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Intelligent Leveling Control Design of the Same Orientation Pursuit Strategy for Suspended Access Platform

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Abstract: A new intelligent levelling system was applied to the suspended access platform (SAP), and a Same Orientation Pursuit Strategy (SOPS) was designed to operate it. Based on SOPS matching test and using the concept of sliding mode control design and Lyapunov synthesis approach, we propose an adaptive fuzzy sliding mode control (AFSMC) scheme for the class of nonlinear systems. This system is proved to be the superior concept in a safer and more intelligent automatic control. Fuzzy controller (FC) and dual-axis inclination sensor are employed for the control system, which automatically changes the motion of lifting equipment according to the inclination of the platform, in order to eliminate the non-level quickly. FC is accepted by the AFSMC scheme. A gate network is used to address the fusion of two sensors' measurements and develops to recognize situation of level. Moreover, the FC with vibration avoidance is also researched in this paper. The system can achieve the synchronized drive accuracy of multi-point suspended platform. Furthermore, the influence of the disturbance signals and different protect time of eliminating flutter are evaluated in this paper.

Keywords: same orientation pursuit strategy, fuzzy sliding mode control, suspended access platform

1. Introduction

Suspended access platform (SAP) is a scaffold or a working platform suspended from a building or structure by means of lifting gear and capable of being raised or lowered by lifting equipment, including all lifting devices, lifting gears, counterweights, ballast, outriggers, other supports and the whole mechanical and electrical equipment required in connection with the operation and safety of such a scaffold or working platform. Because the features of SAP are operation simplicity and flexibility, easy shifting, convenience and practicability, safe and reliability, it is widely used in high-rise construction decoration, wall repairs or cleaning, and brings much benefit for the builders in the construction technology, quality and schedule.

With the rapid development of construction industry, in China, the height of buildings is increasing, as well as the diversity of shape, not only making construction more difficult, but also causing more security troubles. Every year, there are many falling accidents in the operation of SAP, thus intelligent control of SAP has a higher requirement [1].

SAP includes the suspended framework, suspended platform, hoist, safety lock, electric control boxes, working rope, safety rope, etc. There are many serious and fatal accidents caused by failure of suspended ropes or improper maintenance of mechanisms. The leveling is the major technical factor of SAP. Reducing the time of adjusting level effectively and improving accuracy are important issues for SAP [1].

With the development of automatic control and electronic technology, a variety of intelligent leveling technology have been developed, and the key of leveling control technology is the choice of leveling algorithms and the realization method of automatic leveling techniques[2, 3].

Algorithms in the area of intelligent control have the advantages of not requiring a model of the system. Examples include neural networks based control [4,5] and

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fuzzy control [6–8]. The advantages of fuzzy control include simplicity and intrinsic robustness since it is not affected by the plant model selection [9]. Many authors have proposed various control techniques for target tracking control problems, which consist of state feedback control, fuzzy logic control(FLC)[10], potential field[11], neural network[5], etc.

Fuzzy Sliding mode control (FSMC), also known as variable structure control, a well-applied technique for systems whose accurate mathematical models are difficult to obtain [12]. Fuzzy logic system (FLS) has found wide application in industrial and commercial practices for over several decades. One of the main features of FLS is that it can solve problems with the experience of human being for the plants which are difficult to model; it is particularly suitable for those systems with uncertain or complex dynamics.

In this paper, we examine the control strategy of an automatic levelling system in the multi-point drives SAP. This system uses the FC as the levelling control of electromechanical system, which has the advantages of fast response and high precision of levelling. At the same time, the stability of the system is considered in the system design process, and the vibration in the system will be effectively avoided. This system can perform the functions of real-time monitoring and timely adjustment for the suspension platform in the operation. The experiment results show that the proposed system has high test precision and reliability.

This paper is organized as follows. Section 2 addresses the principles of control, and the hardware architecture of the intelligent levelling system. In Section 3, we introduce the configuration of control system firstly, and then design FSMC-based fuzzy target tracking control (FTTC) schemes and the SOPS; then we propose a intelligent leveling system (ILS) which comprises a gate network for combining all the information of the levelling sensor. Experiment results are given to verify the effectiveness of the proposed control strategy in Section 4; Section 5 concludes this paper.

