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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (14): 2921-2928, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.2921.2928

Analysis and Test on Rough Terrain Adaptation Performance of the Rocker-type W-shaped Track Coal Mine Exploring Robot

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Abstract: The primary task of the rescue work for the coal mine exploring robots is to enter the disaster area of underground coal mine. However, the underground terrain after explosion disaster is unstructured and rough. The robot has to overcome all terrain in laneways and disaster area. In this study, a rocker type asymmetrical W-shaped track robot has been designed. In order to test the rough terrain adaptation performance of the robot, a dynamic measurement system for tracking the important positions and motions of the robot has been built in laboratory using NDI dynamic measuring machine. The differential mechanism, rough terrain-crossing, trafficability characteristic of the robot are carried out in a construction complex rough waste field. the test results shown that the differential can keep the main body posture balance and reduce the influence of rough terrain on main body, the fluctuation and vibration of the main body is smaller than the walking mechanism and the track suspensions can passively rock to adapt to rough terrain, the four tracks of which can contact with the obstacles and terrain very well and collectively supply propulsion to overcome the terrain. This work has indicated that rocker type asymmetrical W-shaped track robot has a good rough terrain adaptation performance and can be used in coal mine disaster rescue missions in the next future.

Key words: Coal mine exploring robot, W-shaped, rough terrain, adaptation performance, test

INTRODUCTION

After the gas and coal dust explosion accidents in underground coal mine, the gas atmosphere is extremely unstable explosive and noxious, rescue mission is very dangerous, may easily cause rescuers casualties. So in order to perform the rescue mission successfully in good time and decrease the casualties, it is necessary to research on and to develop the coal mine rescue robots that are sent to enter the mine disaster area and detect environment after the disaster (Li *et al*., 2010a). The primary task of the rescue work for the robots is to enter the disaster area of underground coal mine. The terrain in underground coal mine after explosion disaster is unstructured. There are artificially built independent steps, continuous stairs, slopes, drainage channels and rails in the laneways. Roof falling and rib spalling often occur accompanied by the explosion disaster and make coal and rock pile up into rough and mess terrain. The robot have to overcome all terrain just mentioned in laneways and disaster area. Therefore, the walking mechanism for coal mine exploring robot is the research focus and difficulty in robot research field.

Many universities and organizations have showed a keen interest in research of coal mine rescue robots (Fu *et al*., 2011; Gao *et al*., 2009; Murphy *et al*., 2009; Nonami *et al*., 2003; Doroftei *et al*., 2009; Aoyama *et al*., 2007; Xiong *et al*., 2009; Zhang and Gao, 2011; Cheah *et al*., 2010; Cui *et al*., 2010). A rocker-type track mobile system using the symmetrical W-shaped track suspension is presented, but there are bend wheels outside middle of the W-shaped track and the bend wheels influence and reduce obstacle surmounting performance of the robot (Li *et al*., 2010b). The rocker type asymmetrical W-shaped track robot mobile platform was introduced and the obstacles capabilities of the robot prototype, including stair-climbing, channel-crossing, down-stair were analyzed (Li *et al*., 2010c). In this study, a improved rocker type asymmetrical W-shaped track robot is introduced, the explosion-proof design was adopted, kinetic characteristics of rough terrain crossing is testedusing the dynamic measurement system in the laboratory, the rough terrain trafficability test is carried out in the field.

ROCKER-TYPE W-SHAPED TRACK ROBOT MOBILE PLATFORM

The rocker type W-shaped track robot mobile platform is shown in Fig. 1. The platform is comprised of

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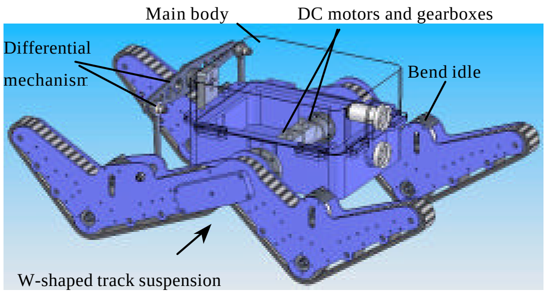


