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The structure design and analysis of a wheel-track robot

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Abstract **- This paper mainly introduces the system components of the wheel-track robot, mainly comprising a body structure and control system. Through the analysis of the driving power and the power of the selection of crawling, motor drive of the robot is chose. Variable structure adopts a screw rod transmission mechanism and the screw rod transmission structure is designed, and the simulation in variable structure verifies the screw drive design principle of rationality. Finally, variable structure of the robot in expansion and contraction experiments were carried out. Experimental results show that the correctness of the variable structure.**

Key words - wheel-track,structure design, **m*obile robot.***

I. Introduction

Up to day, there have been numerous studies on the mobile robots since they can help human perform the dangerous missions in complex and unpredictable environments, such as planetary exploration, intelligence and reconnaissance, anti-terrorism, and rescue, and so on[1-3]. For example, when a sudden disaster happens, it is required that the robot should go through the irregular terrain quickly and arrive at its destination in time. If the robot had a poor ability to overcome the obstacles, it would fail to finish its work because it possibly wanders or runs aground in a place. Therefore the robots should have prominent flexibility and traversability. In such situations, various robots have been developed. Generally, the track mechanism and the hybrid mechanism are more adaptive to the rough terrains. Since it has the advantages such as excellent stability, low terrain pressure and simple control system, the tracked-type robots have been widely applied in irregular environments, and one kind is called 'transformable track robot'. For example, CALEB-2 [4], VSTR [5], VGTV [6], Single-Tracked [7], ROBHAZ-DT [8], NEZA-I [9] and some others belong to this kind of robots. They are designed to maximize flexibility and adaptability to rough terrains by adjusting configuration of tracks. They can reduce the energy consumption by minimizing the contact length with the ground.

According to advantages and disadvantages of above types of robots, a new type robot called wheel-track robot has been researched in recent years [10-15]. On flat ground, it can walk in wheel mode to save energy and has a relatively high velocity; while on rough road or stairs, it can go through in track mode as shown in figure1.

In this paper, a novel transformable wheel-track robot has been developed, and referring to previous researches [16][17], the structural design of the robot are analyzed. Section II introduces the structural system of the robot, Section III introduces the control system of the robot, Section IV briefly chooses drive motor according to driving power and climbing power and introduces the variable structure design of the robot. Section V validates the rationality of the robot's variable structure. Finally, our conclusions are offered in section VI.

II. Mechanical Structure of the Robot

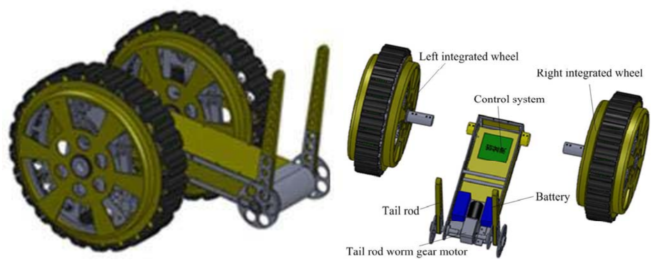


Fig. 1 Mechanical structure of the robot.

The structure diagram of the robot is showed in figure 1, including four parts, variable structure device, a walking device, the box body and the tail rod. The robot adopts the integrated wheel scheme. Worm gear motor and screw type variable structure of variable structure mechanism and DC motor are arranged in the walking wheel. So the box contains only power supply, the tail rod motor and control system etc. Track mode realizes the meshing of tracked tooth and tooth ring under wheeled and tracked different length. The tail adopts 360 degree turnover form. This form of integration is very high, adopting a highly integrated modular, easy disassembly, very suitable for people to carry module.

III. Control System of the Robot

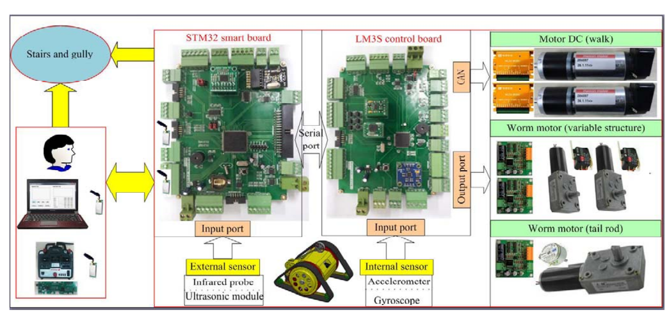


Fig.2 Control system of the robot.

