THREE OMNI-DIRECTIONAL WHEELS CONTROL ON A MOBILE ROBOT

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Abstract

Traditional two wheels differential drive normally used on mobile robots have manoeuvrability limitations and take time to sort out. Most teams use two driving wheels (with one or two cast wheels), four driving wheels and even three driving wheels. A three wheel drive with omni-directional wheel has been tried with success, and was implemented on fast moving autonomous mobile robots. This paper deals with the mathematical kinematics description of such mobile platform, it describes the advantages and also the type of control used.

1 Introduction

RoboCup is a scientific challenge created to foster research and development in fields like mobile autonomous robotics, automation, electronics, computer vision and image processing, and other related areas. It consists of a football and rescue competition with several different leagues. For those unfamiliar with the RoboCup event, they can read the objectives and games rules on [1]. Although many teams prefer to buy off the shelf standard robotic platforms and implement some changes in hardware/software, Minho team which participates on RoboCup since 1999, builds its own platforms from scratch. Being part of an Industrial Electronics department they build the mechanics, the hardware and the software, bearing in mind the low budget. This continuous participation in RoboCup has led to new developments in many fields. The next step was to develop a mobile platform, which could optimized the robot's reaction speed and one came to the conclusion that a three wheels platform was the solution to follow. This solution reduces the robot's reaction time, simplifies the game strategy, and the motor control algorithm is not as complex as it might first look.

2 Background

There exists a great variety of ways to move across a solid surface by mobile robots. The most important are wheels, tracks and legs [2]. Wheels are the most used since they offer simpler mechanics and construction easiness. Legs and tracks require complex mechanics and heavier hardware for the same payload, but these have the advantage of running across uneven surfaces.
At the moment, legged robots are being used in the humanoid league (standard two legs only), in the sony-legged league (standard four legs) and in the rescue league. Tracks are used mostly in the rescue league. But wheels are being used in most football leagues for its speed and mechanical and software easiness. For the RoboCup challenge in 2050, wheels will definitely not be the best solution, but for now all teams from middle size league use wheels to continue research in other areas, leaving the locomotion problem for later. Even with the use of wheels, there are several solutions developed by as many teams participating on RoboCup Middle Size League.
For a wheeled robot, one may choose among several significantly different arrangements of driven and steerable wheels; differential drive, car drive, synchronized drive, tricycle drive, etc., as shown in Figure 1.

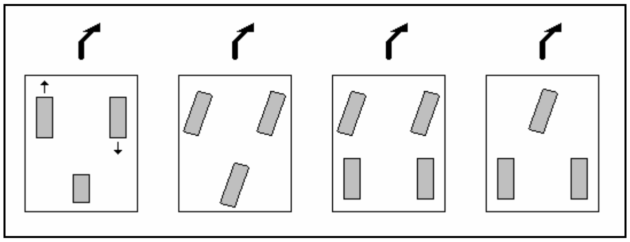

Figure 1: Different driven and steerable drives

The number of wheels is the first decision. Two, three and four wheels are the most commonly used each one with different advantages and disadvantages. The two wheels drive has very simple control but reduced manoeuvrability. The three wheels drive has simple control and steering but limited traction. The four wheels drive has more complex mechanics and control, but higher traction.
Most teams use two wheel drives with some caster wheels and control them with a differential drive technique. Many teams including Minho have been using the two wheels drive [3]. The CMU team [4] used a two-wheeled drive unit with a passive trailer. Other teams prefer to use steering on some wheels like the Sharif team[5]. Philips team [6] uses a four

wheels drive and four wheels steering. The Matto team [7] used four pairs of omni wheels, each pair being driven by a unique DC-motor. The Artisti Veneti team also used an holonomic platform as described in [8].

3 Three wheel drive

Minho team decided to use a three-wheel drive because of the rich manoeuvrability and also due to the simple control. This type of wheels has small rollers to allow the wheels to move freely on any direction. They move along the primary diameter, just as any other wheel. Though, the smaller rollers along the outside of this diameter allow free rotation along an orthogonal direction to the powered rotation.

The mechanics were even simplified in this case, because the previous built robot platform used three chains to reduce the speed of each motor by a ratio of 1/48. With this new platform the motors are coupled directly to the omni wheels simplifying the mechanics. The traction reduction is slightly compensated by the third wheel and therefore the traction loss is partly compensated. The mechanical construction is shown in Figure 2.

On the left image, the grey circle represents the robotic platform, and the three motors coupled to the Omni wheels are mounted with 120 degree between them, aligned like in an equilateral triangle so that their axis intersect at the robot centre. In the centre it can be seen the specially built encoders coupled to each motor axis.