Fig. 1: Mechanical structure of the rocker-type W-shaped track mobile platform

two asymmetrical W-shaped rocker track suspensions, a differential mechanism and a main body and the explosion-proof design was adopted into the main body (Li *et al*., 2010b;c). The track suspensions are hinged with the main body, which can rock around the hinge axis. Each suspensions is comprised of two track assemblies which are connected by chain transmission and there is a bend idle outside the track of each track assembly, which is also a tensioner. The track suspensions are driven by the DC motors installed in the main body. The link rods type differential mechanism link the main body and the two suspensions. Then the main body and two suspensions are connected by differential mechanism. The suspensions will rock with the rough terrain during the robot running in the unstructured environment, the main body will swing in a small angle range.

DYNAMIC MEASUREMENT SYSTEM USING NDI DYNAMIC MEASURING MACHINE

The NDI Dynamic Measuring Machine (DMM) is one of the most powerful and capable tools for dynamic measurement and advanced motion analysis. The DMM uses an Optical Tracker to track specially designed targets that mark specific points of interest. The basic components of DMM include position sensors, system control unit, markers, marker strobers and data collection software. The DMM is used to track the important positions and motions of the robot. Three position sensors is distributed in a triangle in the laboratory, as shown in Fig. 2. The detection area is the intersection area of detection regions of three position sensors. According to the tests, different test frames are put in the detection area. System control unit, data collection system of DMM and the robot control unit are arranged in a corner of the laboratory, as shown in Fig. 3.

The activity components of Rocker-type asymmetric W-shaped robot involve both right and left track suspensions, main body, swinging rod and two connecting rods of differential mechanism. These activity components are all rigid bodies. In the process of robot moving, all these components move conjunctly. The main activity components need to be detected.

A rigid body in DMM is a group of markers where the positions of the markers relative to each other is fixed.

Fig. 2: Laboratory layout

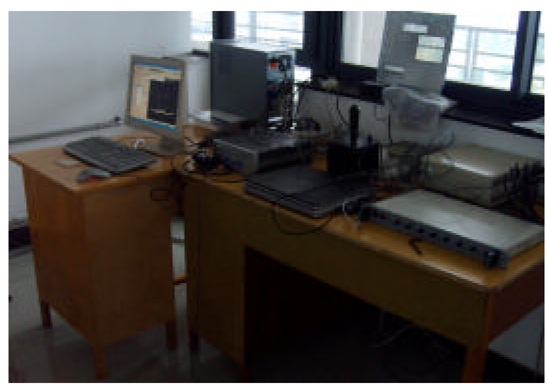
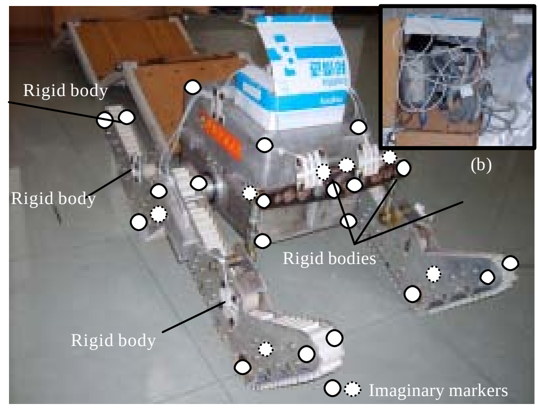


Fig. 3: Data acquisition and robot control platform

The minimum number of markers is three. Markers consist of an infrared light emitting diode fastened to a base. Rigid bodies can include both real and imaginary markers. imaginary markers identify points on a rigid body where it is difficult, undesirable or inconvenient to attach actual markers. So, rigid bodies are made using three or four real Markers and a rigid base and the rigid bodies are attached to the track suspensions, main body, swinging rod and two connecting rods of differential mechanism of the robot, then the imaginary markers of the rigid bodies define points on robot components, illustrated in Fig. 4a. So, in the process of robot moving, as long as the rigid bodies can be detected, even if the imaginary markers are not in detection region, the position and orientation of the imaginary markers still can be detected.