The robot control system adopts hierarchical structure, composed of smart board and control board, complishing collaborative human computer interaction, external environment detection and pose control function as shown in figure2. The command is input intelligent plate by the operator according to the change of external environment through the wireless terminal, through the wireless terminal is sent to the control board to analyse, controlling 2 DC gear motor and 3 worm gear motor movements, so as to realize the control of the robot's pose. Pose information is got through real-time sensor sensing robot connected on the control board gyro internal and this information by the smart board is feedback to the operator, reflecting in the PC man-machine interface. The operator according to the feedback information and real-time environment resets robot pose requirements and requirements through the PC interface or the remote control are sent to the robot end. In the process of mobile robot, the external sensor, infrared ultrasonic probe will detect some external environment information sent to the control board to assist the operator some obstacle avoidance work.

IV. WALKING DEVICE DESIGN OF WHEEL-TRACK ROBOT

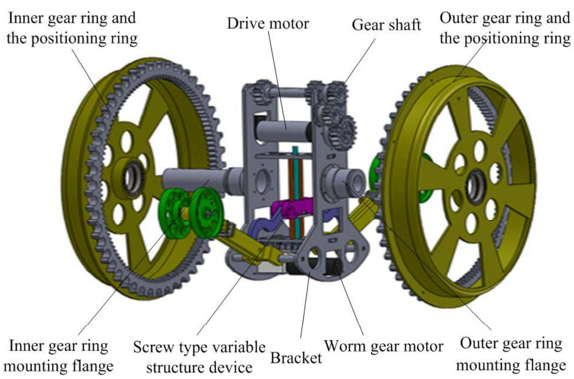


Fig.3 Walking device design of wheel-track robot.

The design of the integrated wheel scheme is shown in figure3. Inner gear ring fixedly is connected with the positioning ring through a bearing installed on the bracket (with the box body fixed) to complete radial location of the ring gear, and then through the card spring realizes axial positioning, outside the ring gear and inner gear ring are exactly the same. A driving motor is fixed on the bracket and the driving gear shaft is driven through a gear, the other two gear on gear shaft and inside and outside gear through the gear meshing transmission. In order to ensure the motor line through the connecting shaft, supporting a two through holes, the inner gear ring mounting flange is made of hollow structure. The positioning method is simple and compact.

In order to make the robot obtain the large dynamic characteristics, according to track dynamic performance as the standard, so the robot can achieve better performance to switch to the wheel.

A. *Driving power*

According to the technical requirements, assuming that the acceleration of the robot on the ground is 0.5m/s2, in the movement of the mobile robot, the forces are showed in figure 4, the balance equation.

$$F_t = F_a + F_r + F_i \quad (1)$$

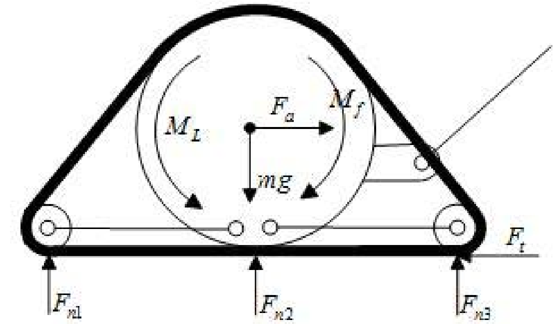


Fig.4 Forces of robot driving on flat ground.

F_t —traction force

F_r —soil resistance force

F_a —inertia force

F_i —inertia force when the robot starts

$$F_r = \frac{2W}{(n+1)\left[\frac{K_C}{W} + K_\varphi\right]^{1/n}} \left[\frac{2mg\cos\alpha}{3W}\right]^{n/(n+1)} \quad (2)$$

n —characteristics of ground subsidence parameter

K_C —ground cohesion modulus

K_φ —ground friction viscosity

W —weight of the robot

$$F_a = ma \quad (3)$$

$$F_i = \lambda_i mg \quad (4)$$

The parameter λ_i according to the soil ground condition is 0.01—0.05.

The traction force can be expressed as

$$F_t = (M_L - M_f) / R \quad (5)$$

M_L —output torque of the driving wheel

M_f —driving wheel friction resistance torque

R — Walking wheel radius

In order to simplify calculation, M_f =0.2 M_L, calculating the torque of the driving wheel M_L =3.12 N·m.

