Proceedings of 2016 IEEE
International Conference on Mechatronics and Automation
August 7 - 10, Harbin, China

The Novel control method for the Adit data collection system

Lei Yang, En Li, Zize Liang

The State Key Laboratory of Management and Control for Complex Systems
Institute of Automation Chinese Academy of Sciences
Beijing 100190, China

University of Chinese Academy of Sciences
Beijing 100049, China

{leiyang2014,en.li & zize.liang}@ia.ac.cn

***Abstract* - With the continuous development of modern surveying and mapping technology, robotics has been gradually adopted to achieve the autonomous digital measurements. In this paper, a mobile robot platform is designed and controlled to travel inside the Adit environment to collect data for 3D reconstruction and measurement. In traditional control applications, PID-based methods(PID) are widely used for the motion servo control and present good performance in most cases. However, for some nonlinear systems, especially for the complicated applications in Adit environment, traditional PID-based method cannot get desired results. Meanwhile PID controller with fractional order(FPID) can have better control effect than traditional integer order PID controllers and is addressed in the application for the mobile robot platform inside the Adit. In this paper, a mobile robot platform is designed and the servo control system of the mobile robot platform is designed and analyzed. Meanwhile, a motion controller based on fractional order PID method is designed. With the following simulations, performance of the presented method is compared with that of traditional integer order PID method which shows that the fractional order PID controller is easy to design and has the ability of fast response and robust.**

Index Terms – FPID, PID, Adit, 3D reconstruction, Robustness.

I. INTRODUCTION

In recent years, the construction of infrastructural facilities in our national life occupies a large proportion. In the construction of infrastructural facilities, the Adit is the ground level channel on the ground and bears the transportation of people and materiel, drainage, wind inflow, setting up pipelines and other important tasks. Therefore, the Adit acts as the basis of the construction and plays a key role in the progress of engineering geological prospecting. The safety analysis of the Adit structure is very necessary in the development of the construction. In early time, geological exploration relies on artificial measurement. But the environment of the Adit is very complex and dangerous and the space in the Adit is very narrow, artificial measurement is not suitable. At the same time, artificial measurement has some disadvantages, such as high labor intensity and low efficiency[1]. With the development of photography technology, the automation of photogrammetry technologies is gradually applied in engineering geological exploration. Compared with the artificial measurement, this method has the advantages of high speed and high efficiency. Therefore, automated photogrammetric applications in geological exploration would be a mainstream at present, even in the future. The environment of the Adit is shown in Fig. 1.

Fig. 1 The environment of the Adit

The core of the photography is data acquisition and it is the basis of the photography. Aimed at the requirements, in this paper, an automation mobile robot platform for photogrammetry is designed. The functions of the device combine the process of moving forward of the mobile car and the rotation shooting of the cameras are to realize the data acquisition. Since the Adit is the cave temporary drilled during the process of exploration, so the planes of the roads are usually not flat and will produce large fluctuations to the car. In order to ensure the measure accuracy during the moving and realize the continuous and stable operation for the mobile car, this puts forward higher requirements for the stability control of the motor. Meanwhile, the rotation of the cameras will cause the rotary motor to produce changing loads. So it requires the rotary motor could have a good motion control performance to adapt the changing in loads to keep the rotation process continuity and accuracy. So the stability of the travelling platform and the accuracy of the camera rotation will have a direct impact on the measurement accuracy of the Adit. Therefore, the control performance of the servo control system plays a key role for the precise control of the car and the camera. Therefore, the design of a stable and fast response mobile platform servo controller is a key part of the whole servo control system.

Traditionally, the field of control theory has been dominated with the integer order controllers. However, the integer order PID controller in the control system of nonlinear, time variable and uncertain parameters, cannot ensure good control performance. Through the verification of experiments, the system combining the integer order controllers and stereo vision system does not work well. Because the integer order PID controller cannot ensure more precise control effect. Therefore the image quality is not good and the system just realizes the 3D reconstruction of the contour of the surrounding environment. But the final result is not only to realize the 3D reconstruction of contour of the surrounding environment, but also to realize high precision reconstruction of crack details. Faced with the current terrible results and the weakness of the integer order controllers, a new control method must be proposed and implemented.

