A Development of Remote Control Golf Ball Retriever Car

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Abstract

A remote control golf ball retriever car was developed to replace traditional equipment normally used in golf driving ranges. Typically, a professional golf ball retriever car requires the operator to be in the field during the operation. Therefore the machine is typically shielded for the operator safety. To reduce the risk and cost of the protection, a remote control ball retriever car has been successfully introduced. The machine has a simple configuration due to the absent of In-Car driver, and thus the equipments for the driver comfort is needless. In addition, the smaller and lighter car is more efficient and better in maneuver. This machine is powered by batteries and equipped with two independent driving wheels with a modified Ackerman steering mechanism. A permanent magnet DC brush motor was used in each wheel and its speed was varied using a PWM driver. The steering system is proportionally controlled by a microcontroller. Both driving and turning system were commanded through a standard pulse code used in common remote control radios. The prototype car was practically designed and made based on simple and economical considerations. The same configuration can be useful for similar applications which require Drive-by-Wire system.

Keywords*:* Drive-by-Wire, Golf ball retriever, Remote Control Car

1. Introduction

Today, golf is one of the most popular sports in Thailand, and it has been wildly played not just for wealthy people as it used to be. This sport is now affordable and available to all middle class people who mostly live in the city. Due to its particular requirement for a large play ground, in urban region, most people practice golf in driving range where all players can keep hitting golf balls out to the field without completing regular score. In this particular field many golf balls are circulated and require an efficient equipment to retrieve balls from the field back to the players.

Typical golf ball retriever vehicle requires the operator to be in the field during the operation. Therefore the car must be shielded using metal fender or similar materials for the operator safety. An example of these cars is presented in figure 1. This usually makes the vehicle heavy, cumbersome and expensive.

Fig. 1 A conventional golf ball retriever car

To reduce the risk of operator injury and cost of this protection, a remote control golf ball retriever car has been proposed. The objective of this development is to produce a prototype vehicle which has a simple configuration and low cost. The absent of In-Car driver eliminate the need for driver comfort components. In addition, the smaller and lighter car is more efficient and better in maneuver.

There has been numerous of the development for unmanned vehicle, but mostly they are automatically operated or semi-automatic. Certain developments are intended for cost sensitive applications which require just a remote control feature. Similar to this golf ball retriever car, most remotely controlled vehicle operate for the safety of the operator such as an insecticide vehicle used in farms [1]. For a long distance a real time remote visual system may be applied to assist the operator.

In this development, the drive by wire steering system was specifically designed for the remote control vehicle. Based on the typical Ackerman steering linkage which requires an optimum synthesis [2], the modified Ackerman system used in this design also needs a proper selection of all parameters in order to gain its best maneuver ability. The steering mechanism in this design is made for independent driven wheels which need compensation during the turn. This is similar to the versatile steering system made by Besselink [3] except that this retriever car need less maneuver ability. The car movement mainly relies on the operator skill and the interface using a remote control. This will also be presented in a later section.

2. The Design of Golf Ball Retriever Car

The design concept of new golf ball retriever is based on unmanned vehicle configuration. For this type of vehicle, driver does not travel with the car. Therefore the vehicle configuration is different from the traditional version, especially for certain components such as steering system. In addition, the main objective of this development was aimed for high efficiency machine and low production cost. The design of all systems and mechanism was carried on in such way.

2.1 Overall Vehicle Configuration

In order to determine the vehicle configuration, first the operation of golf ball picking device must be reviewed. There are several ways to collect ball from the ground. The most simple but effective method is by using ball picking roller. A diagram of this roller is presented in figure 2. The roller comprise of a series of rubber dishes mounted on a roller drum with a proper gap between the dishes. The size of each gap is slightly less than ball diameter. In this case a 40 mm gap is used. When the picking roller is driven on the ground, it rolls over the golf balls, and the flexible rubber dishes grab on the balls along the dish circumferences. As the ball sticks with the rubber dishes, it rolls up to the upper side of the roller and meets an incliner rail which sticks halfway into each gap. This rail is simply made of a rigid bar. It forces golf ball out of the dishes, and the ball fall to a container located in the front.