B. *Climbing power*

Compared with the flat ground running, climbing ability is an important index to measure the ground mobile robot and driving ability. If the robot is in the maximum index on the thirty degrees slope with the acceleration of linear motion a=0.25m/s^2, accelerating to 0.5m/s, in this process, the forces of the robot are showed in figure5, balance equation.

$$F_t' = F_r + mg\sin\alpha - F_a' + F_i \quad (6)$$

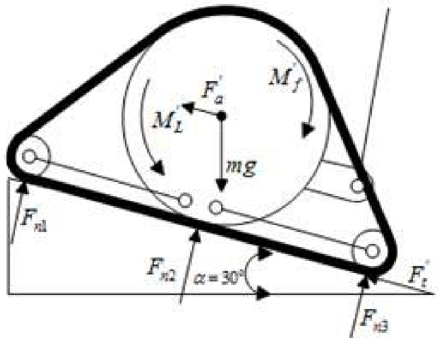


Fig.5 Schematic diagram of robot climbing caterpillar in track mode.

The traction force can be expressed as

$$F_t' = (M_L' - M_f') / R \tag{7}$$

Comprehensiving type(6),(7), the follow parameters are available.The torque of the driving wheel is M_L=28.16N·m.The single axle resistance torque is M_f =13.14 N·m.

The maximum mechanical power of the single motor is

$$P = KM_L' n \frac{\pi}{30} / \eta \tag{8}$$

K —safety factor ,getting 1.3.

η —transmission efficiency, getting 85%.

n —speed, r/min.

Getting P=118W, according to the above calculation, selection of motor performance is showed at the table1.

TABLE I
DRIVE MOTOR PERFORMANCE PARAMETERS

Motor data	Company	index
Nominal power	W	150
Rated voltage	V	24
No-load current	mA	137
Rated speed	rpm	6370
Starting torque	mNm	2280
Rated current	A	5.77
Rated torque	mNm	170
Maximum efficience	%	88
Torque constant	mNm/A	30.2
Weight	Kg	0.48

When the motor is selected, according to the demand of the maximum continuous torque and rated torque, the selection of gear box is decided.

$$i = \frac{M_L'}{M_{rated}} \tag{9}$$

Getting i=79.41.Ultimately determining the 3 stage planetary gear box GP42C matching motor, the reduction ratio is 81, the quality is 0.46kg, the maximum transmission efficiency is 72%, the maximum output torque is 15N·m, the allowing instantaneous output torque is 22.5 N·m.

In determining the reduction ratio, the maximum speed value is checked.

$$v = \frac{n_{rated} \times 2\pi \times R}{i \times 60} \tag{10}$$

the value v=1.57m/s>1.5m/s meets the requirement of speed.

C. *Screw drive design*

Variable device all as shown in figure 6 is integrated between the within slice piece wheel and the outside slice piece wheel, including worm drive motor, which is arranged on the bracket and the bracket is fixedly connected with the box, the trapezoidal screw rotation is driven by gear, the nut matched with the trapezoidal screw is fixedly connected with a driving rod, The driving rod to move up and down direction is achieved through the optical axis fixed between the two connecting plates and the internal installation of linear bearing. Through the pros and cons of worm motor rotation, so as to realize the swing arm to shrink and expand the function.

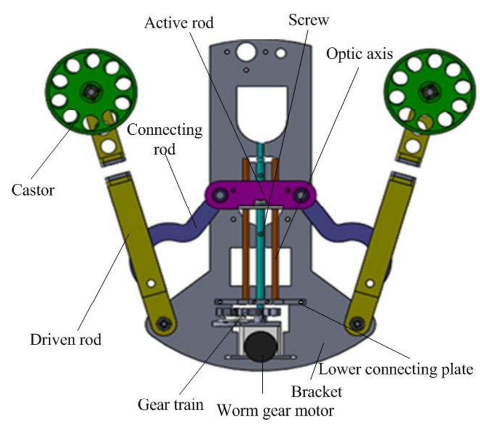
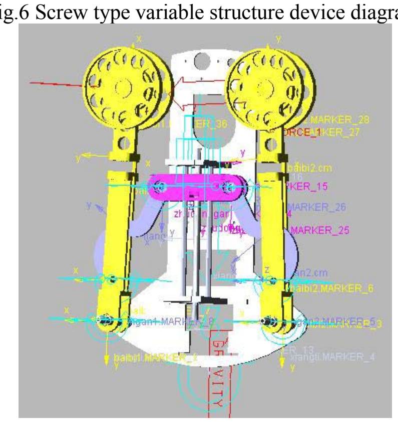


Fig.6 Screw type variable structure device diagram.