With the computer technology and related research on fractional theory, the fractional order PID controller gets great development and is proved that it could provide more flexible and better control effect. Ding-yu Xue provides the method about scatter the fractional order calculus operators to the integer order operators and applies the method into tuning the values of the parameters[2]. Zhen-bin Wang proposes a method for the realization of the Fractional Order PID controller which combines the G-L definition and Z transform to design the controller[3]. Chunyang Wang proposes the frequency method based on amplitude-frequency margin and phase-frequency margin to tune the values of the parameters[4]. Chun-na Zhao designs the fractional order PID controller for the position servo system and compares the control effect with the traditional integer order PID controller. The results of the experiments show that the fractional order PID controller is better in the position servo control system than the traditional integer order PID controller[5]. Richa Sharma applies the Fractional order PID controller to the robotic manipulator. The results show that the Fractional order PID controller can provide better effect[13].Meanwhile, he also combines the fuzzy controllers to the Fractional order PID controller in the robotic manipulator[14]. During the realization of the fractional order PID controller, the core of the process is parameter optimization. During much methods about the tuning of the control system parameters, the most commonly methods for parameters tuning are the dominant pole order search method[10], the ITAE parameter optimization method[11] and the Fractional controller design method based on BF-PSO[12].

In this paper, the contributions of this work have two aspects. First, in view of the special and complex environment of the Adit, an automation mobile robot platform is designed to realize automation data acquisition. Second, faced with the problem that the integer order PID controller cannot provide the desired results and the fractional order PID controller is designed and applied to the servo control system of the Adit mobile robot platform to realize fast and robust control. The organization of this article is as follows. Firstly, design the Fractional Order PID controller for the servo control system. Secondly, the structure design of the servo control system is briefly described. Thirdly, the system design of the mobile robot platform is described in detail. Finally, in order to verify the control performance of the system, compare the control performance with the integer order PID controller and test the robustness of the system. The experiments show that the Fractional Order PID controller is better than the integer order PID controller in providing the better control performance.

II.THE DESIGN OF THE CONTROLLER

A. The Fractional Order PID controller

In the control system of the Adit measurement, due to the changing and complex environment inside the Adit, during the process of moving forward of the mobile robot platform, it puts forward higher requirements for the stability control of the motor for moving forward. Meanwhile, it requires the rotary motor could have a good motion control performance to adapt the changing in loads during the rotation process of the cameras continuity. Therefore, in the design of the controller, the selection of a suitable controller is particularly important. In the most practical applications, the traditional integer order PID controller still plays a very important role. However, in the environment of the Adit, it cannot get a good control effect through experiments.

The fractional order controllers are mainly including the following four types: TID controller[6], CRONE controller[7], the fractional order PID controller[8] and the Compensator for Lead-lag correction[9]. The common used approach in the field of control is the fractional order PID controller. Through experiments and validation of many researchers, compared with the traditional integer order PID controller, the Fractional Order PID controller has better control effect in control. It could provide more flexible, delicate control.

The Fractional Order PID controller can be viewed as a generalized form of the traditional integer order PID controller. While the Integer order PID controller can be viewed as a special case of the Fractional Order PID controller. Traditional integer order PID controller relies on three adjustable parameters to adjust the system performance. Compared with the traditional integer order PID controller, in addition to the three adjustable parameters, the fractional order PID controller has more two adjustable parameters than integer order PID controller for adjusting the performance of the system to ensure optimal performance of the control system.

The mathematical of the fractional order PID controller in the time domain can be written as follows:

$$u(t) = K_p + K_i D^{-\lambda} e(t) + K_d D^{u} e(t) \quad (3)$$

The mathematical of the fractional order PID controller in the s domain can be written as follows:

$$C(s) = K_P + K_i s^{-\lambda} + K_d s^{u} \quad (4)$$

In the above formula, $u(t)$ represents the inputs of the controller. $e(t)$ is the errors. K_p ,K_i and K_d represent proportional gain, integral constant and derivative constant. The symbol of λ and μ represent correspondingly Differential Order and Integral Order. $u(t)$ represents the inputs of the system. $C(s)$ represents the transfer function of the fractional order PID controller.

From the above formula, when the value of λ and the value of μ are 1, the type of the controller is the Integer order PID controller. When the value of λ is 1 and the value of μ is 0, the type of the controller is the Integer order PI controller. When the value of λ is 0 and the value of μ is 1, the type of the controller is the Integer order PD controller. When the value of λ and μ is in other conditions, the type of the controller is the fractional order PID controller.

