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Study on the Calculation method of the Light Mobile Robot Motor Power

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***Abstract*—Light mobile robot's motor powers calculate and design is an important problem. It includes weight, velocity, motor power, slope angle, reduce gearbox, battery, etc. These factors influence each other. It is difficult to calculate precise each parameter. But it decides function and ability of mobile robot. In this paper, motor powers calculate method is advanced. There are many factors to consider. There are several aspects of calculate method are analyzed. The method can help mobile robot designers on how to design a robot's motor quickly and easily.**

***Index Terms*—mobile robot, vehicle, motor, power**

I. INTRODUCTION

LIGHT mobile robot a kind of robot. It moves freely on ground and completes some tasks. It can be used to dangerous environment detective, chemistry test, anti-terror, fight. It uses varied task models according to varied tasks. It can diminish death and hurt of people. Today, mobile robotic is a hot point in robot field. There are many techniques in a robot, include: mechanic, control, computer, sensor, wireless communication, remote control and navigation, etc [4].

One important problem is how to calculating robot's motor power. Because calculating motor power includes many factors, and it is very complex to calculate. It includes weight, velocity, motor power, slope angle, reduce gearbox, battery. These factors influence each other. How to select and calculate motor is very difficult. Some time we know weight, velocity, slope angle, want to know motor power. Some time we know motor power, velocity, slope angle, want to know weight. Some time we know motor power, weight, slope angle, want to know velocity. Some time we know motor power, weight, velocity, want to know slope angle. And upper velocity limited is fixed by technology of motor and battery [2].

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If motor power calculating is wrong, mobile robot may be slow, cannot climb slope even cannot turn direction.

Motor is driver of robot. It is made of copper and magnetite steel. All is heavy materials. So Motor is heavy in robot. The ratio of power and weight is the most important parameter of a motor. High ratio motor is better than low ratio motor.

Because motor is droved by electromagnetism force, electromagnetism force is determined by current, intensity of magnetite flied, air gap. It is difficult to raise electromagnetism force. But power of motor is determined by electromagnetism force multiply turn velocity. If motor velocity is high, power is correspondingly high. So a high velocity motor can supply more power than low velocity motor. High velocity motor is available in robot.

Step motor is not in very high velocity. Ratio of power and weight is low. AC motor needs AC power supply. But mobile robot only have DC power supply. If we use AC motor, it needs DC to AC convert device. And high volt of AC is dangerous to people. Moment of force motor is large in moment of force, but it is low velocity. Its ratio of power and weight is low. DC motor can turn very high velocity, usually reach 7000~8000rpm for commercial product. Its ratio of power and weight is high. So DC motor is propose to use in mobile robot.

Use advanced international DC motor can reduce weight. But price is much higher than ordinary motor. So we should balance price and parameter of motor. Advanced international DC motor is very precise. It cannot bear large force vibration. It is need to design protect device to protect motor, in order to prevent motor's damage.

If total robot is over weight, but motor is often have been fixed. Result is moving slowly, cannot climb slope, even can not turn. Robot across ability is low. To solve the problem, you have to change motor or gearbox, reduce motor velocity or change a bigger motor. Reducing velocity means robot is slow. A bigger motor means a new design and more heavy, and battery is bigger too. These will all waste time and money.

Because many robots are more weight than their design scheme, motor is designed according to design weight. Over weight often make robot cannot reach target performance of design.

In this paper, some motor power calculating methods are advanced. There are many factors to consider. There are several aspects of calculate method are analysed.

Because some people are beginner to design mobile robot, experiment is insufficient. Fail design may waste time and money. This paper helps those people on how to design a mobile robot. And it is useful to other designer to exchange experiment and point, design better mobile robot.

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This paper analyse five aspects of motor power calculate as follow:

1) Know weight, velocity, slope angle, calculate motor power.

2) Know motor power, velocity, slope angle, calculate weight.

3) Know motor power, weight, slope angle, calculate velocity.