2. Problem statements

2.1 The same orientation pursuit strategy (SOPS)

The levelling is coinciding suspended platform with the horizontal plane [13]. Currently, suspended platforms have two-point drives, three-point drives, and four-point drives and so on. The SAP with two-point drives is easy to implement, and easy to level, the drawback is a large levelling error. Four-point suspension enhances the reliability of the SAP, but there is a series of statically indeterminate structure issues, and the internal force will be changed with the translation of the supports, easily producing a "hanging" suspended point. Considering these factors, three-point drives platform as an automatic levelling system example of the multi-point lifting suspended platform is studied. The application of the multi-point drives

Figure 1 The application of the multi-point drives SAP

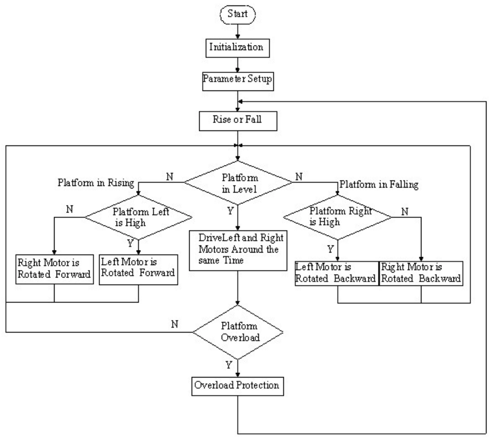

Figure 2 Schematic of control strategy of the multi-point drives SAP

SAP is shown as Fig. 1. From this figure, we can see the cirque shape SAP with four-point drives. According to the theory of "Three points determine a plane", it is used, in this study, the leveling method to the same orientation pursuit [13].

When the platform is raised and has got access to the leveling operation, the highest hoist of the platform is fixed; the followed hoists need to coincide with it by continually rising. Similar to rising, when the platform is lowering and has got access to the leveling operation, the lowest hoist of the platform is fixed; the followed hoists need coincide with it by continued lowering. An overall schematic of control strategy is shown in Fig. 2. The application of the SOPS in the automatic leveling control system greatly improves measurement accuracy.

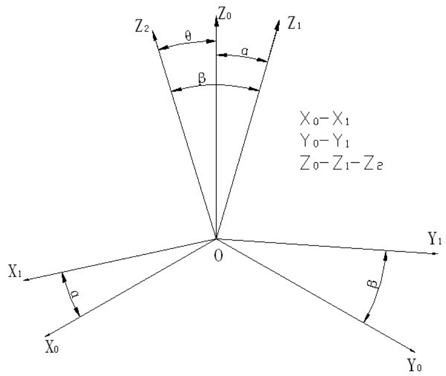

Figure 3 Rotating of a certain three-dimensional coordinate the three-dimensional coordinate axis

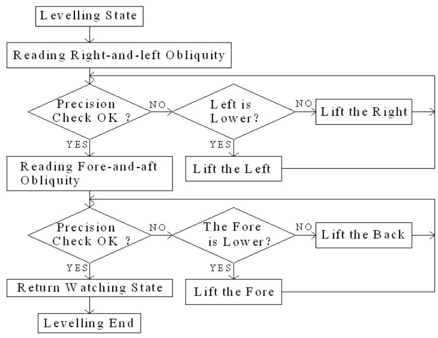

Figure 4 Communication flow chart of levelling control, this shows the flow chart of the implementation for PLC levelling algorithm

2.2. The inclinations of sensor and SAP

General biaxial inclination sensors with the two-axis for 90, keep the two-axle inclination sensors measuring the direction same as x-axis and y-axis, so the angle for x-axis and y-axis can be measured. If the control accuracy is $\pm\delta^{\circ}$ in the x-axis and y-axis direction, the overall accuracy error of the platform is $\eta = \delta^{1/2}$. The error relates with the angle of the two axis of the biaxial inclination sensor. When the angle is 60,$\eta = 2\delta$.