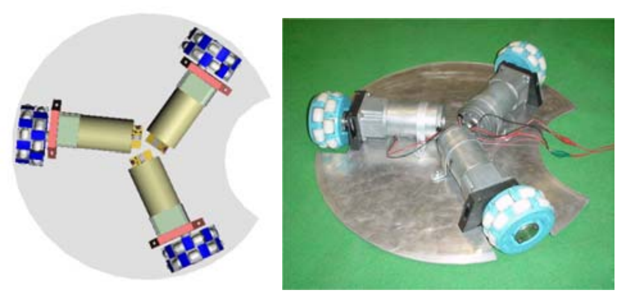

Figure 2: Three-Wheel drive mechanical construction (design and physical)

4 Kinematics of Minho Robotic Platform

The inverse kinematics model is simple. It was considered that the representative coordinates of the robot were located in its centre. Each wheel is placed in such orientation that its axis of rotation points towards the centre of the robot and there is an angle of 120º between the wheels. The velocity vector generated by each wheel is represented on

Figure 1-b by an arrow and their direction relative to the Yr coordinate (or robot front direction) are 150º, 30º and 270º respectively.

4.1 Linear Movement

For this type of configuration, the total platform displacement is achieved by summing up all the three vectors contributions, given by:

$$\vec{F}_T = \vec{F}_A + \vec{F}_B + \vec{F}_C \qquad (1)$$

A software simulator was built and is depicted in

Figure 1. The user inputs three variables (linear speed, linear direction and angular speed) and the program outputs each motor contribution. For now, only linear speed is described.

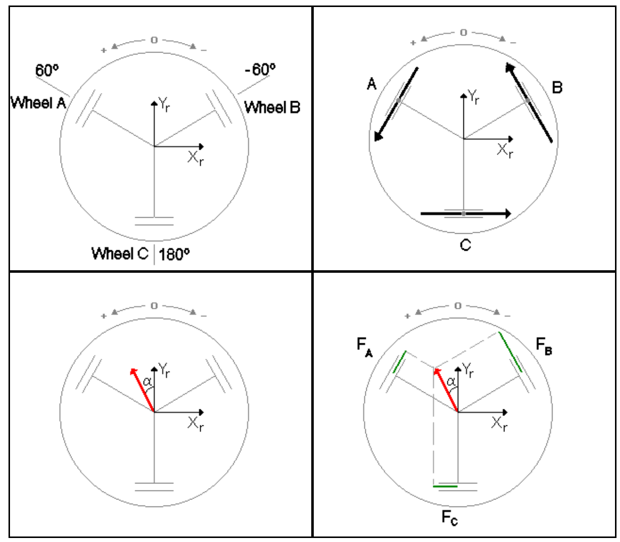

Figure 1: Graphical representation of motor contribution; a) platform motors/wheels distribution; b) wheels driving axis; c) desired movement; d) motor contributions

First of all, some definitions need to be considered.

Figure 1-a) represents the diagram of the mobile robot platform with the three wheels. It was assumed that the front of the robot represents 0 degrees direction, and the positive side to its left. The three wheels coupled to the motors are mounted at angle position +60, -60 and +180 degrees respectively. It is important to remember that the wheel driving direction is perpendicular to the motor axis (therefore 90 degrees more). The line of movement for each wheel (when driven by the motor and ignoring sliding forces) is represented in

Figure 1-b) by the segments A, B and C. The arrow indicates positive direction contribution.

The total platform displacement is the sum of three vector components (one per motor) and is represented as a vector in the platform body centre. In

Figure 1-c) it is depicted a vector representing the desired movement; the angle α represents the direction and the vector length represents the velocity. In order to find out the three independent motor contributions, this vector is projected on A, B and C axis representing the line of movement of each wheel.

Figure 1-d) shows the projections that represent the three vector components of the contributions. The vectors can have a positive or negative direction which represents the direction in which the motor has to move (forward or backwards respectively).

Since the robot forward direction is represented by Y_r, each motor contribution consists of the cosine of the angle α (*DesiredDirection*) projected on each wheel drive direction, multiplied by the velocity, given by:

$$F_n = velocity \cdot \cos(WheelDriveDirection_n - DesiredDirection) \quad \textbf{(2)}$$

Considering now that the three wheels driving directions of this robot are 150, 30 and 270 degrees respectively, the contribution for each motor for linear velocity is given by:

$$F_A = velocity \cdot \cos(150 - DesiredDirection) \quad \textbf{(3)}$$

$$F_B = velocity \cdot \cos(30 - DesiredDirection) \quad \textbf{(4)}$$

$$F_C = velocity \cdot \cos(270 - DesiredDirection) \quad \textbf{(5)}$$

Where: *F* - is the motor vector contribution
A, B, C – represent the motors
Velocity - is the linear velocity the robot should move
DesiredDirection - is the angle α of the desired movement

Figure 2 shows each motor contribution according to the desired direction from 0 to 360 degrees.