4) Know motor power, weight, velocity, calculate slope angle.

5) Upper velocity limit.

□ MOBILE ROBOT'S CONSTRUCTION AND MATHEMATIC RELATION INTRODUCE

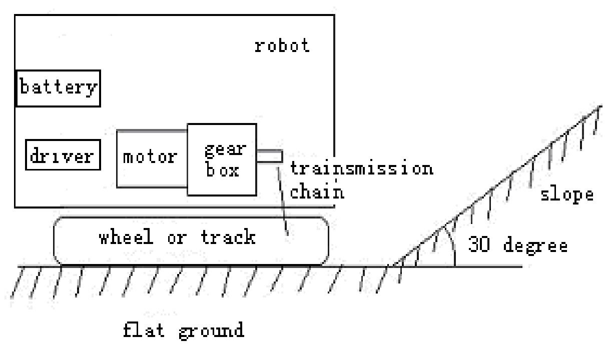

Fig.1. Mobile robot climb slope

Mobile robot is made up of body, motor, gearbox, wheel, track, driver, battery, computer, communicator, etc. Motor is original drive force of robot. Motor drives gearbox, wheel, and tracks. Robot moves on ground. Ground includes flat, slope, gully, stone, stair, and any obstacles. Main robot parameters include velocity and slope angle. See Fig.2.

If we know robot weight m, max velocity V_{max} m/s, max slope angleθ_{max}, motor max turn velocity R_{max}（rpm）, reduce gearbox ratio is i, wheel diameter is D（m）, friction coefficient isμ, motor power is P, calculate formula is :

$$P= F\times V= mg(\sin\theta+\cos\theta\times\mu)\times V \quad (1)$$

$$V = R/60/i\times\pi\times D \quad (2)$$

These two formulas are the most important formulas in this paper.

Because most robot haven't change ratio gearbox, moment of force is keep constant. It has to use max force in max velocity. That is equal to climb max angle slope in max velocity. This makes motor have more power than needed.

Motor rated power is not its real power. Motor' power is difference in difference work condition. Some motor rated power is 400W, but it real power is 300W.

□. MOTOR POWER CALCULATE METHOD

A. Know weight, velocity, slope angle, calculate motor power

(1) Calculate gearbox ratio:

Know weight, velocity, slope angle.

$i= R/60\times\pi\times D/V_{max}$

(2) Max motor power calculate:

$P_{max}= F_{max}\times V_{max}$

$= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu)\times V_{max}$

(3) Actual power calculate:

$P_{actural} = P_{max}/\eta_{effective}$

Example 1: A robot, weight is m=100kg, max velocity V=3.6km/h=1m/s, max slope angleθ_{max}=45 degree, friction coefficientμ=0.2, wheel diameter D=0.4 m, motor max turn velocity R_{max}=6000rpm, please calculate motor power and gearbox ratio.

1) Ratio calculate:

$i= R/60\times\pi\times D/V_{max}$

$=6000 /60\times\pi\times0.4/1$

$=125.6$

2) Max power Pmax calculate：

$P_{max}= F_{max}\times V_{max}$

$= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu)\times V_{max}$

$=100\times9.8\times(\sin45+\cos45\times0.2)\times1$

=831W

3) Actual power calculate:

$P_{actual} = P_{max}/\eta_{effective}$

=831/0.8

=1039W

So we should select motor power more than 1039W.

4) Drive part weight.

Switzerland Maxon DC motor is top motor in the world. Maxon DC motor and gearbox's ratio of power to weight is very high. It reaches 61.5W/Kg. Li storage battery's ratio of energy to weight is 107 WH/kg.

1039W motor and gearbox is 1039/61.5=17Kg

1 hour move time's energy is

1039W×1H=1039WH，

Battery is 1039WH/107 WH/kg=9.7kg

Motor, gearbox and battery is

17+9.7=26.7kg

This means drive part of the robot is 26.7kg. Occupy 26.7% of total robot.