In the process of marching, the robot attitude changes with terrain. To ensure the components can be detected, two rigid bodies are attached to each important component, such as two ones on each side of the main body, two ones on each end of the track suspension. Even if one rigid body on the component is obscured by other parts of the robot, the positions of the specific points of interest on the component still can be tracked. Marker strobes and redundant twisted pair cables for markers are collected and stored into a box attached on the main body, shown in Fig. 4b.



(a)

Fig. 4: Rigid bodies and imaginary markers on robot

ROUGH TERRAIN ADAPTATION PERFORMANCE ANALYSIS AND TEST

Analysis on rough terrain-crossing performance: In the mobile system, the link rods type differential mechanism links the main body and the two rocker type W-shaped track suspensions. When the robot driving on the rough terrain, the W-shaped track suspensions on both sides of the main body swing to adapt to the terrain and the differential mechanism keeps the main body at an average angle between the two track suspensions. The mobile system limits the amplitude of swing of main body, effectively reduces the influence of rough terrain on main body. So, the mobile system has a good stability and passive terrain adaptation performance.

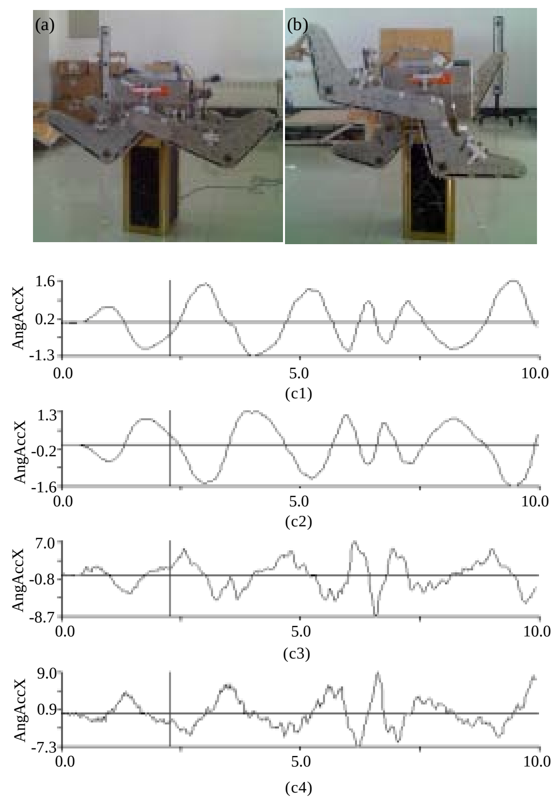


Fig. 5(a-c): Angular velocity and acceleration curves of left, right suspensions and main body referenced to x axis

Test of the role of differential mechanism: In order to test and verify the role of the differential of the robot, main body of the robot is supported and the right and left track suspensions hang in the air freely, as shown in Fig. 5a. The x shaft of detecting coordinate system is set on the rotation axis of the track suspensions. Keeping main body still, one tester toggles one suspension at will, then the angular velocity and angular acceleration of the right and left suspensions around x axis are obtained. In Fig. 5b, c1, c2 are the angular velocity curve of right and left suspensions, c3, c4 are the angular acceleration curve of right and left suspensions.

Establish detecting coordinate system on the ground, the robot are placed on the floor. And the length direction

