Evaluation of Wheel-based Mobile Robot Performance for Simple Environmental Obstacles

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Abstract: For the evaluation of the mobile robot performance in complex environments, the experimental approach in an actual physical environment has been commonly taken. In the physical experimental approach, however, it is quite difficult to define the proper environment for the evaluation due to the lack of commonly agreed characteristics of the test environment. Particularly the number of combinations of types and physical parameters of the obstacles that the mobile robot is expected to deal with is practically unlimited. In an effort to simplify and improve the effectiveness of the evaluation process, we propose an evaluation method using decomposed environmental elements, where we evaluated the performance of the robot for a small group of simple and decomposed obstacle components, for examples projection and slope, instead of a large group of complicated random obstacles. The paper describes a set of simple obstacle models and performance parameters that we have chosen for the effective evaluation process. As an alternative to the physical experimental evaluation approach, in this paper, we used a virtual evaluation environment where the robot and the physical test environment has been modeled using a commercial multi-body dynamics analysis packaged called RecurDyn.

Key word : Mobile Robot, Performance Evaluation, Obstacles,

1. Instruction

The necessity of the evaluation standard for a robot has been issued since the robot market became one of the most valuable industrial fields, however there is not yet any international evaluation standard due to different structure, ability and parameters that the robot individually have according to the using purpose..

To evaluate various robots and establish the evaluation standard, many local evaluation methods are developed and among them, the most common method is to run and evaluate the actual robot in a physical environment that the robot is anticipated to be operated in.

National Institute of Standards and Technology (NIST) in USA, one of representative robot evaluation institutes in the world, is developing a test course for evaluating the performance of autonomous mobile robots operating in an urban search and rescue mission (USAR). [1][2] However, it involves many difficulties including the difficulty in the actual construction of various and complex test environments, the restriction of the access to the evaluation facility due to the geometrical distance, the long process time required for the test and etc. evaluating in the complex environments like USAR we can not find out what kind of ability the robot is lack of if it can not achieve the tasks.

The actual dynamic environment that a mobile robot may be operated in is not too complex to be defined and constructed. It consists of many kinds of materials with different parameters: friction, roughness, density, weight and etc. It also has many obstacles, which is based on projection, slope and so forth. Consequently we can anticipate the evaluation results of the robot in the complex dynamic environment through the evaluation results in the individual obstacles with different parameters. In the other word, if the robot can get over the each obstacle then it can do in the composite environment which the obstacles compose. Moreover if the robot can not do we can find out which obstacle or what parameter are matters. Also we can evaluate the robot according to the kind of obstacles as well as the complex dynamic environment.

In order to evaluate the ability of overcoming obstacle, which is one of the robot mobility, the researches used the environment for the robot mobility test. However it also has difficulties as we described above.

To approach these difficulties, researchers have begun to consider the evaluation method on the computer with simulation programs to resolve those difficulties and inconveniences. It is believed that the simulation method has significant advantages in constructing the required test environments (consequently reducing the test cost), and in analyzing the dynamics of the performance of a robot as a whole and the performance of each individual module. In addition, the limited access to the test facility due to the geometrical location is no longer valid in the simulation approach. Recently, researchers in NIST have developed an evaluation method based on simulation for the autonomous robotic system. As the core of their simulation program, they used graphical simulation engines which are originally developed for the 3D games. On the simulation platform they constructed a simulation model of the mobile robot and the environment same as the physical evaluation environments (USAR). However, in the simulation approach they focused on the overall performance of the robot in complex dynamic environments, USAR, not in the environment which has each simple basic obstacle.[3]

In this paper, we measure this ability with RecurDyn to evaluate mobility of wheel based mobile robot as ability of overcoming obstacles. We also propose the evaluation standard as one of examples, which shows ability of overcoming.

2. Simulation test bed

2.1Simulation Tool; RecurDyn

In this paper we used a commercial multi-body dynamics analysis package called RecurDyn. Due to the improved integration algorithm and improved analysis capability in the surface contact behavior, the package produces more accurate results in much smaller computing time than the other currently available analysis packages. Using RecurDyn, a user can get the detail dynamics response of a robot as a whole and the dynamic responses of each individual module of the robot. In addition, RecurDyn is suitable for construction of various environments because for the construction of an environment it has a CAD tool box that includes obstacles and a material tool to create a required material.[4]

2.2 wheels based mobile robots

Due to most of wheel based mobile robots have three or four wheels to move, in this paper, we consider these two models. We also determine test parameters, velocity, weight,, friction and wheel size according to common wheel based robots', which are close to the parameter averages of the most indoor mobile robot. [5] It is shown on Table 1.

Table 1. Wheel based robot parameters

Wheel (mm)	Driving Shaft	100 * 40, 200 * 40
	Assist Wheel	50 * 30
Velocity	150 mm/s, 300 mm/s 450 mm/s	
Weight	10Kg , 20Kg	

* All assist wheels can be rotated according to external force.
* Wheel size: diameter*depth [cm]
* All of the robots are the front drive system.