B. Know motor power, velocity, slope angle, calculate weight.

Because motor is fixed sometime, we have to calculate how much weight it can drive.

Example 2: If we select 800W motor, V=3.6km/h=1m/s, climb 45 degree slope, calculate max robot weight.

$P_{max}= F_{max}\times V_{max}= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu)\times V_{max}$

$800= mg\times(\sin45+\cos45\times0.2)\times1$

m=94.6公斤

So we know max robot weight is 94.6kg.

C. Know motor power, weight, slope angle, calculate velocity

Velocity is important in robot. If we change max velocity, motor will change very big. In short, if weight is big, velocity is slow. If weight is little, velocity is fast. Some time, if robot is over weight, we can reduce velocity to have move ability.

Example 3: In example 1, if we change velocity to 2m/s, then motor power is:

Max power calculate:

$P_{max}= F_{max}\times V_{max}$

$= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$=100\times9.8\times(\sin45+\cos45\times0.2) \times2$

$=1662W$

Actual power calculate:

$P_{actual} = P_{max}/\eta_{effective}$

$=1662W/0.8$

$=2077W$

So we should select power more than 2077W.

The drive part weight:

$2077/61.5+2077\times1/107=33.8+19.4=53.2kg$

This means about 53.2% weight is occupied by drive part.

With rising of velocity, motor power and battery is increasing. Drive part ratio is increase too. So if it is possible to complete task, we should select velocity as low as possible to reduce drive weight.

A American light robot is 18kg weight, max velocity is 14km/h.

$P_{max}= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$=18\times9.8\times(\sin45+\cos45\times0.2) \times14/3.6$

$=595W$

Drive part weight is

$595/61.5+595/107=9.67+5.56=15.23kg$

This means motor is too big. It must have change ratio gearbox or cannot climb slope.

If it has change ratio gearbox, in flat ground:

$P= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$=18\times9.8\times0.2\times14/3.6$

$=140W$

Drive part weight is

$140/61.5+140/107=9.67+5.56=3.58kg$

And a change ratio gearbox weight about 2 kg, total 5.58kg. It is available.

D. Know motor power, weight, velocity, calculate slope angle

If robot weight, motor power, velocity are fixed, cannot change, we have to reduce degree of slop to climb.

Example 4: In example 1, if motor is fixed 800W, and cannot reduce velocity, how to design robot.

We could reduce slope angle.

$P_{max}= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$800\times0.8=100\times9.8\times(\sin\theta_{max}+\cos\theta_{max}\times0.2)\times1$

$0.653=(\sin\theta_{max}+\cos\theta_{max}\times0.2)$

$\theta_{max}=29$ degree

So, this robot only can climb 29 degree slope.

But there is a limit of the degree: 0 degree on flat ground.

$P= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$=100\times9.8\times(\sin0+\cos0\times0.2)\times1$

$=196W$

$P_{actual} = P_{max}/\eta_{effective}$

$=196W/0.8$

$=245W$

This is lowest robot motor power. If motor power is lower than 245W, robot cannot move on flat ground.

E. Upper velocity limit. (Max velocity is fixed by technology of motor and battery)

Example 5: If we use all weight 100kg on drive part. Let us calculate the upper limit of velocity. We set all 100kg is drive part: motor, gearbox and battery.

$100kg= P/61.5+ P\times1/107$

$P=3900W$

Because $P_{max}= F_{max}\times V_{max}= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$3900W =100\times9.8\times(\sin45+\cos45\times0.2) \times V_{max}$

$V_{max}=4.7m/s=17Km/h$

This velocity is upper limit of 100kg robot use electrical battery as energy supply. It can climb 45 degrees slope.

Actually, this is theory-calculating result. In fact, we need frame, wheel, track, axle, computer, communicator, supply convert, sensor and many other elements on robot. The velocity cannot reach 17Km/h. This robot can climb 45 degrees slope.