Fig. 3 is the three-dimensional coordinate axis x, y, z, and the subscript values of an axis coordinates of the standard base-level state is zero. In case that the measurement angle of the sensor on the x-axis is α, the measurement angle on the y-axis is β and the angle between the platform and base-level plane is θ, the following analysis is the relationship between them: when x_0-axis and z_0-axis deflection angle α formation x_1 and $z_1$around y_0. Then, y_0-axis and z_1-axis rotate rotation angle of β formation newly z_2-axis and y_1-axis around x_1-axis. This moment the angle between the z_2 and z_0 is the angle θ between the platform and base-level plane. Here θ is $\sqrt{(\alpha^2+\beta^2)}$ [13]. At the same time, the precision of biaxial inclination sensors has a direct relationship with the position the sensor installed in the platform. In order to avoid large computational error, the sensor needs to be installed in the location equidistant from the hoists[14].

2.3. System description

According to the principle of leveling, the measurement inclination sensors for the system, an important component, should be installed in the middle of the bottom of the suspended platform to close the center of the gravity of the platform as much as possible. During the operation, angle signals α and β will be input to the controller from the sensor. As the core of controller equipments, controller mainly performs functions of signal acquisition, data processing, and signal output and so on. The Fig.4 shows the flow chart of the implementation of controller leveling algorithm. For the platform of multi-point drives, three or four points often were used. Most of platform's leveling algorithm needs to coincide with the three-point algorithm, so a suspended platform with multi hoists is studied in this paper, as shown in Fig.1. The hoists of platform are marked with the label A,B,C. In the flow chart, A and B will be set to the front group, C will be set to the back group, A and C will be set to the left group, B will be set to the right group. A uniaxial adjustment procedure is employed as follows:

First, x-axis is leveled accordance to the angle α (left and right direction);

Then y-axis is leveled accordance to the angle β of the (before and after direction).x, y, z, the subscript values of an axis coordinates of the standard base-level state is 0.

In the adjustment process of the uniaxial method, adopting the leveling strategy keeps the same direction with working direction of platform.

Specific operations lie as follows: if the data from the sensor shows that the platform is not leveled to the requirements of accuracy, it should be judged that the higher side between A-C side and B side in the lifting group of the x-axis direction according to the data from the sensor. Stopping signal of pulse is imputed to the hoist in order to make platform is leveled to the requirements of accuracy in the x-axis direction. After the requirement of precision is satisfied in x-axis direction, it should be judged the higher side in the y-axis direction. Similarly, stopping signal of pulse is imputed to the hoist in order to make platform is leveled to the requirements of accuracy in the y-axis direction, thus, end a leveling process. When the platform is in the process of declining, the controller stops the lower point and then the hoist of higher points continues declining along with working direction. The shortcoming of this way is taking a long time for leveling; and the advantages are excellent coordination and stability.

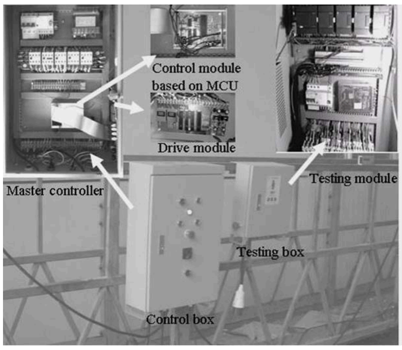

Figure 5 Structure figure of the control box equipped FC module (Up section of the picture is the system of FC and down section is the Platform)

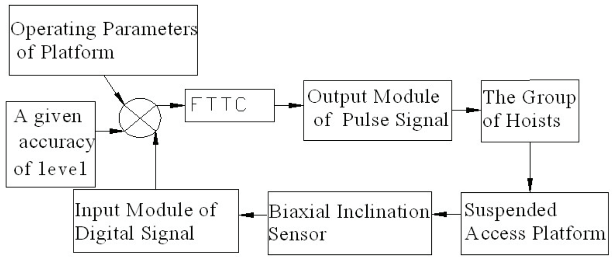

Figure 6 Block diagram of the entire system

3. Control design and Rule mapping

3.1. Schematic of measurement sensors

The measurement sensors uses biaxial inclination SCA 100T sensor which produced by the Finnish company and its working principle is to measure the weight of acceleration of gravity. Maximum output range is $\pm 40°$of each axis, and the effective output range is $\pm 30°$. Structure figure of the control box equipped FC module is shown in Fig. 5. Up section of the picture is the system of FC and down section is the Platform. Block diagram of the entire system is showed in Fig. 6. From the block diagram, it can be seen that the system is a negative feedback control system and the controller deal with the feedback signal of the sensor. A certain range error is allowed by leveling system in order to reduce the operation times of leveling. The drive precision of the working platform, it is assumed that, is less than $\pm 2°$. That is, the accuracy of x-axis and y-axis are $\pm 1.41°(\pm 2° \times \sqrt{2})$, respectively. At this time the upgrade point appearing moving distance is height $\times \tan 1.41$, If the length between two points of hoists is 7.5m, the height is about 0.18m.