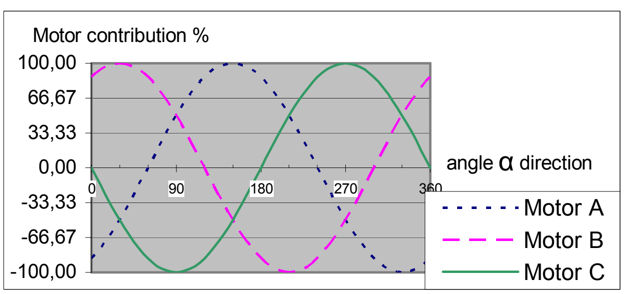

Figure 2: Motors contribution for robot platform movement

4.2 Angular Movement

Considering now angular movements, and assuming accurate wheels alignment, pure rotation over its centre can be achieved by driving all wheels in the same direction and at the same speed. The angular velocity of rotation is the linear peripheral speed of the wheels divided by the radius of the robot.

Figure 3 still applies for angular velocity. Once again, the positive values make the robot rotate to its left and negative values to its right.

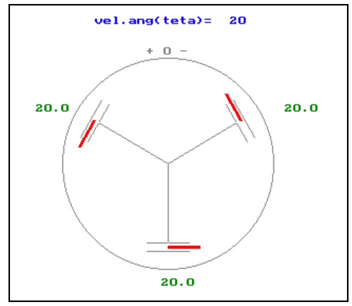

Figure 3: Graphical representation of motor contributions for a positive angular velocity

4.3 Mixed Linear and Angular Movement

Should the robot need to rotate its body while moving towards the ball, linear and angular velocity can be combined by calculating the sum of both contributions. In
Figure 4 a linear and angular movement is described. Added to a typical linear velocity (as described in
Figure 1) an angular velocity contribution is computed by adding the two vectors. On the left side the two contributions are separated and on the right side only the final value is represented.

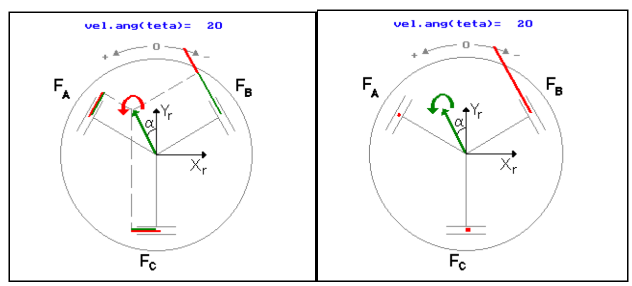

Figure 4: Combined linear and angular velocity

It is important to point out that this movement is always relative to the robot centre. By adding both linear and angular contributions, speeds over the motor maximum speed can happen, but this saturation is avoided by limiting the maximum sum between linear and angular velocity, in which case, angular velocity is given priority over linear velocity.

5 Motor

In order for the mathematics here described to work, the wheels need to grip and that forces the motors very much. Therefore, the motors had to be chosen very carefully, taking into account its consumption, force, speed, etc.

The motor chosen is the Crouzet DC geared motor with brushes, with 5Nm at 33 Watts.

Characteristics	
Voltage	24 V (dc)
No load speed	170 rpm
Mechanical Power	33 W
Nominal Power	27 W
Starting torque	150 mNm
Starting current	6.2 A
Terminal Resistance	3.9 Ω
Life time	5000 hours
Gear Box Maximum torque	5 Nm
Weight	1.540 Kg

Table 1: Motor Characteristics

As seen in Figure 2 each motor will work at its maximum velocity only when the desired direction is parallel to a driving wheel (for Motor A it will be on 150 or 330 degrees). The units of F (motor vector contribution) are not very relevant at this stage since each value has to be converted, by multiplying it by a K factor, in order to give the right amount of energy to the motors.

The wheels used (see **Error! Reference source not found.**) are 100 mm diameter and 50 mm thickness. Tests on the motors were made using 24 V and no load at all, and the maximum speed achieved was 170 rpm.
Since the motors torque is 5Nm and the wheels are made of rubber, slippery can be almost neglected, even though the robot total weight is about 35Kg.
Other gearbox could be used which could give more speed but then the control would be more difficult.

5.1 Motor Control

PID control is by far the widest type of automatic control used, probably because it is very simple and easily implemented. Our approach used the ideal PID algorithm [9]:

$$y(t) = Kp\left(x(t) + \frac{1}{Ti}\int_0^t x(\tau)d\tau + Td\frac{dx(t)}{dt} \right) \qquad \textbf{(6)}$$

The transfer function of our system was unknown, so a trial and error approach was carried out to determine the best type of control and the optimal parameters. Several experiments were carried out to optimise rotational movement. First, only proportional gain was implemented, and then added the integral gain, and finally the differential gain. The robot started from 70º position and rotated to a reference value of 180º.