If we make new motor or new battery in future, this limit velocity may raise, but we can only reach this value now.

Now we calculate upper velocity if there is change ratio gearbox, on flat ground:

$P= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$P=(P/61.5+ P/107)\ g(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$3.984=(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

If in flat ground,

$\theta_{max}=0$ degree.

$3.984=(\sin0+\cos0\times0.2) \times V_{max}$

$V_{max}=19.92m/s=71.7km/h$, this robot have change ratio gearbox, run on flat ground.

71.7km/h is max velocity of mobile robot use battery. And all weight is motor and battery. If we add others elements, this value is low.

In ordinary experiments, mechanical part is weight equal to electrical part. In this ratio, only half weight can be used for motor and battery. Then

$P= mg(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$P=(P/61.5+ P/107) \times2\times g(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times V_{max}$

$1.992=(\sin\theta_{max}+\cos\theta_{max}\times\mu) \times2 \times V_{max}$

If in flat ground , $\theta_{max}=0$ degree.

$1.992=(\sin0+\cos0\times0.2) \times V_{max}$

$V_{max}=9.96m/s=35.9km/h$

This is an available velocity of robot.

Note: All above calculate is in condition of 1 hour move time.

□.CHANGE RATIO GEARBOX

From above analysis, we can see change ratio gearbox is very important. If there isn't a change ratio gearbox, we have to design motor power as they can climb max angle slope at max velocity. This method is very wasted. Because when robot is run on flat ground, some motor power is waste. When it climb slope, power is often not enough. We have to reduce max velocity to adapt this limit.

In fact, big vehicles we used in usually all have change ratio gearbox. There 4~10 different ratios can be changed to adapt different conditions. In flat road, we use little ratio, vehicle have little force but very fast. If you want climb a slope, you use large ratio, vehicle is slow but force is very large.

Mobile robot is in same principle. In flat road, it needs little ratio. Robot force is little but velocity is very high. When robot climbs a slope, it needs large ratio, robot is slow but force is very large to climb slope.

Because robot may be very far from you, this change ratio gearbox must be controlled by electric.

A. Electric control change ratio gearbox

There are many constructions to electric control change ratio gearbox. One is showed in Fig.2:

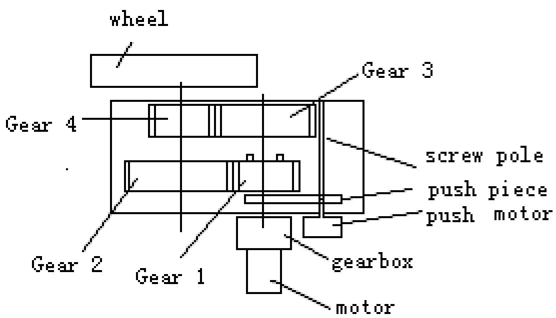

Fig.2. Change ratio gearbox

This gearbox has four gears. Motor and first reduce gearbox is fixed out side. First reduce gearbox out axle drives gear 1. Gear 2 and gear 4 is in same axle. When gear 2 is turn, gear 4 is turn too. Gear 4 drives wheel. Wheel drives track. Track drives robot moving on ground. If gear 1 is pushed up to gear 3, two nails on gear 1 will thrust into two holes on gear 3. Then gear 1 and gear 3 is fixed together. Motor will drive gear 1 and gear 3. Gear 3 drives gear 4. Gear 4 drives wheel. Wheel drives track. Track drives robot moving on ground.

The ratio gear 1 to gear 2 is 1:3. The ratio gear 3 to gear 4 is 3:1.Ratio changes from 1:3 to 3:1.This ratio can change 9 times. High ration is used to climb. Low ratio is used to run on road.

There is a push motor push gear 1 to two position. Up position is one ratio. Down position is the other ratio. When gear 1 is push up, robot is stop. Push motor turn, gear 1 raise slowly and turn slowly, until nail on gear 1 is thrust into hole on gear 3. When gear 1 is push down, robot is stop. Push motor turn, gear 1 down slowly and turn slowly, until teeth on gear 1 is engaged with teeth on gear 3.