3.2. FC based FTTC

The main goal of the FC is to make leveling of suspended access platform. The parameters used to construct the FC are shown in Fig. 6, where O are the position of the center of the platform, α is its orientation angle corresponding to the x-axis, β is its orientation angle corresponding to the y-axis, and υ is its orientation angle corresponding to the z-axis. The adjustment angle of control is ϕ . For speed and adjustment angle controls, two two-input-single-output FCs are adopted respectively.

Let the input variables of the FC be defined as:

$$e(k) = d_{hope} + d_{act}(k) \tag{1}$$

$$\Delta e(k) = \Delta e(k) - \Delta e(k-1) \tag{2}$$

$$\varphi(k) = \alpha(k) \cdot \beta(k) \cdot \theta(k) \tag{3}$$

$$\Delta\varphi(k) = \varphi(k) - \varphi(k-1) \tag{4}$$

where d_{hope} is the desired adjustment distance of the leveling side of platform. We want to design the FC for the suspended access platform such that it can pursue the level within a constant distance. The fuzzy control rules can be represented as a mapping from input linguistic variables $e, \Delta e, \varphi$ and $\Delta\varphi$ to output linguistic variables n as follows:

$$n(k+1) = FC(e(k), \Delta e(k), \varphi(k), \Delta\varphi(k)) \tag{5}$$

where n is the number of pulse, such control information transfer to the group of hoists continually [13]. Because pulse n and speed υ of the hoists can be driven individually, thus we decompose $n(k+1) = FC(e(k), \Delta e(k), \varphi(k), \Delta\varphi(k))$ into the following equations:

$$n(k+1) = FC(e(k), \Delta e(k)) \tag{6}$$

$$\upsilon(k+1) = FC(\varphi(k), \Delta\varphi(k)) \tag{7}$$

The membership functions of input linguistic variables e, Δe, φ and $\Delta\varphi$ and the membership functions of output linguistic variables n and υ are shown in Fig. 7, respectively.

They all are decomposed into seven fuzzy partitions, such as: negative big (NB), negative medium (NM), negative small (NS), zero (ZE), and positive small (PS), positive medium (PM), and positive big (PB).

Since each input is divided into seven fuzzy sets, 49 fuzzy rules for speed control and leveling angle control must be determined, respectively. Following the FSMC concept, a diagonal type rule table is adopted and tabulated in Table I.(in the table, Case 1: $u = v, p = e, \Delta p = \Delta e$; FC for v. Case 2: $u = n, p = \varphi, \Delta p = \Delta\varphi$; FC for υ) The FSMC provides control action to drive state trajectories toward a sliding surface (in fact, the sliding line in this application) in the state-space, and to maintain the state trajectories sliding on the sliding surface until stable equilibrium state is reached. In this paper, we first have to choose the sliding surface that represents the control purpose. The sliding surfaces for speed control and steering angle control are defined as $s = e + \Delta e$ and $s = \theta + \Delta\theta$, respectively.

For example, in the beginning, the tracker is fixed and far away from the target, that is, e is NB and $\Delta e$is ZE; we have to speed up the tracker to decrease e and increase C. In this case,$s = e + \Delta e < 0$, we give a positive action. On

Table 1 Rule Table of the FSMC

$p,\varphi,\Delta p$	**NB**	**NM**	**NS**	**ZE**	**PS**	**PB**	**PB**
PB	ZE	NS	NM	NB	NB	NB	NB
PM	PS	ZE	NS	NM	NB	NB	NB
PS	PM	PS	ZE	NS	NM	NB	NB
ZE	PB	PM	PS	ZE	NS	NM	NB
NS	PB	PB	PM	PS	ZE	NS	NM
NM	PB	PB	PB	PM	PS	ZE	NS
NB	PB	PB	PB	PB	PM	PS	ZE

the other hand, suppose e is PB and is ZE, which presents the tracker is very close to the target, we must back the tracker in full speed in order not to crash into the target. In this case, $s = e + \Delta e > 0$ a negative speed command is given.