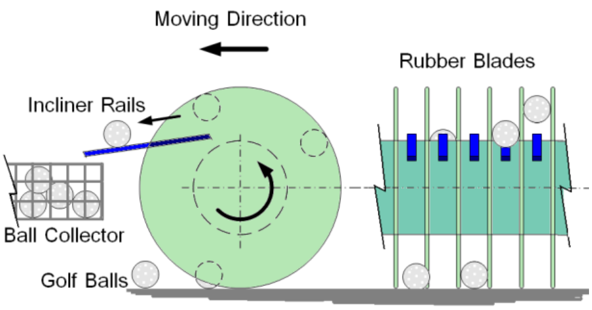


Fig. 2 A diagram shows golf ball picker device

Based on the ball picker working principle, the vehicle should have picker in front of it so that the wheels will not run over golf balls before the picker is able to pick the ball up. And because the ball picker roller must rolls on the ground when vehicle is moving, it can also serve as front wheels. However, because the width of ball picker roller should be equal to the width of the vehicle, driving and turning it will be difficult. For this reason, the ball picker roller is placed as a fixed position free wheel. The driving and turning wheels are designed to be at the rear of the vehicle.

There are several ways to steer a vehicle. In most small remote control vehicles with two independent driving wheels, different speed adjustment between two wheels is often used to control the vehicle direction due to its simple mechanism. However the golf ball picker roller cause very high friction and is not suitable to use such a steering method. Therefore a steering mechanism which is similar to the typical Ackerman type was selected to use with this vehicle.

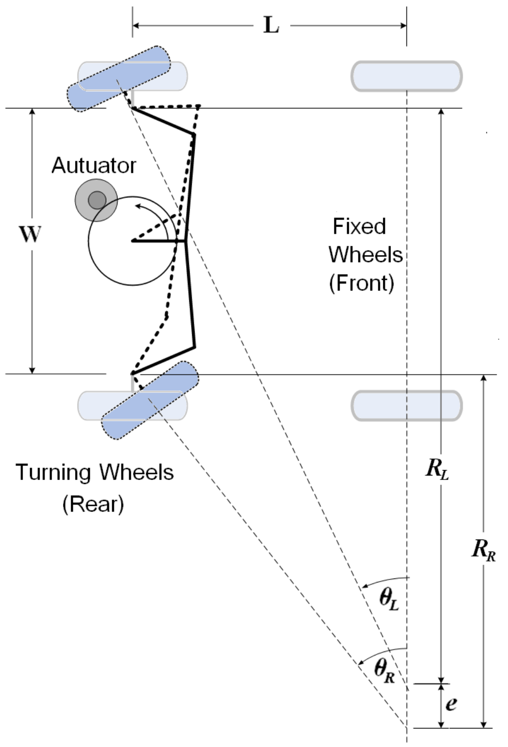
2.2. Modified Ackerman Steering Mechanism

Because the vehicle is remotely controlled and the steering mechanism is powered by a motor, it is more convenient to make driving mechanism symmetrical by placing a steering arm in the center. This will make the steering analysis same in both turning directions. The steering arm connects to both side of the wheel in a form of four-bar linkage. When the steering arm rotates, it pulls on one wheel and simultaneously pushes on the opposite wheel creating a turning action similar to the Ackerman steering mechanism. Figure 3 shows the diagram of this steering mechanism and its related parameters.

Typically if the four-bar mechanism has an equal length on each pair of the opposite linkage, it will turn both wheels in parallel manner which is the characteristic of the parallel four-bar linkage [4]. This will result a large different location between the turning centers of each wheel. Based on the diagram from figure 3, when the vehicle turns right, the error, e, measured between the centers can be expressed as:

$$e = R_R + W - R_L \tag{1}$$

where W is the width between both wheels, and R_R and R_L are the turning radius of right and left wheels respectively. In order to reduce this radius difference, the length of each linkage in this steering mechanism should be determined properly.