B. Calculating motor power when robot have electric control change ratio gearbox.

If robot has electric control change ratio gearbox, we calculate motor power as follows:

1) Calculate motor power on flat ground.

Example 6: In example 1, we use a change ratio gearbox, ration from 1:3 to 3:1. Others parameters is same.

$P_{max}=mg(\sin 0+\cos 0\times\mu)\times V_{max}$
$=100\times 9.8(\sin 0+\cos 0\times 0.2)\times 1$
$=196W$
$P_{actual} = P_{max}/\eta_{effective}$
$=196W/0.8$
$=245W$

2) Calculate motor power on slope with electric control change ratio gearbox.

This is equal to velocity is 9 times slow.

$Pmax=mg(\sin 45+\cos 45\times\mu)\times V_{max}$
$=100\times 9.8(\sin 45+\cos 45\times 0.2)\times 1/9$
$=92.5W$
$P_{actual} = P_{max}/\eta_{effective}$
$=92.5W/0.8$
$=116W$

Think all above, we select 245W motor as robot motor. This is much smaller than 1039W motor. And is much light than that in example 1.

Drive part weight:

Motor weight: 245/61.5=3.98kg

1039w motor is 17kg. Although change ratio gearbox is 2 kg×2=4kg, total weight is 3.98+4=7.98<<17kg.

So change ratio gearbox can raise level of robot movement. It is proposed to use it in your robot.

3) In flat ground ratio calculate:

$i= R/60\times\pi\times D/V_{max}$
$=6000 /60\times\pi\times 0.4/1$
$=125.6$

This is total ratio of the first gearbox and change gearbox. In flat ground, we use first gearbox ratio is 125.6×3=377

When climb slop, change ratio, total ratio is 377 ×3=1131.

So in flat ground, total ratio is 125.6. On slope total ratio is 1131. This ensure robot run fast in flat ground and have large force to climb 45 degrees slope.

C. High velocity robot needs change ratio gearbox

Example 7: In example 1, if we use change ratio gearbox and use the original motor 1039W. We can raise robot velocity.

In example 1, we have 1039W/17kg motor. When we use change ratio gearbox:

In flat ground:

$P_{max} =P_{actual}\times\eta_{effective}$
$=1039W\times 0.8$
$=831.2W$
$P_{max}=mg(\sin 0+\cos 0\times\mu)\times V_{max}$
$831.4=100\times 9.8(\sin 0+\cos 0\times 0.2)\times V_{max}$
$V_{max}=4.24m/s=15.2km/h$

Velocity is much high than 3.6 km/h in example 1.

In slope, we change ratio, ratio change from 1:3 to 3:1. Velocity is 0.471 m/s=1.69km/h, but force is 9 times bigger than flat ground. That is enough to climb 45 degrees slope.

So if we want to design a high velocity robot, change ratio gearbox is a good device.

D. Change ratio gearbox is not suit to all robots.

When robot is bigger than 30kg, change ratio gearbox is a good device to reduce motor power. But in small robot, change ratio gearbox may be not available. Because in small robot, change ratio gearbox is also heavy, we may use a bigger motor instead of little motor and gearbox. And change ratio gearbox is complicated in construction. Use a bigger motor may be more suitable for a little robot.

□. OTHER MOTOR

Use electronic motor and battery, we cannot run very far away. Because that needs many batteries, it is too heavy to loading on robot. So we need other method to solve the problem.

Mobile robot can use other motor, such as oil engine. Oil use oil burn as source of energy. Oil energy is large than electronic motor and battery. If there is plenty oil in tank, it can run very long distance. The ratio of energy to weight is higher than electronic motor and battery.