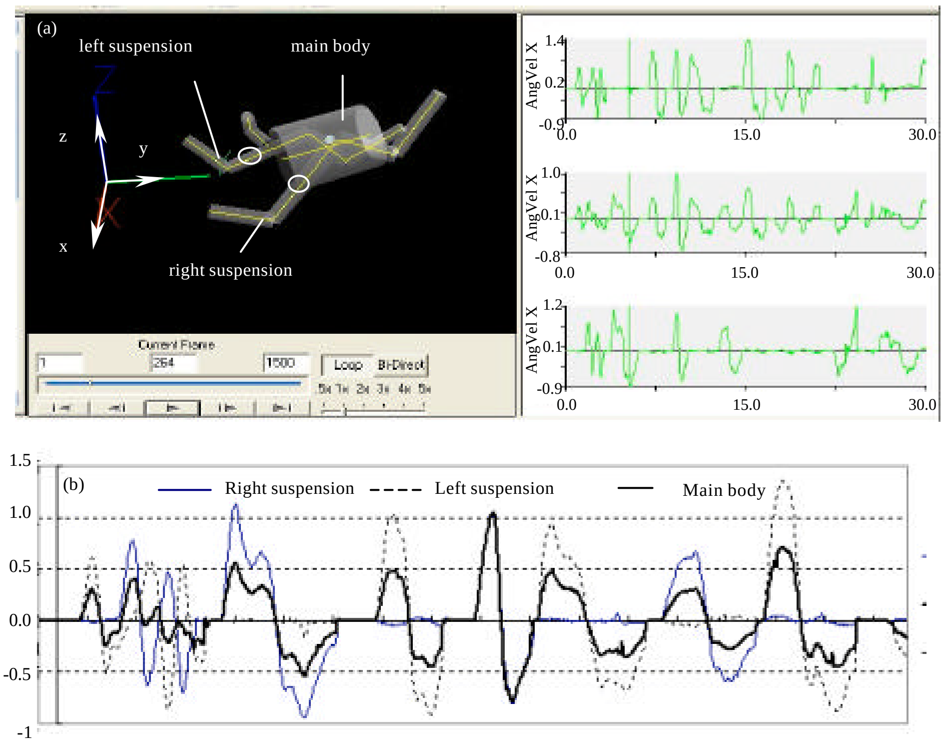


Fig. 6(a-c): Angular velocity curves of left, right suspensions and main body referenced to x axis

of the robot is consistent with y axis direction. Two testers respectively uplift and put down the front ends of the two suspensions taking the rear-bottom track wheels as fulcrums. The positions of center of No.3 tracks of right and left suspensions are detected, the angular velocities around x axis of them are gotten. 1500 sets of data in 30 sec are collected. The left part of Fig. 6a from data collection software illustrates the robot pose at some point and the right part illustrates the three angular velocities referenced to x axis of left suspension, main body and right suspension. The three curves are drawn in one picture, taking 900 sets of data from 1500 sets, shown in Fig. 6b. The angular velocity curve of main body is at middle position between the two angular velocities of right and left suspension, in other word, the angular velocity is the mean value of the two angular velocities of suspensions. The above two tests indicate that differential can keep the main body posture balance and reduce the influence of rough terrain on main body.

Rough terrain-crossing test: Rugged terrain simulation test frame is composed of two staggered groups of wavy frame, which is used to simulated the rugged terrain. The positions of markers are recorded during the robot crawling on the test frame. Figure 7a shows the test scenarios robot rough terrain climbing.

Figure 7b illustrates the displacement curves in Z axis direction of the No.2, 3, 4 wheel and a point C on main body, which have been marked in Fig. 7a. Because the terrain simulated is fluctuant, the curves are waved. The data is collected in a cycle of forward and backward, so the data curves are approximately symmetrical. There are local sharp fluctuations in displacement curves of wheel 3 and 4, because the rigid bodies pasted on the left suspension has a displacement due to vibration.

For ease of observation, the displacement curves in Z axis direction of the left wheel 2 and right wheel 2 are drawn in a figure, as shown in Fig. 7c. The left suspension crosses two peak of wave and the right one crosses one peak of wave. The maximum and minimum displacements in Z axis direction of left wheel 2 and 3, right wheel 2 and 3 and a point near center of mass are Listed in the Table 1. It is thus clear that Z axis displacement amplitude of fluctuation of main body is smallest.