2.2.1 A mobile robot with 3 wheels

The basic construction of a mobile robot with 3wheels that we modeled by RecurDyn is like Figure.1 and Table.2.

Fig 1. A basic model of 3 wheel based mobile robot.

Table 2. Wheels of three wheel based mobile robot

Wheel	Driving Shaft	2 units	1 DOF
	Assist Wheel	1 unit	2 DOF

2.2.2 A mobile robot with 4 wheels

The basic construction of a mobile robot with 4wheels is like following. figure.2 and table.3..

Figure 2. A basic model of 4 wheel based mobile robot

Table 3. Wheels of four wheel based mobile robot

Wheel	Driving Shaft	2 units	1 DOF
	Assist Wheel	2 units	2 DOF

2.3 Dynamic environment

Dynamic environment for a simulation is shown on the table 4, Figure 3 and 4. In the test bed, all obstacles, projection and slope, is at right angle to the direction of the mobile robots operation..

Table 4. Contact conditions between robot & ground

Installed coefficient list	value(unit)
Static friction coefficient	0.4 , 0.7, 1.0
Dynamic friction coefficient	0.2, 0,5, 0.8
Projection (square) [mm]	10, 15, 30
Slop [degree]	15, 20

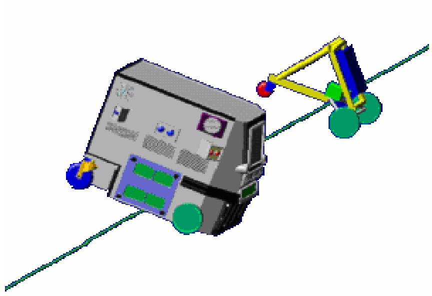

Fig 3. Test bed of Projection

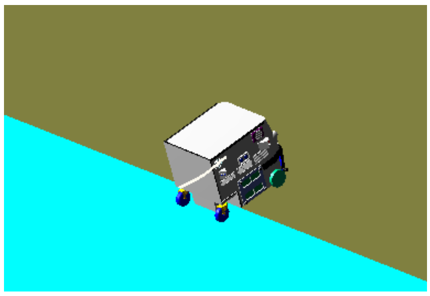

Fig 4 Test bed of Slope

4. Simulation results

4.1 The evaluation in the environment with projection

4.1 .1 the evaluation standard

In this paper, we define and divide the experiment results into 5 steps according to the evaluation standard as following descriptions and figure 5

1. First step O - The robot can overcome the projection with accuracy.
2. Second step ≗ - it can do with the angle error under 20 degree as Figure
3. Third step △- it can do with the angle error over 20 degree as Figure
4. Fourth step ⓧ - it can just run over the projection, however the direction is extremely different as Figure.
5. Fifth step X - it is stuck due to the projection

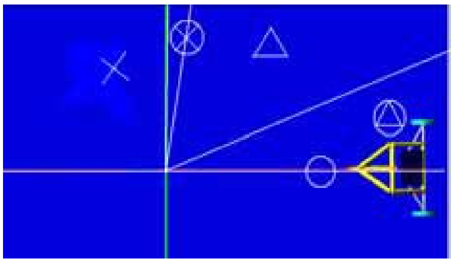

Fig 5. Definition of the evaluation standard for the projection

4.1.2 The evaluation result for the projection

The evaluation results of the wheel based mobile robot are shown in the Table 5~7

* Unit V : cm/s,   W : Kg,   projection size : mm

Table 5 the evaluation result for projection 10*10 mm (Wheel size [diameter]: 100 mm)

a. the mobile robot of 3wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	O	O	ⓧ	ⓧ	O	X	O	O
W 20	x	O	O	X	O	O	X	O	O

b. the mobile robot of 4wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	[illegible]	O	[illegible]	O	O	[illegible]	O	O
W 20	X	X	O	△	△	O	O	O	O

Table 6 the evaluation result for projection 15*15 mm (Wheel size [diameter]: 100 mm)

a.the mobile robot of 3wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	X	ⓧ	X	X	X	X	X	ⓧ
W 20	X	X	X	X	X	X	X	X	X

b.the mobile robot of 4wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	X	X	X	ⓧ	△	X	ⓧ	ⓧ
W 20	X	X	X	X	ⓧ	△	X	X	ⓧ

Table 7 the evaluation result for projection 30*30 mm (wheel size [diameter]: 200 mm)

a.the mobile robot of 3wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	O	△	O	O	X	O	O	O	O
W 20	△	X	O	O	X	O	O	O	O

b.the mobile robot of 4wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	O	ⓧ	[illegible]	[illegible]	O	O	O	△	O
W 20	O	O	O	O	O	O	O	O	O

4.2 The evaluation in the slope environment

In this case, we divided the simulation results into 3 steps as following and Fig 6.

1. First step O - The robot can climb on the slope
2. Second step △ –it can not do exactly, but it will run up on the slope over 10cm high as Figure 6. It may overcome a small projection.
3. Third step X – it is stuck or run up on the slope only under 10 cm as shown in the Figure 6.

