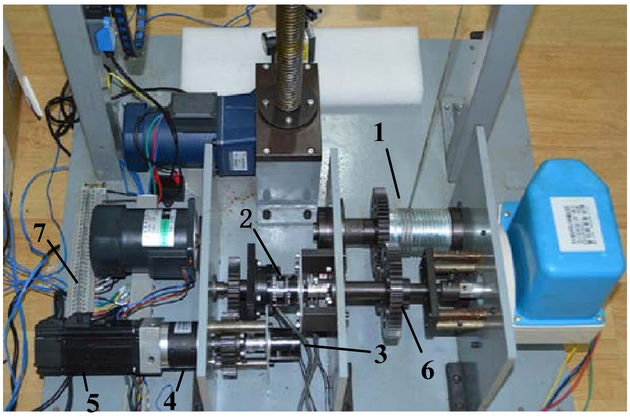


Figure 2. Experimental system composition diagram

The principle of system control experiments basic is: Equivalent relative motion of the tender and the supplied ship to the tender of the heave movement. Fixed one hand of the rope sensor on the hoist and the other hand to the analog supply ship deck motion together with board, real-time measure the hoist and the relative speed of tender. Interface into the control system by DSP internal quadrature pulse signal acquisition capture after sensor signal be processed by the signal conditioning circuit.DSP speed PWM output pulse signal as well as continue to collect the rope convert sensor signals into the relative velocity and compared with the target speed .Seek error rate and the error rate changes and then through the control algorithm to convert the output PWM Pulse speed signal. Passes control servo motor servo motor drive the next cycle reducer and gear train, driven reel close, put the rope to achieve control of the hoist.

3.1 Machinery and driving part

Mechanical main part is the skeleton of the entire experiment platform which implements the structural design based on the composition of the official marine crane, including reducer, gear train, rolls, pulleys, ropes and other lifting frame. Lifting device component, considering the relevant structure size, carrying capacity and connectivity requirements. Prototype mechanical system shown in Figure 3:



1. reel; 2 lost power brakes; 3 rotary encoder; 4. reducer; 5 servo motor; 6 gear train; 7 terminal block.

Figure 3. Mechanical transmission

3.2 Detection system

As shown in Figure 4, using motion sensors to detect the speed of incremental rope weights, with a resolution of 0.02mm / pulse, differential output to enhance anti-jamming capability. Since the switch signal quadrature signal and limit switch sensors for TTL level, while the DSP IO port can accept 3.3V COMS level signals, and therefore need to do their level conversion, the design uses 74LVC4245 completed three level road signal conversion, see Figure 5.

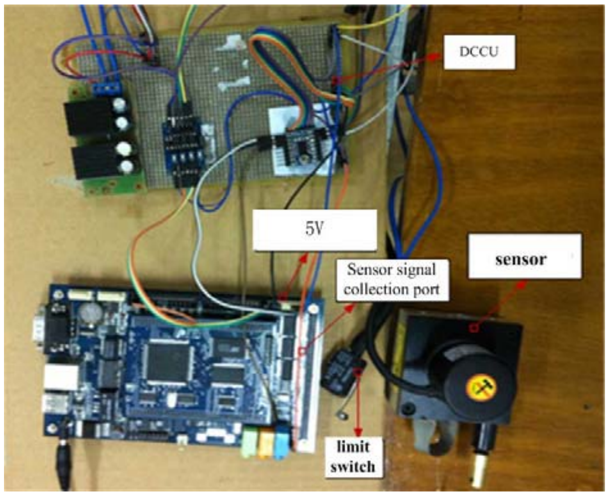


Figure 4. Sensor signal transfer

3.3 DSP and MATLAB/Simulink real-time control systems

(1) Real-time control system based on embedded DSP control system of a high capacity for data processing and real-time requirements, so the choice of DSP (TMS320F2812) as a core component to control. 5V power supply for the Sensor leads from the DSP development board. Motor during operation , will produce a series of interference , in particular interference signal produced by the sensor , will seriously affect the signal acquisition speed , resulting in speed feedback signal generating error or an error . To ensure the normal operation of the system, the need for servo motor and drive isolation.