Acceleration curves of the point on main body, the left wheel 2 and 4 and the right wheel 2 and 4 referenced to z axis is shown in Fig. 8a-e. The maximum and minimum accelerations are listed in Table 1. We can know from the

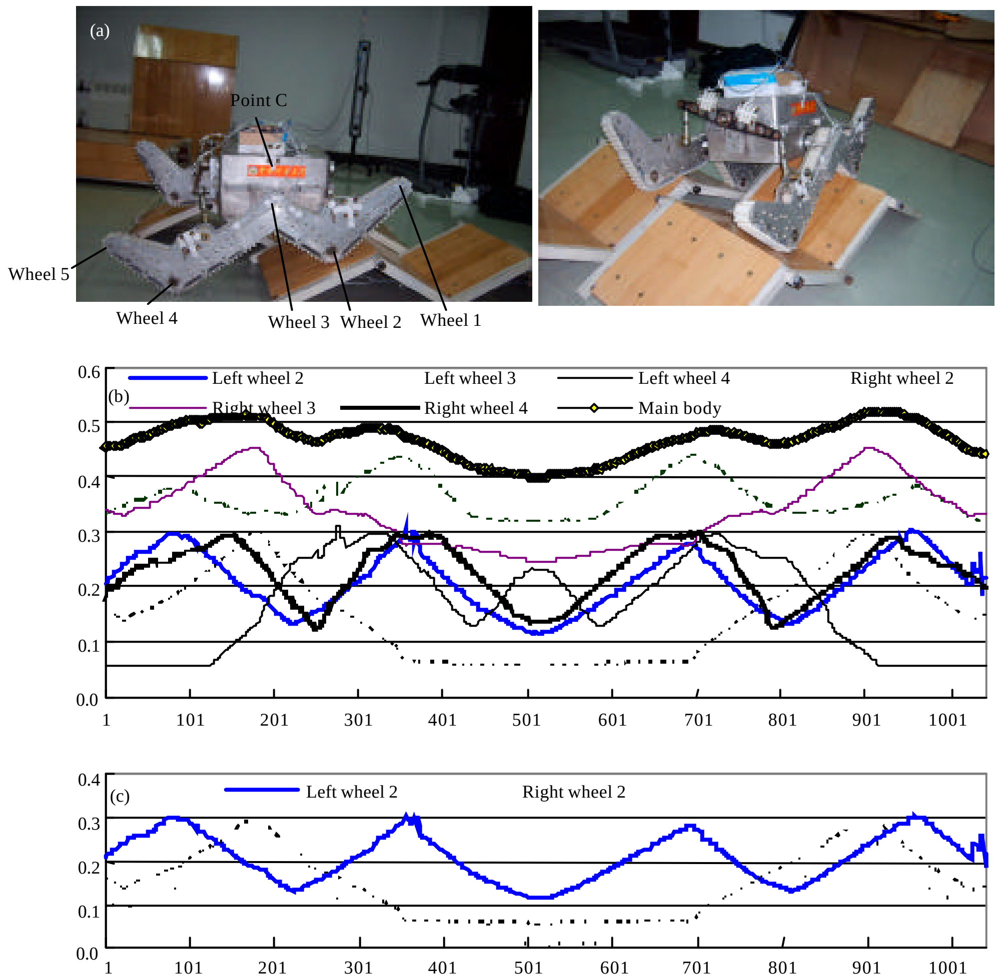


Fig. 7(a-c): Rough terrain-crossing test and the data curves

Table 1: z-axis displacement and acceleration extremums of wheels and main body

Points detected	Maximum displacement (m)	Minimum displacement (m)	Amplitude of fluctation (m)	Maximum acceleration (m sec^{-2})	Minimum acceleration (m sec^{-2})	Corresponding acceleration curve in Fig. 8
Left core wheel 2	0.32	0.12	0.20	0.11	-0.19	(a)
Left core wheel 3	0.44	0.31	0.13	0.09	-0.10	(b)
Right core wheel 2	0.30	0.05	0.25	0.07	-0.16	(c)
Right core wheel 3	0.30	0.12	0.18	0.20	-0.11	(d)
Point C on main body	0.52	0.40	0.12	0.06	-0.05	(e)

table, the accelerations variation range of main body is smaller than the ones of track wheels that contacts to the terrain. From the above test and analysis, the fluctuation and vibration of the main body is smaller than the walking mechanism, during the robot crossing rugged terrain.

Taking a construction waste field from demolished buildings as proving ground, the test of robot trafficability characteristic in complex rough terrain is carried out. As a whole, the field is not smooth and is full of construction waste such as broken bricks, stone, concrete used in construction. Because of the random and irregular accumulation of construction waste, the complex and rugged terrain forms.