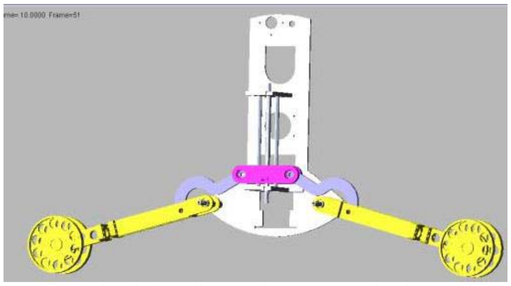


Fig.7 ADAMS simulation diagram in screw mechanism with variable structure.

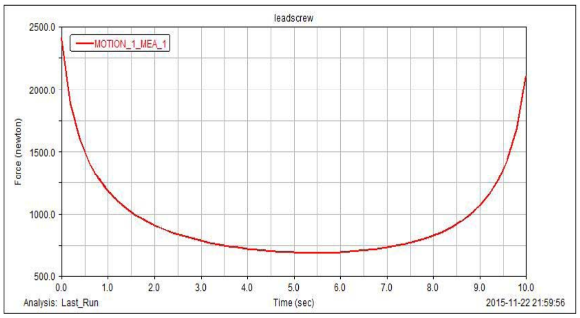


Fig.8 Simulation results of Adams in screw mechanism with variable structure.

By the simulation experiment of the robot, getting the torque curve in figure 8, It is visible in the beginning and end the stage of the torque demand is the biggest, mainly the end was considered, because track was in a relaxed state at the beginning,so start phase of the simulation results should be ignored, but according to the second half of the simulation results shows push force active bar demand is about 2100N.

According to the calculation formula of screw thrust

$$P = 2\pi\eta T / L \tag{11}$$

η — Screw drive efficiency about 0.9-0.95.

T —torque, N·m.

L —screw Lead,mm.

The screw lead is 2mm, calculating the required motor torque. In the final the selection of variable structure motor is GW31ZY and its rated speed is 27r/min, rated torque 2.5N·m, rated current1.2A.

V. EXPERIMENT PROTOTYPE AND EXPERIMENTAL ANALYSIS

A. *Experimental prototype and parameters*

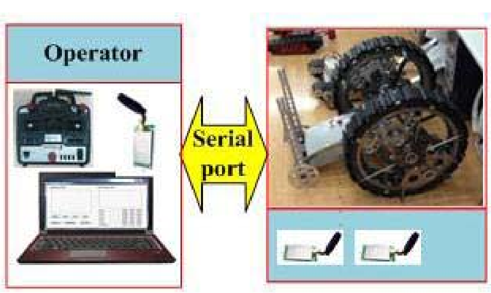


Fig.9 Experiment prototype.

Wheel-track variable structure mobile robot experimental system includes robot platform and user control terminal, as shown in figure 9. The operator through the remote controls robot wheel and track switch, tail rod rotation and forward backward position transformation, All attitude data during operation are sent to the computer PC interface through the wireless transmission module, including the attitude data of the wheel / track robot when it runs.

The basic parameters of the robot platform developed by the laboratory such as weight, size, each part of the structure are showed in table 2.Two modes are shown in the figure 10 and figure 11.

TABLE II
PROTOTYPE PARAMETERS

Parameter type	value
Length*width*height(mm)	620x580x470
Weight (kg)	24
Material	Aluminum
Variable structure mode	Screw drive

Fig.10 Robot track mode diagram.

Fig.11Robot wheel mode diagram.

B. *Variable structure device test*

The purpose of this experiment is testing variable structure of the wheel/track robot dynamic switching by the single wheel, to verify the motion characteristics of wheeled and tracked mechanism and motor selection is reasonable.