Oil engine power calculating method is same as electronic motor:

$P= mg(\sin\theta+\cos\theta\times\mu) \times V$

$V =R/60/i\times\pi\times D$

But Oil engine is noisy. We can hear them from far away. This is bad to many tasks, such as detective enemy or anti-terror. And oil engine is complex than electronic motor and battery.

We can use mix scheme to solve problem. We use electronic motor-battery and oil engine on one robot. When robot runs long distance, oil engine is used to supply energy. When robot is closed to enemy, we use electronic motor-battery to move in silence.

□. CONCLUSION

This paper proposes a method of calculating mobile robot motor power. Every parameters of robot is analysed carefully and deeply. Think about many elements and factors of robot. A general method of motor power is proposed. Some examples of mobile robot are analysed and calculated. To vary aspects of conditions and requests, we can calculate corresponding parameters request. And technology limited is given to prevent unrealistic design target. Under the task of robot, adapt restriction of technology. The successful or fail robot design is judged by task of robot. This paper helps those mobile robots designer. And it is useful to other designer to exchange experiments and points, in order design a better mobile robot.

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REFERENCES

[1] Buccieri, D.; Perritaz, D.; Mullhaupt, P.; Zhong-Ping Jiang; Bonvin, D. Velocity-Scheduling Control for a Unicycle Mobile Robot: Theory and Experiments.;Robotics, IEEE Transactions on Volume 25, Issue 2, April 2009 Page(s):451 - 458

[2] Minguez, J.; Montano, L. Extending Collision Avoidance Methods to Consider the Vehicle Shape, Kinematics, and Dynamics of a Mobile Robot; Robotics, IEEE Transactions on Volume 25, Issue 2, April 2009 Page(s):367 - 381

[3] Ji, M.; Sarkar, N, "Supervisory Fault Adaptive Control of a Mobile Robot and Its Application in Sensor-Fault Accommodation", Robotics, IEEE Transactions on , Volume 23, Issue 1, Feb. 2007 Page(s):174 - 178

[4] Antonelli, G.; Chiaverini, S. "Kinematic Control of Flatoons of Autonomous Vehicles" Robotics, IEEE Transactions on , Volume 22, Issue 6, Dec. 2006 Page(s):1285 – 1292.

[5] Mariottini, G. L.; Oriolo, G.; Prattichizzo, D, "Image-Based Visual Servoing for Nonholonomic Mobile Robots Using Epipolar Geometry". Robotics, IEEE Transactions on. Volume 23, Issue 1, Feb. 2007 Page(s): 87 - 100

[6] Pei-chun lin,Haldun Komsuoglu,Daniel E.koditschek. "A Leg configuration measurement sys for fuu-body pose estimate in a hexapod robot," IEEE TRAN ON ROBOTICS, 2005, 21(3), pp.411~422.

[7] Bhattacharya, S, Murrieta-Cid, R, Hutchinson, S. "Optimal Paths for Landmark-Based Navigation by Differential-Drive Vehicles With Field-of-View Constraints". Robotics, IEEE Transactions on, Volume 23, Issue 1, Feb. 2007 Page(s): 47 - 59

[8] C.Laugier, TH.Fraichard, etc. "Sensor-Based Control Architecture for a Car-Like Vehicle," Autonomous Robots. 6, 1999, pp.165-185.

[9] Daigle M. J.; Koutsoukos, X. D; Biswas, G.;Robotics. "Distributed Diagnosis in Formations of Mobile Robots", Robotics, IEEE T ransactions on. Volume 23, Issue 2, April 2007 Page(s): 353 – 369

[10] Aleksandar D R, Miomir K V. "Contribution to the Integrated Control Synthesis of Road Vehicles" IEEE Transactions on Control Systems Technology, V 7(1), 1999, pp.64-77.

[11] Campion G.Bastin G.Novel B, "Structural properties and classification of kinematic and dynamic models of wheeled mobile robots," IEEE Trans. on Robotics and Automation, 1996, 12(1), pp.47-62