There is a certain distance between the bottom of main body and the ground, because of the support of the two W-shaped track suspensions. The some collisions between main body and obstacles on ground can be avoided. In the progress of traveling, the track suspensions passively rock to adapt to rough terrain. The four tracks of each track suspension can contact with the obstacles and terrain very well and supply propulsion to

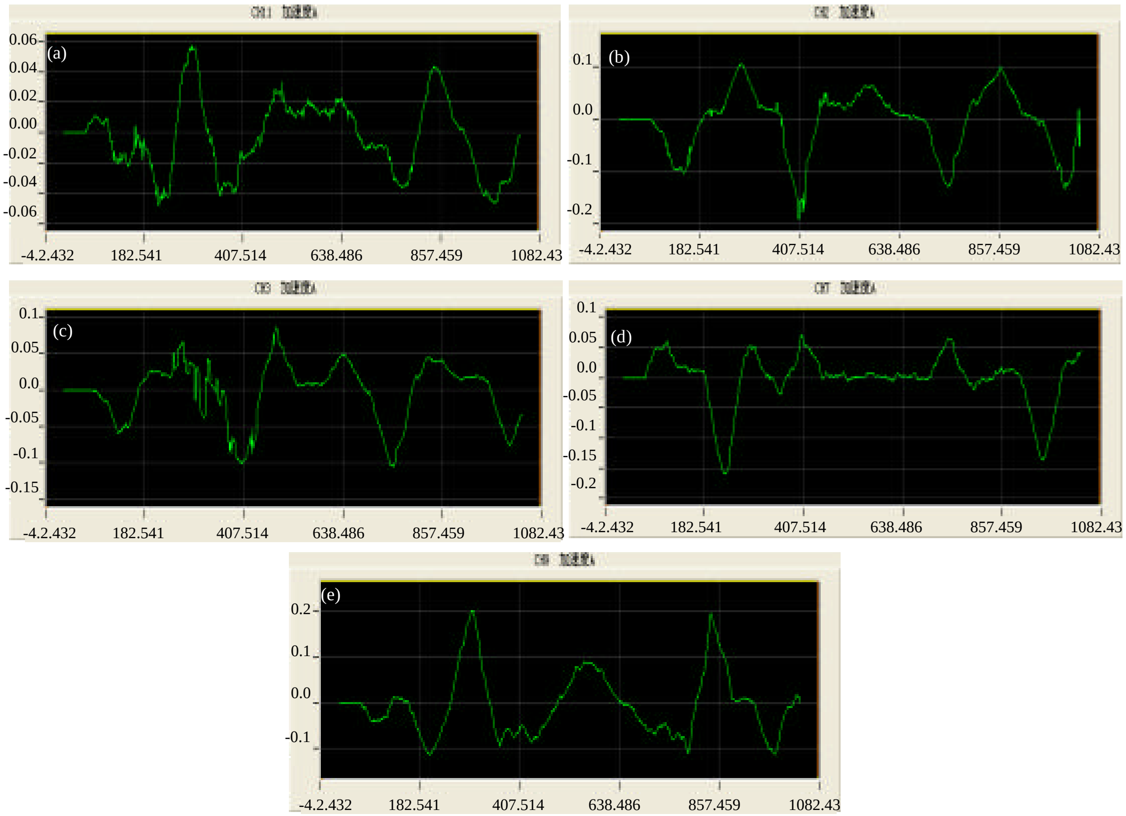


Fig. 8: Acceleration curves of the main body and the track wheels center

Fig. 9: Test of rough terrain-crossing

drive the robot. Figure9 is the video capture, which illustrates the robot overcoming the rough terrain in the proving ground.

When the common track robot climb stairs, the center line of the robot should parallel to slope direction of the stairs. If not, the robot may slip and turn over. But it is difficult to keep the robot climbing stairs in parallel situation in actual environments. The outdoor tests of stairs and step climbing and crossing are carried out. When the robot climb continuous stairs obliquely, the two track suspensions will swing to adapt to the stairs, the tracks can contact with the step edge and the tread and climb stairs easily. Figure 10 shows the test of building stairs and step climbing and crossing.