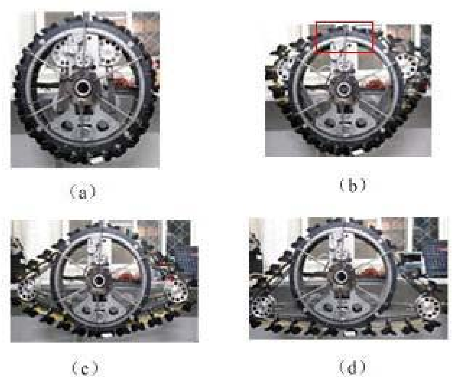


Fig.12 Expanding process of variable structure.

Figure 12 shows the expansion process of wheel /track variable structure. wheel state of the wheel/track robot is showed in figure12(a), When the user sends 'expand' instruction, the swing arm on both sides are drived by integrated worm motor of screw mechanism at the lower part of the wheel and the track gradual distracts. The position of swing arm wheel is higher, so the upper part of track is partial from the ring gear, as shown in figure 12 (b) Then with small arms further down the track appears meshing on the top and the ring gear, and the lower end of the track gradually apart the ring gear, as shown in figure 12 (c). In this process, the red area in figure 12(b) is located in the top gear ring, When the swing arm is expanding, and several teeth with gear ring meshing does not spread to have effective support, so the teeth of the track is in contraction state without effective tension, During the stretching process, when the track stretching to a certain length, such as in the intermediate state of figure 12 (c), can be short driving wheel rotation, so that the red area of track will mesh gear ring. Then stop walking wheel, driving track wheel makes the swing arm to finally complete switch to the track as shown in figure 12 (d).

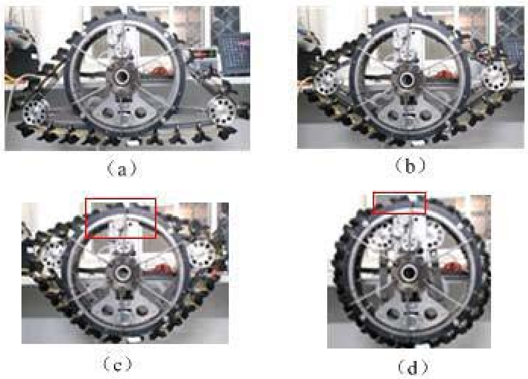


Fig.13 Contraction process of variable structure.

Figure 13 shows the retraction process of wheel /track variable structure. wheel state of the wheel/track robot is showed in figure 13(a),When the user sends 'retract' instruction, the swing arm on both sides are driven by motor of screw mechanism. At the end of track gradually meshing gear ring, and the top meshing of the track is the same compared to track mode meshing, as shown in figure 13 (b) shows, Then the swing arm for further recovery is engaged with the ring gear of the track, and the upper part is gradually away from the ring gear, as shown in figure 13 (c). Due to the upper several teeth on the swing arm in the process of contracting to a swing arm wheel effective support, resulting in not by the track meshing state switching to wheel meshing state, culminating in the shrinkage phenomena such as figure 13 (d) shown in the swing arm contraction process. The same solution is short slowly rotating wheels, contraction effect will be better. In fact, from figure 13 (d) in the state of contraction, the track has become a basic institution in the round, less demanding occasions can walk to the wheel.

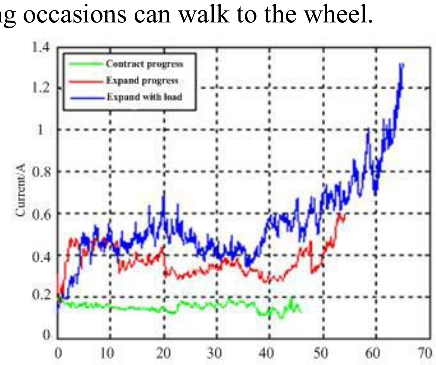


Fig.14 Current chart of screw expanding and contracting mechanism.

Figure 14 is the rated voltage and current curve in the motor in the process of the contraction and expansion process .The expanding time is about 55s, and the middle section of the torque needed is smaller, the required current in 20s before and after 10s is relatively large, the maximum torque appears at the end, the size is about 0.65A, and recover the process takes about 45s or so, the whole curve is relatively stable; the load expansion refers to prop up its body of the robot, in the first 10s, the current curve and the expansion process is basically the same, this is because the track has not yet begun to propup the grounding box, and the box grounding current larger, continuous the whole process is maintained at current rated current of 1.2A motor, but in the beginning of 60s, the motor current increases sharply, mainly due to the track tension caused by the increasing, in practice can be considered reasonable setting the opening degree.