. Fig. 3 A diagram of the vehicle and its steering system

Considering the four-bar linkage applied to this steering mechanism as shown in figure 4, on each side, half of the wheel base width is the fist link which has a length of W/2. The steering arm, wheel arm and connecting rod represent the rest of the linkage elements and were designated as link A, B, and C respectively. At a neutral state where the steering arm locates at a zero turning angle, ø, both wheels are parallel, and the initial wheel arm angle, β, can be determined by:

$$\beta = \sin^{-1}\left(\frac{4A^2+4B^2+W^2-4C^2}{4\sqrt{4A^2B^2+B^2W^2}}\right) - \tan^{-1}\left(\frac{2A}{W}\right) \tag{2}$$

According to the vehicle geometry, this initial wheel arm angle also represents the angle between the wheel direction and the wheel arm when there is no turning. Typically if the steering arm and wheel arm have a similar length, the initial wheel arm angle should be set more than zero by making the connecting rod, C, to be less than W/2. When the steering arm rotates, this will result a contraction between the turning angles of the both wheels and reduce the difference of turning radius. The turning angles of right and left wheel, θ_R and θ_L, can be determined by:

$$\theta_R = \frac{\pi}{2} - \beta - \cos^{-1}\left(\frac{W^2+2AW\sin(\phi)}{\sqrt{W^2+4A^2+4AW\sin(\phi)}}\right) - \cos^{-1}\left(\frac{4A^2+4B^2+W^2+4AW\sin(\phi)-4C^2}{4B\sqrt{W^2+4A^2+4AW\sin(\phi)}}\right) \tag{3}$$

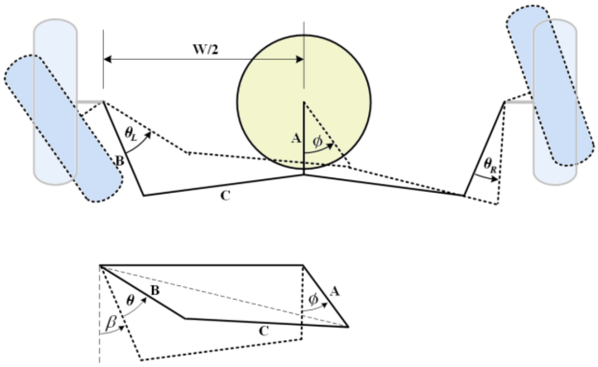
$$\theta_L = \beta + \cos^{-1}\left(\frac{W^2-2AW\sin(\phi)}{\sqrt{W^2+4A^2-4AW\sin(\phi)}}\right) - \frac{\pi}{2} + \cos^{-1}\left(\frac{4A^2+4B^2+W^2-4AW\sin(\phi)-4C^2}{4B\sqrt{W^2+4A^2-4AW\sin(\phi)}}\right) \tag{4}$$

Note that the turning angle is a function of steering arm angle. Typically for any set of a four-bar linkage, there will be a position of the steering angle where the turning centers of both wheels are overlaid. Unfortunately when the steering angle locates at different position, the error will present. The radius of each wheel can be determined as:

$$R_R = \frac{L}{\tan(\theta_R)} \tag{5}$$

$$R_L = \frac{L}{\tan(\theta_L)} \tag{6}$$

By applying Eqs. (5)-(6) into Eq.(1), the error between turning center of each wheel can be determined as a function of the steering arm angle.



. Fig. 4 Analysis of the four-bar linkage steering mechanism

The objective of this analysis is to reveal the design criterion for the steering mechanism, so that all link lengths can be properly determined for lowest slip and turning radius. For this particular design, the steering arm was made at 15 cm long, and the wheel arm was made at 20 cm long. The width of the wheel based is 110 cm, and the connecting rod is 43 cm. This gave an initial wheel arm angle at 28.6 degree. The plot of turning angle of both wheels and the difference of turning center is presented in figure 5.

At a small steering angle or slightly turning angle, it can be seen that both wheels have almost equal turning angles. As the steering angle increase the difference between both wheel angles is amplified in a way that the error between turning centers are reduced. The steering angle has a limited rage due to the reversion of the linkage movement. In this steering geometry, the maximum steering angle can be determined as:

$$\phi_{mzx} = \sin^{-1}\left(\frac{4(B+C)^2 - W^2 - 4A^2}{4AW}\right) \qquad (7)$$

Practically the actual steering angle will be made about 80-90% of the maximum value so that there will be a safe operation range. In this case the maximum steering angle was set at 35 degree which will give the vehicle turning radius at 1.4 m. The maximum error of both turning radius is 40 cm which occurs during a smallest turning angle. At the maximum steering, this error is reduced to only 12.5 cm. which is about 9% of that specific turning radius.