Fig. 10: Test of building stairs-climbing

CONCLUSION

This study designed the rocker type asymmetrical W-shaped track robot, which rough terrain adaptation performances are analyzed and tested in the field.

The dynamic measurement system for tracking the important positions and motions of the robot is built and the positions and motions of the robot are detected.

The link rods type differential mechanism linked the main body and the two rocker type W-shaped track suspensions are designed. The differential mechanism can keep the main body at an average angle between the two track suspensions.

The test of robot trafficability characteristic of complex rough terrain is carried out. The track suspensions passively rock to adapt to rough terrain and the four tracks of each track suspension can contact with the obstacles and terrain very well and supply propulsion to overcome the terrain.

The coal mine exploring robot that adopts the mobile system can overcome most terrain in underground coal mine in the near future. We look forward to get application in coal mine disaster rescue missions, when the robot are carried out explosion proof design strictly and equipped all kinds of detecting instruments.

ACKNOWLEDGEMENTS

This study was financially supported by the Fundamental Research Funds for the Central Universities of China (No. 2010QNB18), the China Postdoctoral Science Foundation (No. 20110491479), National Natural Science Foundation of China (No. 51205391).

REFERENCE

Aoyama, H., K. Ishikawa, J. Seki and M. Okamura, 2007. Development of mine detection robot system. Int. J. Adv. Robotic Syst., 4: 229-236.

Cheah, C.C., S.P. Hou, Y. Zhao and J.J.E. Slotine, 2010. Adaptive vision and force tracking control for robots with constraint uncertainty. IEEE ASME Trans. Mechatron., 15: 389-399.

Cui, Y.A., Z.X. Cai and L. Wang, 2008. Scene recognition for mine rescue robot localization based on vision. Trans. Nonferrous Met. Soc. China, 18: 432-437.

Doroftei, D., E. Colon, Y. Baudoin and H. Sahli, 2009. Development of a behaviour-based control and software architecture for a visually guided mine detection robot. J. Europeen des Syst. Automatises, 43: 295-314.

Fu, G.Q., P. Corradi, A. Menciassi and P. Dario, 2011. An integrated triangulation laser scanner for obstacle detection of miniature mobile robots in indoor environment. IEEE/ASME Transa. Mechatronics, 16: 778-783.

Gao, J.Y., X.S. Gao, J.G. Zhu, W. Zhu, B.Y. Wei and S.L. Wang, 2009. Coal mine detect and rescue robot technique research. Proceedings of the IEEE International Conference on Information and Automation, June 22-24, 2009, Zhuhai/Macau, Chin, pp: 1068-1073.

Li, Y.W., S.R. Ge and Z. Zhu, 2010. Deduction of the rocker-type track suspension configurations and their applications to coal mine rescue robots. Robot, 32: 25-33.

Li, Y.W., S.R. Ge, Z. Zhu and H.F. Fang, 2010. Mobile platform of a rocker-type W-shaped track robot. Key Eng. Mat., 419-420: 609-612.

Li, Y.W., S.R. Ge, Z. Zhu, H. Fang and J. Gao, 2010. Mobile platform of rocker-type coal mine rescue robot. Mining Sci. Technol. (China), 11: 466-471.

Murphy, R.R., J. Kravitz, S. Stover and R. Shoureshi, 2009. Mobile robots in mine rescue and recovery. Robotics Automation Magazine, IEEE, 16: 916-103.

Nonami, K.Z., Q. Huang, D. Komizo, Y. Fukao and Y. Asai, 2003. Development and control of mine detection robot COMET-II and COMET-III. JSME Int. J. Series C Mechanical Syst., Machine, 46: 881-890.

Xiong, C.H., D.G. Han and Y.L. Xiong, 2009. An integrated localization system for robots in underground environments. Industrial Robot, 36: 221-229.

Zhang, D. and Z. Gao, 2011. Hybrid head mechanism of the groundhog-like mine rescue robot. Robotics Comput. Integrated Manufacturing, 27: 460-470.