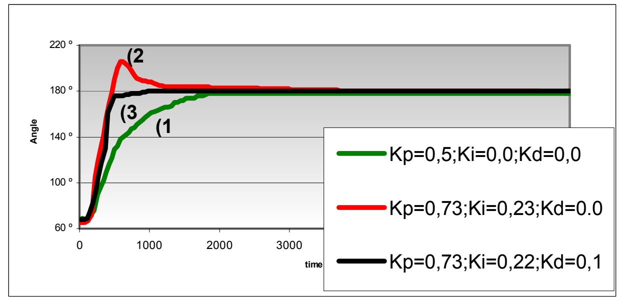

Figure 5: Rotational movement with different Kp, Ki and Kd parameters

As shown in Figure 5, integral gain (2) decreases the rise time and eliminate the s-s error, but increases the overshoot and the setting time. To overcome this, a derivative component (3) was added, and the desired effect was attained: no overshoot, no s-s error, fast rise time and settling time.
A very fast and accurate response was obtained with PID control. The time spent to rotate from 70º to 180º is 900ms.

6 Conclusions

In RoboCup MSL football games, the time a robot takes to reach the ball is of extreme importance. The faster it gets the ball the more chances it has to score a goal. With the 3 wheel drive configuration described in this paper a robot can move in a straight line all the time.
The control software is very simple and efficient as described. According to the direction angle only three values are calculated by using a cosine value and a multiplication. The PWM to control the motors is generated by a PIC, leaving the computer processor free for other more complex tasks like the image processing and the game strategy.
The mobile robot platform here described is relatively fast, reaching high both linear and angular speeds. Most time the motors do not drive at their maximum speed leaving a tolerance for when that is needed, for example, when linear and angular speeds are required at the same time. The platform wheel positioning is influenced by the motors size. In this case that was a problem because the motors were slightly large and the wheels had to be placed at the very edge of the platform.
The platform radius (distance between the wheels and the platform centre) influences the angular speed but not the linear speed.
This configuration allows linear and angular speeds at the same time and this is of extreme importance for this team since each robot carries a fixed kicker. If the kicker is not in the robot moving direction an angular speed needs to be used together with the linear speed while the robot moves towards the ball, in order to point the kicker to the right direction.

Acknowledgements

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References

[1] http://www.robocup.org

[2] J. L. Jones and Anita M. Flynn, “Mobile Robots – Inspiration to Implementation”, A K Peters, Wellesley, Massuchusetts, ISBN 1-56881-011-3, page 139.

[3] F. Ribeiro, C. Machado, S. Sampaio, B. Martins, "MINHO robot football team for 2001", in “RoboCup 2001: Robot Soccer World Cup V”, Andreas Birk, Silvia Coradeschi, Satoshi Tadokoro (eds), Springer, LNAI 2377, Berlim, 2002, page 657-660.

[4] S. Stancliff, R. Balasubramanian, T. Balch, R. Emery, K. Sikorski and A. Stroup, "CMU Hammerheads 2001 Team Description", in “RoboCup 2001: Robot Soccer World Cup V”, Andreas Birk, Silvia Coradeschi, Satoshi Tadokoro (eds), Springer, LNAI 2377, Berlim, 2002, page 631-634.

[5] M. Jamzad, H. Chitsaz, A. Foroughnassirai, R. Ghorbani, M. Kazemi, V.S.Mirrokni, B.S.Sadjad, "Basic Requirements for a Teamwork in Middle Size RoboCup", in “RoboCup 2001: Robot Soccer World Cup V”, Andreas Birk, Silvia Coradeschi, Satoshi Tadokoro (eds), Springer, LNAI 2377, Berlim, 2002, page 621-626.

[6] http://www.cft.philips.com/html/subExamplesAppl/pdf/robocup.pdf

[7] K. Demura, K. Miwa, H. Igarashi and D. Ishihara, “The Concept of Matto”, in RoboCup-99: Robot Soccer World Cup III", M. Veloso, E. Pagello, H. Kitano (eds), Springer-Verlag, Berlim, Alemanha, 2000, pages 723-726.

[8] E. Pagello, M. Bert, M. Barbon, E. Menegatti, C. Moroni, C. Pellizzari, D. Spagnoli and S. Zaffallon, "Artisti Veneti: An Heterogeneous Robot Team for the 2001 Middle-Size League", in “RoboCup 2001: Robot Soccer World Cup V”, Andreas Birk, Silvia Coradeschi, Satoshi Tadokoro (eds), Springer, LNAI 2377, Berlim, 2002, page 616-619.

[9] K. J. Aström, and T. Hägglund, PID Control. Theory, Design and Tuning. 2nd ed., (Instrument Society of America, Research Triangle Park, NC, 1995).