B. The Realization of the Fractional Calculus Operators

In the fractional order controller design process, the process of controller design can be divided into two parts: the realization of the Fractional Calculus Operators and the tuning of the controller parameter.

During the realization of the Fractional Calculus Operators, the G-L definition about the Fractional Calculus Operators is widely used in control. The definition can be written as follows:

$$a^{D}{}_{t}^{\alpha} f(t) = lim h^{-\alpha} \sum_{j=0}^{\left[\frac{t-a}{h}\right]} (-1)^{j} \binom{\alpha}{j} f(t-jh) \qquad (5)$$

In the above formula,

$$\binom{\alpha}{j} = \frac{\alpha(\alpha+1)\ldots(\alpha+j-1)}{j!} = \frac{\alpha!}{j!(\alpha-j)!} \qquad (6)$$

In the above formula, G-L definition by the Laplace transform can be written as follows:

$$\mathrm{L}\left[a^{D}{}_{t}^{\pm\alpha} f(t)\right] = s^{\pm\alpha} F(s) \qquad (7)$$

In the above formula, $\mathrm{a}D_{t}^{\partial}$ represents the basic operator of fractional calculus. The symbol of a and t represents the upper and lower limits of calculus. The symbol of ∂ represents the order of calculus. From the above definition equation, it is obvious that the performance of fractional calculus is not only related to the current state, but also related to the past state of the moment. From the form of expression, it can be seen that fractional calculus has the characteristic of global relevance. Thus, fractional calculus is more suitable to describe the actual system model.

C. The parameters tuning

During the tuning the parameter of the Adit mobile servo system based on the fractional PID controller, the frequency method based on amplitude-frequency margin and phase-frequency margin is adopted[4]. This method is used widely because of simple solution on tuning the parameters. For the actual situation of the controlled object, faced with the robustness of the control system, phase margin acts as a rule as in controller design. That is required to ensure that the phase Bode diagram of the system open-loop transfer function in the vicinity of the cutoff frequency is flat. The specific rules for tuning the Fractional controller parameters are described as follows:

(1) Phase angle characteristics of open-loop transfer function for control system in the Cut-off frequency:

$$\mathrm{Arg}[\mathrm{G}(\mathrm{j}w_{c})] = -\pi + \phi_{m} \qquad (8)$$

(2) Amplitude-frequency characteristics of open-loop transfer function for control system in the Cut-off frequency:

$$|\mathrm{G}(\mathrm{j}W_{c})| = 0 \qquad (9)$$

(3) Robust conditions:

In order to ensure the robustness of the control system, the phase Bode diagram of the system open-loop transfer function in the vicinity of the cutoff frequency must be flat.

$$\left(\frac{d(Arg[G(\mathrm{j}W_{c})])}{d_{w}}\right)_{w=w_{c}} = 0 \qquad (10)$$

(4)Other conditions in the crossover frequency:

$$Arg\left[G\left(\mathrm{j}W_{p}\right)\right] = -\pi \qquad (11)$$

$$\left|G\left(\mathrm{j}W_{p}\right)\right| = 1/M_{g} \qquad (12)$$

In the above formula, ϕ_{m} represents Phase Margin. w_{c} represents cutoff frequency. M_{g} represents Amplitude margin.

In tuning the parameters of the control system, based on the above conditions, the rule (3) acts as the objective function and the rules (1), (2) and (4) acts as the constraint conditions to solve the parameter tuning. Through these steps, we can get the parameters values of system controller and finish the design of the controller.

III. THE EXPERIMENTS PLATFORM

A. The system architecture of the Adit data collection

Aimed at the complex and dangerous environment of the Adit, an automation data acquisition is designed. The function of the mobile robot platform is to realize controlling the mobile unit moving forward continuously. At the same time, it also controls the camera platform constantly rotating to realize data acquisition and storage. The control system architecture of the Adit mobile robot platform includes power system, camera, light system, remote controller, track, the rotating system and translation system. The power system supplies the energy for the entire system to keep the system working normally. The remote controller can control the working of the platform and set the values of the system parameter. The camera is responsible for data collection and storage. The rotating system and translation system is design to control the camera rotation shooting. And the brightness of the Adit is very weak and greatly affects the quality of photos. An auxiliary light system is added into the system. So the system block diagram of the Adit Photogrammetry system can be simply described in Figure 2.