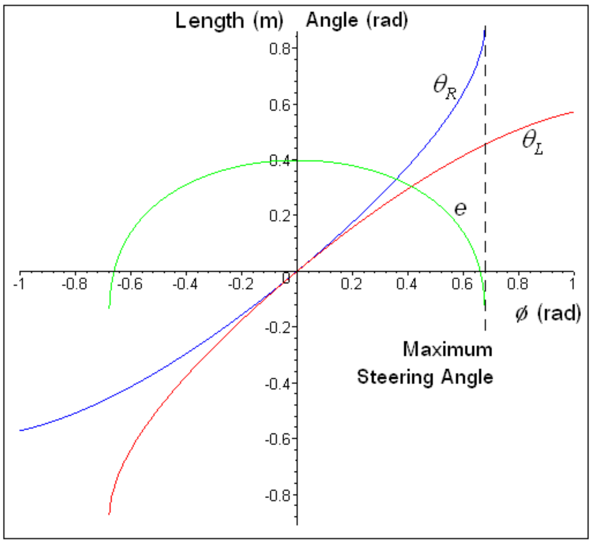


Fig. 5 Wheel turning radiuses and their difference in the function of steering angle

2.3. Actuator and Servo System

According to the design used in the steering system, there is only one actuating link controlling both steering wheels. The link locates at the center and performs similar actions when driving between left and right directions as already described in the previous section. The linkage is attached to a large roller chain sprocket and driven by an actuator. A DC brushed motor was selected as the actuator due to the battery power availability. The diagram of this steering servo system is presented in figure 6.

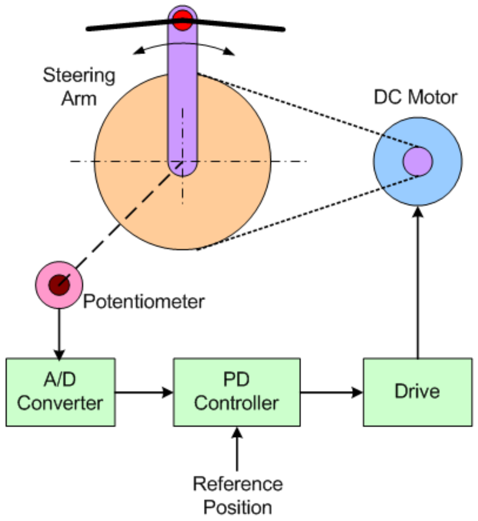


Fig. 6 A servo diagram for the steering system

Due to the main objective of this development which is to produce a low cost remote control vehicle, the steering servo system was also designed for the same purpose. Instead of using expensive encoder, a low cost metal film potentiometer was selected as a positioning feed back sensor. Its position is converted into a discrete value using A/D converter. This digital position is fed to a PD controller which also receives a command position as a reference position from a remote control. The error position, P_{err}, between the reference position, P_{ref}, and the actual steering arm position, P_{arm}, is evaluated by the controller as:

$$P_{err} = P_{ref} - P_{arm} \tag{8}$$

Although the potentiometer has a continuous variable output, its resolution is limited by the capability of the A/D converter. In this development, a 10 bit A/D converter was used and can produce up to 1024 discrete position throughout the turning range. Unfortunately the digital output from A/D results a certain amount of noise which cause the fluctuating position even when the steering arm is not moving. To reduce the fluctuation, a simple signal average routine is used and finds the mean value of error position as:

$$\overline{P}_{err}(n) = \frac{\sum_{i=n-m+1}^{n} P_{err}(i)}{m} \tag{9}$$

where m is the number of the post position before the current position read. This average positioning err is fed to a positioning PD controller. Due to the narrow operating range of the steering arm and the unknown load that may occur differently when the vehicle working in an uneven ground, a PD controller was selected for its stability. This may result a small dead band around the target position due to the absence of the integral term. Fortunately because the vehicle is constantly monitored and controlled by an operator, this small dead band therefore can be compensated by the operator through the command position. The actual command determined by the controller in a discrete form can be presented as:

$$u(n) \;=\; K_p \overline{P}_{err}(n) + K_d \frac{\overline{P}_{err}(n) - \overline{P}_{err}(n-1)}{T_s} \tag{10}$$

where $\overline{P}_{err}(n)$ and $\overline{P}_{err}(n-1)$ are the input error at time step n and n-1. Ts is the sampling time for derivative term. The magnitude of the proportional and derivative terms can be assigned by the gain factors K_p and K_d respectively. Basically the sampling time for the derivative term is larger than the time step which was set at 5 ms or 200 samples per second. All the sequence of converting signal from potentiometer to digital position and performing the PD control is made possible by a single chip 16 bit microcontroller from MicroChip [5]. This controller not only works as a controller for the steering system, but it also determine command input from the proportional remote control which is the interface medium for both steering and speed control systems.