Now, suppose $s = 0$, for instance, e is NS and Δe is PS, which denotes the tracker nears the target and distance between them is in reducing, we can set $\upsilon = 0$. Similar υ can be determined when the pair $(e, \Delta e)$ are (PM, NM), (PS, NS), (NB, PB) and so on. We can conclude that if $e + \Delta e$ is close to the sliding line, the control action is smaller than those are far from the line. Thus, the rule table for the speed control can be deduced and summarized in Table 1 (Case 1). Similarly, for the derivation of υ can be interpreted as follows. For $s = \varphi + \Delta\varphi = 0$ and suppose φ is PB and $\Delta\varphi$ is NB, which indicates the difference of orientation angle and speed are very large but the motors are turning to the level adjustment with all its capability, we let $v = 0$ in order to maintain the sliding line equals zero. If $(\varphi, \Delta\varphi)$ are in the states of (PM, NM), (PS, NS), (NB, PB) and so on, then υ can be determined in the same way. For $s < 0$, this situation implies that the tracker is in left-hand side of the target mobile robot and evades the target, the tracker should turn right (i.e., $\upsilon > 0$) to line up with the target. For $s > 0$, we can know that υ must be negative, i.e., the tracker should turn left. We can infer that the control action is smaller than those are far from the sliding line $\theta + \Delta\theta = 0$. The idea of the steering angle control is the same as that of the speed control and the rule table for the steering angle control is also listed in Table 1 (Case 2).

The defuzzification strategy way is implemented by the weighted average method.

$$u_{crisp} = \sum_{j=1}^{49} \mu_j(u_j).u_j / \sum_{j=1}^{49} \mu_j(u_j) \quad (8)$$

where u_{crisp} may be the speed or steering angle command of the tracker mobile robot, u_j is the support of each fuzzy set j , and $\mu_j(u_j)$ is the membership function value of each rule.

3.3. Design of the fuzzy control unit

For design of control systems, it is required to obtain the dynamic data of leveling device. The controller is an effective form to solve problems about manual control's

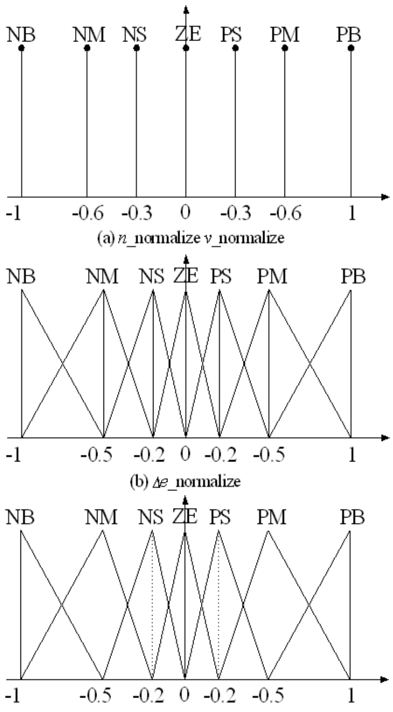

Figure 7 (a) Membership functions of n and υ.(b) Membership function of Δe (c) Membership function of $\Delta\varphi$

inaccuracy and uncertain nonlinear factors of the control process. The control system achieves the automatic start; stops, coordination works with manual control, and realize the synchronization of multi-point control. Because the demand of the multi-point leveling control strategy is high, during the workers walking on platform for operation, it up and down will generate disturbance to the controller, and the mechanical drive transmission using the friction way can form a serious non-linear characteristics of uncertainties, make traditional PID controller cannot achieve control of the dynamic and static factors in the inhibition of various non-linear.

As the leveling system will be able to process the read mathematical signal, the following part can be used to express the process.