Aimed at the Site requirement, the automation mobile robotic platform has two working modes: automated mode or manual mode.

(1) During the automated mode, the operators have to set the system parameters, such as the speed of motor, the Light intensity, the camera mode and so on. Then the mobile platform can work automatically according to the defining system parameters until finishing the data collection.

(2) Faced with the humanized needs and Site special needs, the working mode has to be changed. Meanwhile, the operators want to know about the status of the mobile platform on time. So a remote controller is designed to realize manual mode. Through the remote controller, the operators can adjust the system parameters at any time and get the status of the mobile platform from the TFT monitor at any time.

The appearance of the Adit mobile platform and the remote controller is shown in the Figure 3 and Figure 4.

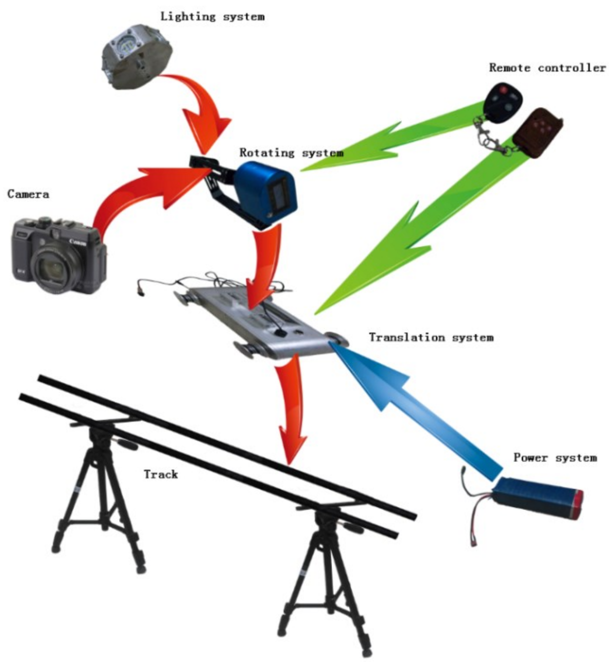

Fig. 2 The each unit of the system

Fig. 3 The appearance of the mobile robot platform

Fig. 4 The appearance of the remote controller

B. The design of the control system

Based on the structure of the system, the hardware design of the mobile robot platform could be described in Figure 5.

During the implementation of the control system, the structure of the system includes the remote controller and the main controller. The main controller is responsible for the control of the movement of the mobile robot platform, the camera shooting, light adjustment and system parameters adjustment and so on. The remote controller is designed to realize the manual control of the mobile robot platform and monitor the status of the system.

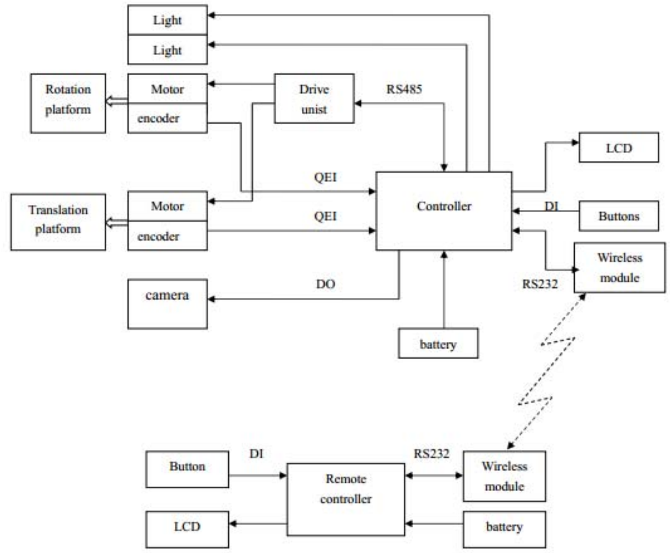

Fig. 5 The structure of the control system

The ultra-low-power and High-performance ARM processor of ST is selected as the controller. And the Brushless DC motor is selected as the actuators. Compared with other servo motors, the advantages of the Brushless DC motors is extremely simple in control. Meanwhile, the Brushless DC motor structure is very simple and it can frequently fast start, brake and stop. The button and LCD is respectively used to adjust system parameters and display the status and some information of the control system. The wireless module is responsible for the communication between the remote controller and the main controller.