2.4. Proportional Remote Control and Interface

The unman ball retriever car is remotely controlled by an operator from outside of the field. This is done by using a typical remote control radio. Two independent channels were needed for speed and direction controls. Each channel is interfaced by a standard pulse code command as shown in figure 7. At a neutral state where the vehicle speed and steering angle are zero, the command signal has a pulse width of 1.5 ms. In speed control the extension and contraction of this pulse width refer to the incremental speed on forward and backward directions respectively. As for the steering system, it tells the degree and turning direction of the steering wheel. Although both speed and steering systems are commanded independently, their actions have to be subjected due to the speed difference during turning.

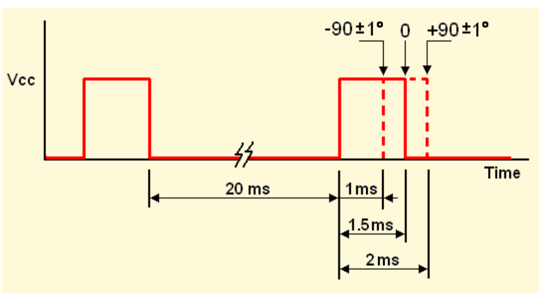


Fig. 7 A pulse code command interface to the controller

This vehicle was designed to have two independent driving wheels. Both are powered by two identical motors. Because the driving wheels are also steered during the turning action, their speeds have to be adjusted according to each wheel turning radius. This is a similar concept to the differential gear used in automotive except that the differential gear is driven by a single actuator. In this design each wheel has it own actuator, and the speed can be varied in two different ways.

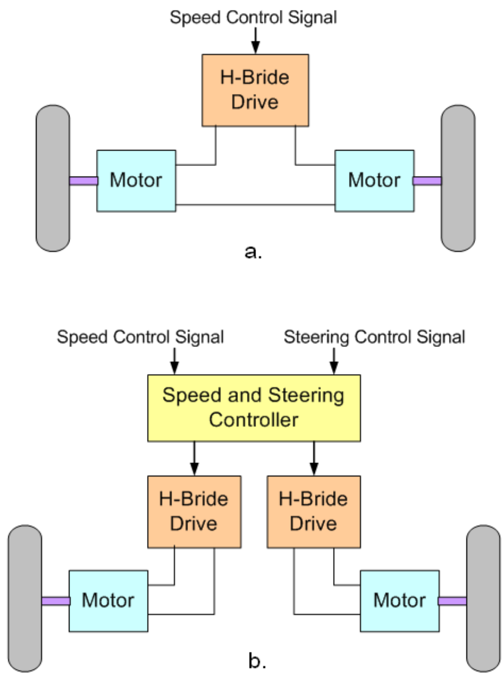


Fig. 8 Two different methods of adjusting wheel speeds

The first method is using electrically differential load and speed of DC motor. By connecting two motor from each wheel in a series circuit as presented in figure 8 a, both motors will carry load based on the torque encountered. The voltage drop on each motor will varies in relation to the load as well. The advantage of this method is its simplicity and the only one drive need. However due to the fluctuation of the drop voltage on each motor, the total voltage that applies to the drive will be divided to each motor. This result a half of the power the motor can produce. The applied voltage can be increase in order to raise the power. But each motor may experience exceeding power when the load between both wheels is not balanced.

Fig. 9 An actual motor used in the prototype

Another method to increase the performance of wheel driving is to have two wheels powered separately as shown in figure 8 b. This way each motor can be controlled to its full load rating. However during the turn, the speed of both wheels has to be adjusted according to the steering angle. This can be done by the controller in which both speed and steering control signal are fed. The controller knows the degree and direction of turning angle. Then it calculates the difference of turning speeds for each wheel. This compensation is made by estimating the wheel path and assuming that each wheel carries an equal torque during the turning.