Using a supposing inclination sensor, the angle value α is obtained by level signal measuring from the sensor, l_{AB} is the adjusting distance between the A hoist and B hoist, the height of adjustable hoist you need to adjust is:

$$h = 2l_{AB} \sin\frac{\alpha}{2} \quad (9)$$

If the average speeds $(\bar{v})$ of the hoist and the pulse clock (ε) of FC are known, the adjusting pulses (n) that leveling system which reflects to the x-axis can be calculated as follows:

$$n = h\frac{\varepsilon}{\bar{v}} \quad (10)$$

According to the angle signal returned from the inclination sensor, the control system can adjust the level of the platform using the pulse signal .The specific form of working lists as follows:

$$p(k) = [p(k+1)p(k+2)\cdots p(k+n)] \tag{11}$$

where n is the number of pulse, such control information transfer to the group of hoists continually. The common algorithm used to control the constant level degree of the platform is the classical intelligent controller of control system. The setting value is 0 degree and the input is the practicable angle. The simplified discrete incremental PI controller is used in this paper.

$$Deltau = u_i - u_{i-1} = K_p(e_i - e_{i-1}) - K_1 e_i \tag{12}$$

In practice, it is proved that this controller can eliminate the oscillation in the control procedure basically and obtain the constant level degree, but the control difficulty increases because there are so many indeterminate disturbances in the control process and the variability of the platform operated. This system adopts the FLC to overcome the upward questions. Its merits are not depending on the object model, the dynamic performance is good and it settles the effect by the indeterminate disturbance in the leveling procedure.

In order to obtain a statistically significant sample of data, at least five samples are selected. If the sampling period is 50ms and 5 samples requires 2.5 seconds, this value of the time lag operator queue improves the control system stability effectively. Before the completion of adjustment, the system is in a wait state, so that treatment can better initialize the controller results.

According to the control theory, a certain degree of the cycle of the empty sampling is designed for this controller. After empty sampling period, system will input the step signals by control pulse. When the changing of output makes the process variable to the area of set value, the system will enter the error-handling to initialize.

4. Experiment and discussion

In the three-point-driven U shape platform, the leveling system has been installed, in order to carry out testing in the laboratory. Fig. 5 is the structure figure of the control box equipped FC module in the laboratory. Section of the picture is the system of FC and down section is the Platform. The effect of the leveling angle and vibration during leveling between manual and automatic is compared, and the data is obtained by VB 6.0 software.

On the U shape platform, a leveling test of manual and automatic-type will be conducted to achieve the ideal pattern. Its design parameters are as follows: weight of 650Kg, width of 0.69m, rated load of 500Kg, and length of double side of 3m, length of unilateral side of 3.5m. The test data of manual pattern contrast with other automatic pattern also revealed dip angle of platform in the

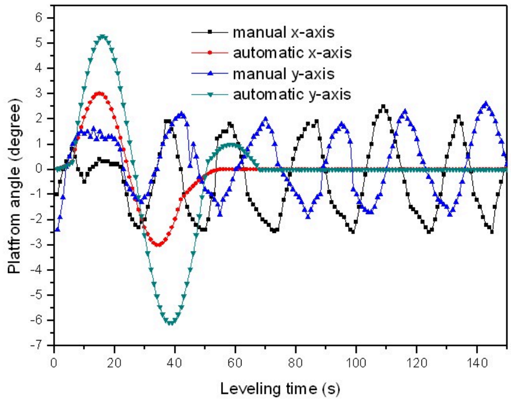

Figure 8 The levelling degree of the upward platform of manual adjustment and automatic adjustment

experiment research. Also, vibrate test was accomplish in leveling process.

Test results through tracing point disposal are as shown in Fig. 8-11. Fig. 8 demonstrates the leveling curve of platform in its upward process both manual and automatic. Fig. 9 presents the leveling curve of platform in its downward process including manual and automatic.

Fig.8 describes data obtained by adjusting the x-axis and y-axis of upward platform leveling for 150 times by modes of manual adjusting and automatic adjusting, respectively.

From Fig. 8, it can be seen obviously that the curve of automatic adjustment is smoother than the curve of manual adjustment, because operation factors were ignored in automatic control. Besides, x-axis adjusted is mare accuracy than y-axis adjusted in the process of automatic control when the platform is lifted. By contrast, the differences of data of x-axis and y-axis are not distinct in the manual control mode. In addition, the maximum angle appears in the y-axis direction by the automatic leveling.

Fig. 9 reveals that there are more errors caused by y-axis adjusting than x-axis adjusting in automatic leveling process, which partly due to the sequence of the automatic adjustment of x-axis and y-axis.