The realization of the controller is based on the platform of the real-time operating system(CooCox CoOS). CooCox CoOS is an embedded real-time multi-task OS for ARM Cortex M series. And it is a Free and open real-time Operating System. Meanwhile the communication between tasks is MailBox.

IV. EXPERIMENTS

A. The Simulation of the servo control system

The model of the Brushless DC motors is simple and it could be obtained through the method of system identification. Combining the G-L definition about the Fractional Calculus Operators, the Fractional PID controller could be designed. Then some simulations experiments in the Simulink during the environment of the Matlab software could be done. First, the results of the PID and FPID are compared. The system diagram is listed in Figure 6.

Then simulations experiment can be done to compare the performance between the Fractional PID controller and PID controller. During the system diagram, a step signal is put into the system and the Step response can be observed to compare the results and verify the new control.

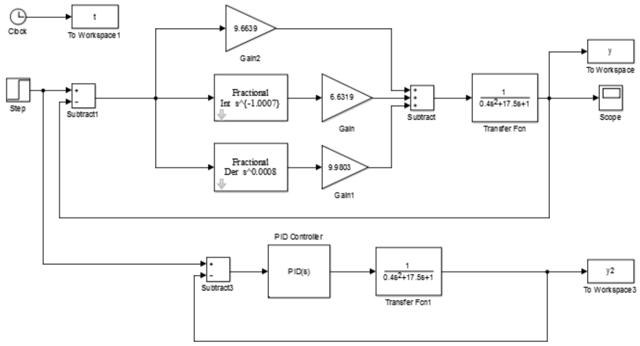

Fig. 6. The control system block diagram of the Adit mobile car

The results of the simulation are listed as follows:

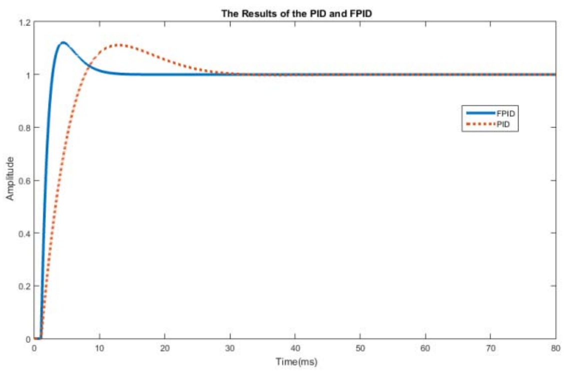

Fig. 7. The Step Response of Adit mobile servo control system

Figure 7 is the step response curve. And the integer order PID controller and the fractional order PID controller are applied into the servo control system and the step signal is put into the input of the servo control system. From the figure 6, compare with the integer order PID controller, the fractional order PID controller has the following several advantage. First, the system has faster motion response. Second, the adjustable time of system becomes shorter.

B. Robustness analysis: Noise suppression

Robustness is the key factor which keeps the system working normally under abnormal situation. It reflects whether the servo control system is robust. It shows the quality of a servo control system design. Robustness is reflected in many ways, e.g., noise reduction, external interference term, mutation system parameters, etc.

During the noise reduction testing, just put into some random noise signal into the system to test the robustness. The results of the simulation are listed as Figure 8.

Figure 8 is the step response curve. In the experiment, we put the random noise signal into the output of the system to test the robustness of the system. From the figure 8, it can be seen that the system can come back into a stable state in a very short period of time. It is clear that the fractional order PID controller has faster motion response and shorter adjustable time than the integer order PID controller.

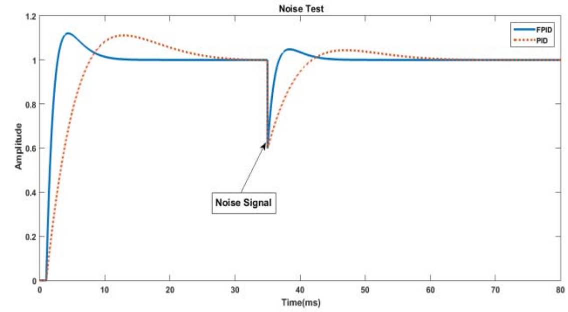

Fig.8. The Step Response under noise signal

C. Robustness analysis: Disturbance rejection

Disturbance rejection is also a key factor for a stable system. It reflects that whether the servo control system is robust and can work normally under abnormal situation. In the most cases, the actual environment of the servo control system working is bad and complex. So the servo control system which has the ability of disturbance rejection is very important. This can ensure the device working normally in the complex environment. In the design of the experiments, the disturbance signal is put into the control system. The results of the simulation are listed as follows:

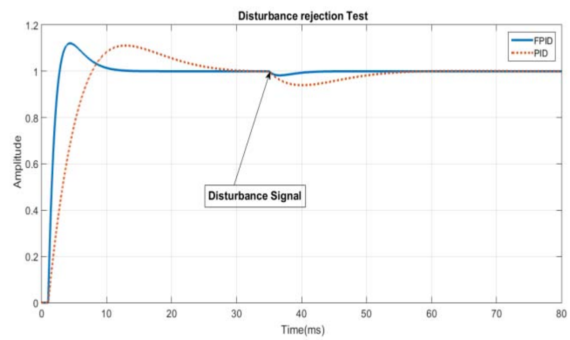

Fig.9. The Step Response under Disturbance

Figure 9 is the step response curve. In the experiment, we put the disturbance signal into the servo control system to test the robustness of the system. From the figure 9, it can be seen that the system can come back into a stable state in a very short period of time and the disturbance signal produce a very small impact to the system. Like the results of noise suppression test, it is clear that the fractional order PID controller has faster motion response and shorter adjustable time than the integer order PID controller.

D. The Results of 3D Reconstruction

The final goal is to realize the high-precision 3D reconstruction. In this work, the data acquisition platform and the stereo vision system are designed. Based on the collection data through the mobile platform with the PID controller and FPID controller, the 3D reconstruction of the Adit is done. Then the results can be analysis to verify the performance of the controller. The final results based on the fractional order PID controllers and the integer order PID controllers are shown as follows:

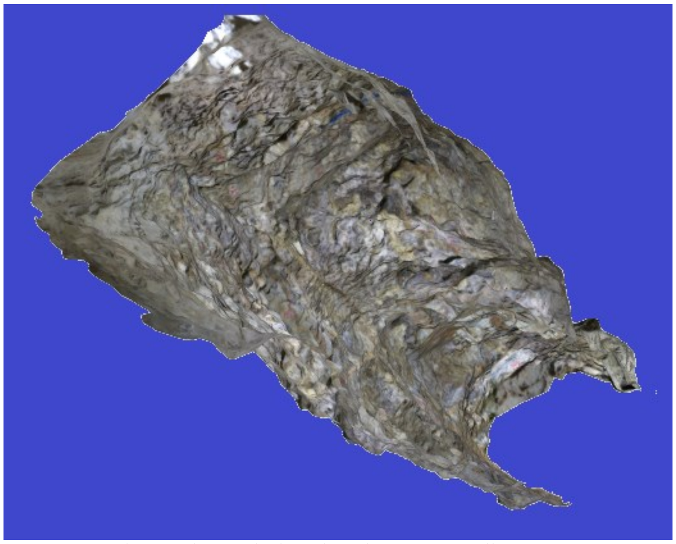

Fig.10. The results based on the PID controller

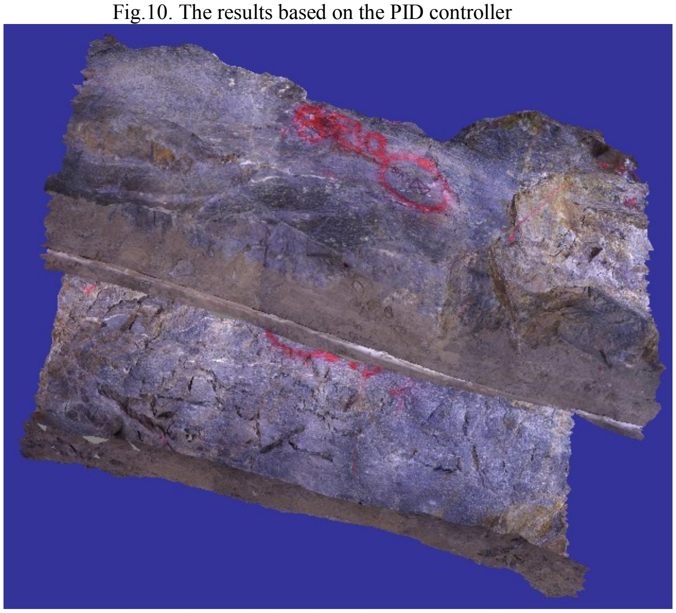

Fig.11. The results based on the FPID controller

Based on the results of the Figure 10 and Figure 11, the 3D results of Figure 11 can realize better reconstruction and show more details, such as the information of texture, section and Split Rock. It could provide more details and more precise data for structure and stability analysis. Through this contrast, it could be proved that the fractional order PID controller could provide better control effect than PID controller.

V. CONCLUSIONS

Faced with the complex and dangerous environment in the cave of the Adit, this paper designs the mobile robot platform for realizing automation data acquisition to replace the artificial labor. Meanwhile aimed at the problem that the integer order PID controller cannot provide the desired results, the fractional order PID controller is designed and applied into the servo control system of the mobile robot platform. In the experiments, this paper compares the control effect and 3d reconstruction results with the integer order PID controller tests the robustness of the servo control system. Through this work, it is clear that the fractional order PID controller is easy to be designed and could provide better control effect than PID controller than integer order PID controller.

ACKNOWLEDGMENT

This work is supported by National Science and Technology Support Program of China (2015BAK06B01) and National Natural Science Foundation(NNSF) of China (61403372).

The author is grateful to the anonymous reviewers as well as to the Editors for their valuable suggestions. Meanwhile, the author is also thankful to the lab of Institute of Automation, Chinese Academy of Sciences for providing the excellent research facilities and environment.

REFERENCES

[1] Guo Qiang. The study of the Gallery Photograph Measure System[D]. Institute of Rock and Soil Mechanics, Chinese Academy of Sciences,2009.

[2] Xue Ding-yu, Zhao Chun-na. Fractional order PID controller design for fractional order system[J].Control Theory & Applications,2008, 24(5):771-776.

[3] Wang Zhen-bin, Cao Guang-yi, Zeng Qing-shan. Fractional Order PID Controller and Its Digital Implementation[J]. Journal of Shanghai Jiaotong University,2004,38(4):517-520.

[4] Wang Chun-yang. Study on Fractional order PID controller Parameter Tuning Methods and Design[D].Jilin University,2013.

[5] Zhao Chun-na, Zhao Yu, Zhao De-xiang. Simulation Research on Fractional Order Controllers with Integer Order Controllers[J].Journal of system Simulation,2009,21(3):768-771.

[6] Raynaud H F, ZergaïNoh A. State-space representation for fractional order controllers[J]. Automatica, 2000, 36(7):1017–1021.

[7] Oustaloup A, Sabatier J, Lanusse P. From fractal robustness to the CRONE control[J]. Fractional Calculus & Applied Analysis,1999,2(1):1-30.

[8] Podlubny I. Fractional-order systems and PI D -controllers[J]. IEEE Trans.automat.contr, 1999, 64(8):1287-1300.

[9] Raynaud H F, ZergaïNoh A. State-space representation for fractional order controllers[J]. Automatica, 2000,36(7):1017–1021.

[10] Monje C A, Calderon A J, Vinagre B M, et al. On Fractional PI λ Controllers: Some Tuning Rules for Robustness to Plant Uncertainties[J]. Nonlinear Dynamics,2004,38(1-4):369-381.

[11] Yan Hui,Yu Sheng-lin,Li Yuan-lu.A Design Method of the Parameters of Fractional-order PID Controller- Poles Orders Searching Method[J].Information and Control,2007, 36(4):445-450.

[12] Li Zhi-ming, Sun Qi-zhen, Han Xu-peng. Design of Fractional-order Controller for Diesel Engine System Based on BF-PSO[J].Control Engineering of China,2015, 19(3):515-518.

[13] Sharma R, Gaur P, Mittal A P. Performance analysis of two-degree of freedom fractional order PID controllers for robotic manipulator with payload[J]. ISA transactions, 2015.

[14] Sharma R, Rana K P S, Kumar V. Performance analysis of fractional order fuzzy PID controllers applied to a robotic manipulator[J]. Expert systems with applications, 2014, 41(9): 4274-4289.