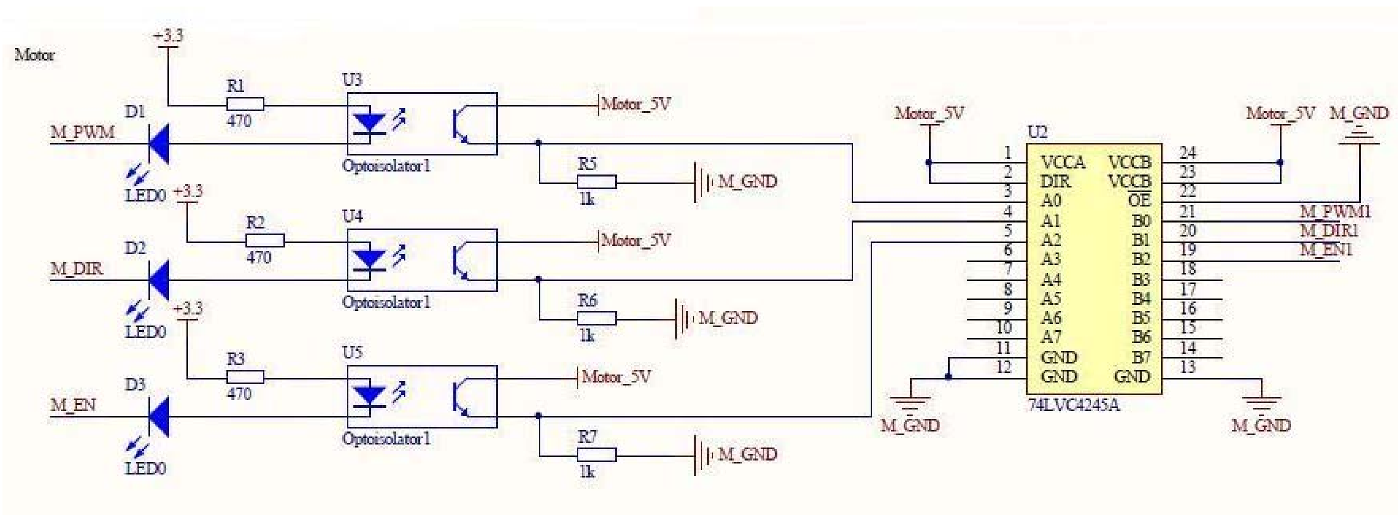


Figure 5. Optocoupler isolation signal circuit diagram

Design signal isolation and level shifting development board, in-kind shown in Figure 6

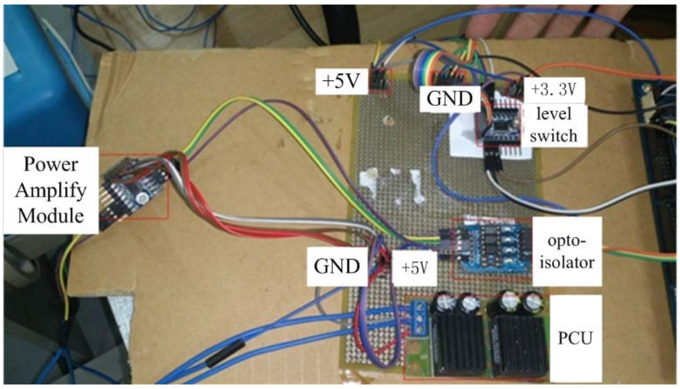


Figure 6. Conversion board development

(2) MATLAB/Simulink real-time control systems Taking into account the experimental system studied in this paper is mainly used to test advanced control methods , in order to facilitate the implementation and commissioning of the control algorithm , in addition to providing real-time environment based on MATLAB RTW , it has the following advantages: You can automatically generate high for different target platforms frequency of code; you can seamlessly with MATLAB and Simulink, and therefore can easily achieve a variety of control algorithms ; provides a shortcut to the application from design and direct way.

MATLAB RTW supports multiple target platforms, this paper choose Window platform for real-time control under Real-time Windows Target (RTWT). It requires only a PC, you can achieve real-time control system, control the minimum period of up to 1 ms. In addition to the PC MATLAB RTW mounted environment, the control system further comprises a data acquisition card, which is used to collect from the hoist and the relative speed of the supply ship signal transmitted to the PC, the PC sends the control command and the conversion into the corresponding the signal sent to the drive section.

4. EXPERIMENTAL RESULTS

In order to test the effectiveness of the heave compensation testing system mentioned in this paper, the usual PID control algorithms had been tested in this experiment system. The experimental results, theoretical analysis and simulation results had also been compared in this paper.

4.1 PID control algorithms

In an automation control system, PID, which is also known as Proportional Integral Differential, is a kind of normal control law in controllers. PID control is to constitute a control volume to control the controlled object through the linear combination of proportion, integral calculus and differential calculus of deviation.

The relation between output u(t) and input e(t) in the PID controller can be expressed as below.

$$u(t)=K_p\left[e(t)+\frac{1}{T_i}\int e(t)dt+T_d\frac{de(t)}{dt}\right] \tag{6}$$

Where k_p is the proportion factor, k_i is the integral time constant, k_d is the derivative time constant.

4.2 Control strategy

The main programs were written in DSP to control the system and to realize the functions of system initialization, control algorithm of computing, real-time monitoring ect. The timer interruption in DSP provided time flags to run the main program.