The automatic adjustment lasted for 60~70 seconds. Its value is almost zero degree, which shows that automatic leveling system is superior to manual adjustment system. Above tests indicated the automatic leveling system can increase its security, however whether this system can reduce vibration of the adjustment leveling process, it will be verified in the next test.

In the course of the adjustment leveling, vibration test of suspended access platform with the application of acceleration sensor, the signal amplification and vibration test software has been done in entire 20 minutes. It is obtained that the x-axis vibration curve (Fig. 10) and y-axis vibration curve (Fig. 11) through processing of the data. The

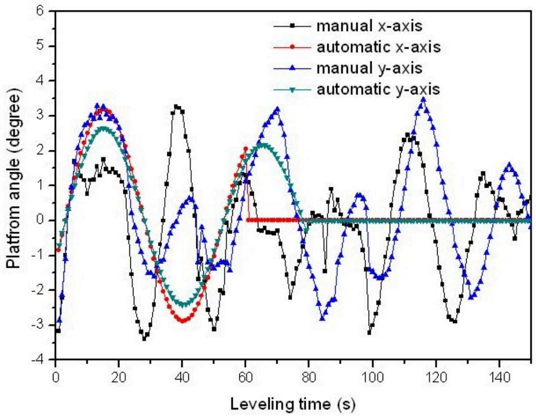

Figure 9 The leveling degree of the downward platform

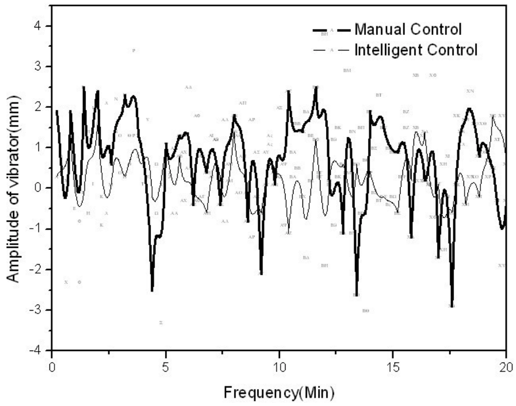

Figure 10 The Vibration curve of the platform working in the x-axis direction

following is the analysis of the vibration of the suspended access platform when it is in a leveling configuration by manual and automatic. Two problems are observed from the x-axis vibration curve (Fig. 10) and y-axis vibration curve (Fig. 11). The first problem is the y-axis vibration curve which is smoother than the curve of y-axis vibration curve. This is mainly because the process of leveling begins from the x-axis direction, and then from the direction of y-axis. It is stop action of adjustment program that increases the vibration of x-axis direction, and the impact is not significant. The second, from the vibration curve can also be seen, intelligent leveling is far superior to the leveling of manual adjustment mode. The vibration amplitude of automatic leveling is very small, fully satisfying the stable operation of platforms. It also confirmed that the system can achieve the synchronized drive accuracy of multi-point suspended platform, and adjusting time of system is about 60∼70 seconds.

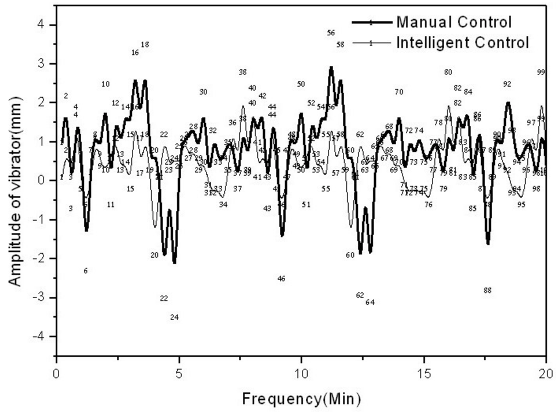

Figure 11 The Vibration curve of the platform working in the y-axis direction

5. Conclusion and future work

Our goal is to search for control techniques that improve the performance of intelligent leveling system of suspended platform. In this paper FSMC is studied in more details with the SOPS based on FC technology. A novel intelligent leveling system is proposed to make the platform more stable and safer while using. Due to the fact that manual adjustment of suspended platform has a certain vibration and the impact of manual adjustment will reduce the safety factor for the usage of platform, we need to reduce the use of manual adjustment platform. The FSMC system can achieve the synchronized drive accuracy of multi-point suspended platform well in a short adaptive time. The results of study show that FSMC of intelligent leveling is superior.

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