VI. Conclusion

This paper mainly introduces the system components of the wheel-track robot, mainly comprising a body structure and control system. Through the analysis of the driving power and the power of the selection of crawling, motor drive of the robot is chose. Variable structure adopts a screw rod transmission mechanism and the screw rod transmission structure is designed, and the simulation in variable structure verifies the screw drive design principle of rationality. Finally, variable structure of the robot in expansion and contraction experiments were carried out. Experimental results show that the correctness of the variable structure.

Acknowledgment

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References

[1] Chaoquan Li, Fangxing Li, Shusan Wang, Fuquan Dai, Yang Bai, Xueshan Gao, Li Kejie. Dynamic Adaptive Equilibrium Control for a Self-Stabilizing Robot Proceedings of ROBIO2010 IEEE.

[2] Chai, X., Gao, F., Pan, Y., Qi, C., and Xu, Y.: 'A Novel Identification Methodology for the Coordinate Relationship between a 3D Vision System and a Legged Robot', Sensors, 2015, 15, (4), pp. 9519-9546

[3] Wang, Y., Miao, Z., Zhong, H., and Pan, Q.: 'Simultaneous Stabilization and Tracking of Nonholonomic Mobile Robots: A Lyapunov-Based Approach', Ieee Transactions on Control Systems Technology, 2015, 23, (4), pp. 1440-1450

[4] H. Kwon, H. Shim, D. Kim, S. Park, and J. Lee, "A Development of a transformable caterpillar equipped mobile robot," in IEEE Int. Conf. on Control, Automation and Systems, 2007,pp.1062-1065.

[5] K. Choi, H. Jeong, K. Hyun, H. Choi, and Y. Kwak, "Obstacle Negotiation for the Rescue Robot with Variable Single-tracked Mechanism," in IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics, 2007, pp. 1-6.

[6] J. Paillat, P. Lucidarme, and L. Hardouin. (2008, November).Variable Geometry Tracked Vehicle (VGTV) prototype: conception, capability and problems. Available: http:// conferences. enst-bretagne. fr/ data.

[7] J. Kim and C. Lee, "Variable transformation Shapes of Single-Tracked Mechanism for a Rescue Robo," in Proc. IEEE Int. Conf. on Control, Automation and Systems, 2007, pp.1057-1061.

[8] W. Lee , S. Kang, M. Kim, and K.Shin. "Rough terrain negotiable mobile platform with passively adaptive double-tracks and its

application to rescue missions." IEEE Int. Conf. on Robotics and Automation, 2005, pp. 1591-1596.
[9] LI Zhi-qing, MA Shu-gen, LI Bin. Analysis of the constraint relation between ground and self-adaptive mobile mechanism of a transformable wheel-track robot[J]. Science China: Technological Sciences, 2011, 54(3), 610-624.
[10] NOVOPLANSKI Avishay, RAIZER Liran, RINBERG Gregory,TRACTION SYSTEM: Israel, WO 2011/004362 A1[P]. 2011-01-13.
[11] Wang D X. Mechanical Study of Barrier-free Wheelchair System with a Wheel-tracked Coupling Mechanism [D].Beijing: Beijing Institute of Technology, 2012.
[12] Fu Y L, Li H H, Zhang F H. Design and Kinematic Analysis of Anti terrorism Robot With Wheel-tracked Variable Structure[J].Machinery & Electronics, 2011, (10): 66-69.
[13] KANG Shao-hua HUANG Lin SHI Cai-hong. Design and analysis on reconfigurable rubber-track variant wheel[J]. Chinese Journal of Construction Machinery, 2014, 12(4), 320-324
[14] Luo Z R, Shang J Z, Xi L, et al. A Wheel-track complex tracked robot: China, 201210089271.X[P]. 2013.01.02.
[15] Pang A S, Ou Y S, Wu X Y, et al. Wheel tracked mobile device and its hub : China, 201310261012.5[P].2013-10-2.
[16] Guo W, Jiang S, Zong C, et al. Development of a transformable wheel-track mobile robot and obstacle-crossing mode selection[C]// Mechatronics and Automation (ICMA), 2014 IEEE International Conference on. IEEE, 2014:1703-1708.
[17] N. Sato, F. Matsuno, Development of a high mobility wheeled rescue robot with a 1-DOF arm. Int. J. Adv. Mechatron. Sys. 1(1), 2008, pp. 10-23.