Figure 7 shows the workflow of this. The system began to initialize when it is powered up; then, in order to illustrate conveniently, adjust the position of the cargo; entered the circulatory system to discriminate whether to stop or put the cargo. If not, to read the parameters in sensors and to do preprocess to send the parameters into control algorithm.

The result would be used to control actuator which would adjust the motor speed and do loop until the cargo were put on the deck successfully.

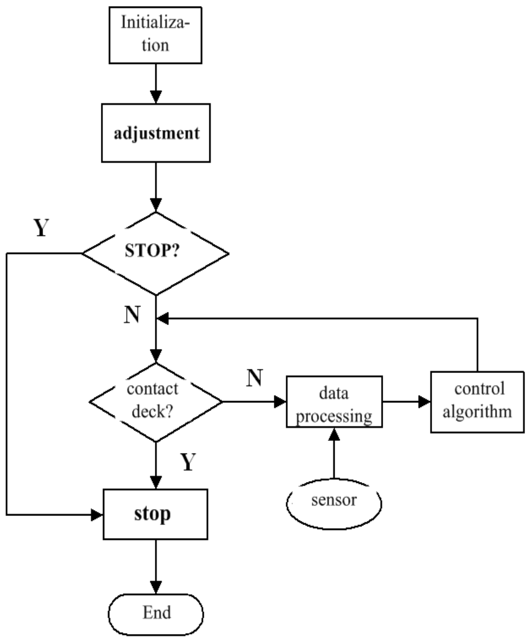
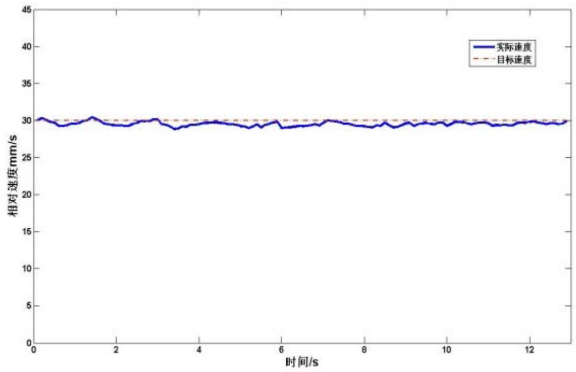


Figure 7. Workflow of control program

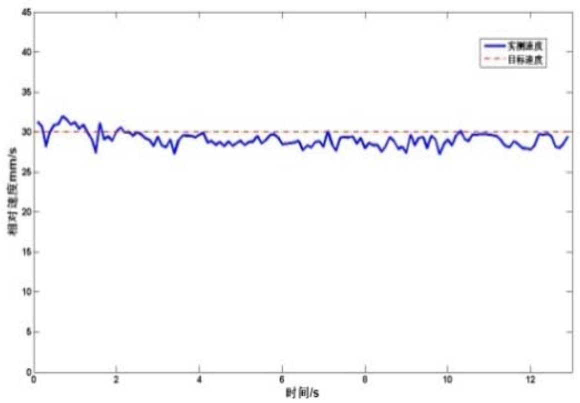
4.3 Record and analysis

The compensation velocity was set to be three centimeters per second. Different frequencies were set to simulate the motion of deck in the heave direction, low frequency was about to 0.1 hertz while high frequency was about to 1 hertz.

The object in this experiment was the relative velocity between the descending cargo and the deck.
The velocity curves which reflected the relative speed between the cargos and being supplied deck were drawn under different frequency disturbance according to a series of experimental data with cubic spline curve interpolation, which were shown in Figure 8.



(a) Velocity of cargos under low frequency



(b) Velocity of cargos under high frequency

Figure 8. Curve of experimental results

The experiment showed that the experimental system mentioned in this paper can test and analysis the related performance of the heave compensation system. The results of the experiment were roughly the same like the theoretical analysis and the results in reference 10 to 12, which proved the effectiveness of the heave compensation system designed in this paper. With the aid of other auxiliary means, this system can also simulate external disturbances like wind forces, collisions etc.

5. RESULTS

To do research on dynamic performances of the heave compensation system and verify the control effect of each control method, an experimental prototype of heave compensation system had been developed in this paper. The construction of this system is based on the actual heave compensation structure on offshore cranes which combined with detecting system, driving system, control system and mechanical executing system. It can response performance of the real heave compensation system accurately, and controllers can be divided into embedded real-time control system and real-time control system based on PC, which is convenient for product developing and experimental detecting for each control strategy based on Simulink platform. Finally, the conventional PID control strategy had been tested in this system. The experimental results were basically in line with the theoretical analysis in references which could confirm the validity of the heave compensation system experimental prototype designed in this paper. In the following research, a visual system may be installed as sensors to do further research on visual control.

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