3. Prototype Manufacturing

The prototype machine was successfully fabricated based on the design previously described. The main component is this vehicle is the DC-brushed motor which is used to drive the wheel and also the steering mechanism. Three 250 watt 24 volt motors were used in each vehicle. These motors are equipped with gear boxes at 9.78:1 ratio, and they are proven to be quite powerful in regards of their size and cost. Figure 9 shows the actual motor used in this prototype. Although the 250 watt motor per wheel is enough to operate the vehicle at the rate about 6 km/hr. More powerful motor with a same footprint up to 500 watt can be used to increase the vehicle speed.

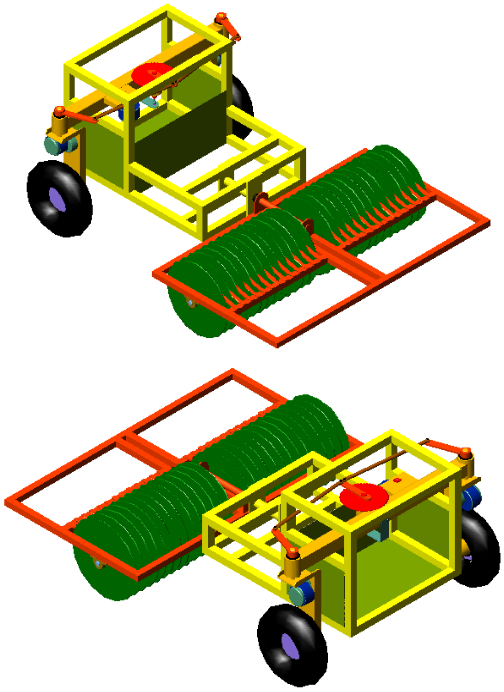


Fig.10 Model of the first prototype

The prototype of this remote control golf ball retriever car was manufactured mainly from steel pipes. In order to minimize cost, the chassis and most part of this vehicle were formed by square pipe welded together. Based on the model of the prototype vehicle which is presented in figure 10, there are three main sections in this design. First is the body chassis which holds all parts together and also store batteries in it. Second part is the driving bar, a large cross bar attached to the chassis. Its both ends locate steering joints and attach to the wheel arms. In the middle of this driving bar, a steering mechanism and its components are mounted. This driving bar can be separated from the chassis during the construction or service. The final section is the ball picker wheels which also serve as the free front wheels. The entire picker frame attaches to the chassis with a pivot joint which allows the ball picker roller to move in a rolling direction and keeps the roller at on uneven ground.

Fig. 11 The actual prototype during a test

4. Testing and Result

After the prototype is made, it was tested on both hard ground and actual field. Figure 11 shows the actual prototype during a common test on a hard ground. In the beginning of this development, both driving wheels were driven using the electrically differential method as already described in section 2.4. Using two 12 volt batteries at 55 Ah each, the vehicle can run at about 5 km/h on the hard ground but only 3 km/h on grassland. Later the vehicle speed was improved by applying another driving method which is driving both wheels separately. By using this method the speed of this vehicle has improved to about 8.5 km/h and 6 km/h on the grass field. However the higher performance drains more energy from the batteries and results less operating time in a single charge.

The prototype ball retriever car was successfully tested on the actual field. It was able to retriever ball slightly slower than the conventional equipment. The main reason is the distance between the driver and the vehicle that causes a difficulty to observe the terrain and control the car accordingly. In addition the back steering wheel is not a common practice for most people who are familiar with regular automobiles. However the skill that is used to control this vehicle can be improved over time. In overall, the vehicle specification and performance are summarized and presented in table 1.

Table. 1 The specification summary of the prototype vehicle

Specification	value	Unit	Note
Wheel Base	1.1	m	Rear wheel
Length	1.4	m	Overall
Width	1.8	m	Overall
Weight	68	kg	No batteries
Curb to Curb Circle	3	m	Minimum
Maximum climb	38	deg	Hard surface
Ball Retrieving Width	1.3	m	
Max Speed	6	km/h	On glass
Average Working hour	4	hr	per charge

5. Conclusion

The development of the first prototype of golf ball retriever car has been successfully conducted. Although the performance of this vehicle is slightly less than the conventional equipment, it is safer for the operator not entering the field. Also, due to its simple configuration, the cost of this car is comparable to the conventional equipment. In the detail, the design of its steering and driving system is very practical and low cost. It can be applied to any application which requires drive by wire system such as remote control rescue or survey vehicle and bomb squad robot.

6. Acknowledgement

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