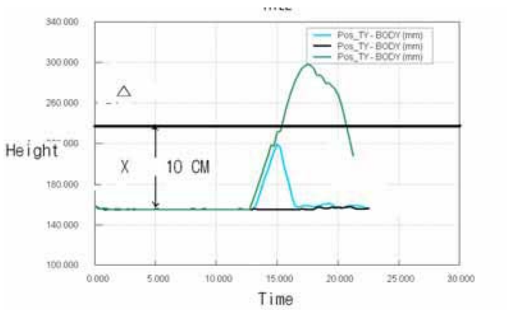

Fig 6. Definition of the evaluation standard for the Slope

If the robot can run up on the slope, its slip phenomenon may rarely occur. So it is not suitable to determine the evaluation standard according to the grade of slip phenomenon. The evaluation results of the wheel based mobile robot in the slope are shown in the Table 8 and 9.,

* Unit V : cm/s,   W : Kg, slope angle : degree
* All of the robot wheel size is 10 cm [diameter]

Table 8.   The evaluation in 15 degree slop

a. the mobile robot of 3wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	△	X	X	△	O	O	O	O
W 20	X	△	X	X	O	O	O	O	O

b. the mobile robot of 4wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	x	x	△	△	△	△	O	△	△
W 20	x	2	x	△	△	△	O	△	△

Table 9. The evaluation in 20 degree slope

a. the mobile robot of 3wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	X	X	O	O	O	O	O	O
W 20	X	X	X	X	O	△	O	O	O

b. the mobile robot of 4wheels

Friction	04. / 0.2			0.7 / 0.5			1.0 / 0.8		
V	15	30	45	15	30	45	15	30	45
W 10	X	X	△	X	△	△	△	△	△
W 20	X	X	X	X	X	△	O	△	△

4.3 The evaluation in the complex environment

We construct the complex environment as Figure 7 with the evaluation results of projection and slope to evaluate the robot. We define and divide the experiment results into 3 steps according to the evaluation standard as following descriptions.

1. First step O - The robot can get over the complex obstacle as shown Fig 7.
2. Second step ◎ - it can just run up with wrong direction as Fig 8
3. Third step △ – it will run up on the slope over 10cm high as definition of △ in slope section. It is shown in Fig 9.

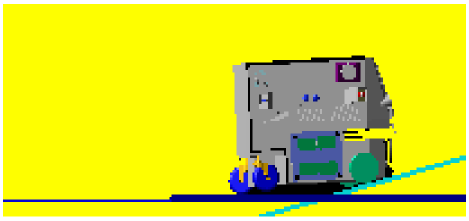

Fig 7. The complex test bed

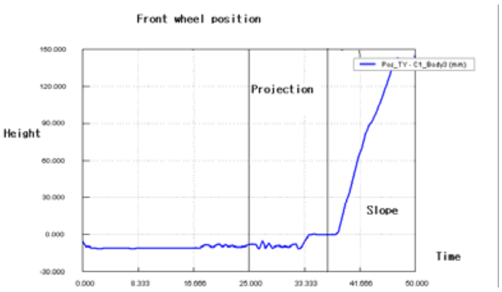

Fig 7. The trace of the first step position, O

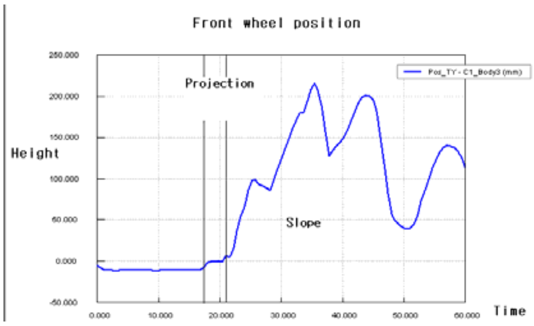

Fig 8. The trace of the second step position, ◎

Fig 9. The trace of the third step position, △

The evaluation results of the wheel based robots in the complex environment like Fig 7 are shown in Table 10.

Table 10. The evaluation in the complex environment

Projection [mm]	Slope [degree]	Result
10*10	15	
O	O	O
	△	△
◎	O	◎
	△	△
△	O	△
	△	△

With these results shown in Table 10, we can anticipate the evaluation results which we do not examine in the complex dynamic environment by using the individual evaluation data of obstacles.

5. Conclusion

In this paper, we proposed and showed one of the evaluation standard examples by simulator in the dynamic environment. With the proposed method, we can anticipate the evaluation results of an actual mobile robot which has the parameters and conditions similar to the simulation before actual test for evaluation. In addition, if the robot can not perform in the given dynamic environment we can find out the reason why the robot can not do with data like numerical value, graph and visual simulation. We can also get the dynamic analysis data of robot performance to improve the robot ability.

However there are lots of basic obstacles like crooked or one side obstacles that we should consider in the dynamic environment. In order to establish the evaluation standard of robot, which is such huge work that individual research or institute can not do. It also takes long time to do. Consequently, the establishment of the evaluation standard for a robot is needed to be co-worked by all of the robot researchers for increasing the robotics industry.

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