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ROLLMOBS, a new drive system for omnimobile robots

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SUMMARY

Typical mobile robot structures (e.g. wheelchairs or car-like robots) do not have the required mobility for common applications such as displacement in an office, hospital, workshop, etc. New structures based on the "universal wheel" (i.e. a wheel equipped with freely rotating rollers) have been developed to increase mobility. However, these structures have important drawbacks such as spurious vibrations and limited load capacity. This paper presents a new type of omnimobile platform using an original combination of spherical wheel and universal wheel. This structure will improve the robot capabilities, i.e., load capacity and surmountable bumps.

KEYWORDS: ROLLMOBS; Omnimobile robots; Universal wheel; Mobility.

1. INTRODUCTION

For mobile robots equipped with conventional wheel, the motions of the platform are subjected to restrictions induced by the kinematic constraints at the contact points between the wheels and the ground. For example, a classical car-like structure is not able to move sideways, with the consequence that a parking operation requires several complex manœuvres. This problem is discussed in detail in reference [1] where it is shown that such motion restrictions always occur when the robot is equipped with fixed and/or centered orientable wheels. Such restricted mobility robots are therefore not suited for applications requiring displacement in a congested room. A significant improvement consists in ensuring perfect mobility of the platform motion ("free flying robots"). Such robots are referred to as omnidirectional. When perfect mobility is achieved without singularity (from the kinematic as well as from the dynamic point of view) the robot is said to be omnimobile.

For robots equipped with conventional wheels, only off-centred wheels, see Figure 1, can be used in order to achieve omnidirectionality, because fixed and centred wheels imply motion restrictions (see, for instance, reference [1]). For such a robot, it can be expected that three independent motors are sufficient to achieve omnimobility, but it is shown in reference [1] that, unfortunately, there exists no motorization involving only three motors and satisfying the omnimobility requirement: for any 3-motor realization there always exists a singular configuration where the robot is no longer controllable. It is therefore necessary to use (at least) four motors (providing, for instance, the full motorization of two wheels, in orientation and rotation) with the consequence that the motorization is generically (i.e. almost everywhere, except at the singular configurations) redundant. This complicates the design of control laws and can lead to trajectory planning errors.

Another solution to achieve omnimobility and omnidirectionality is to use "universal wheels", i.e. wheels where the treads are not tyres but consist of several freely spinning rollers (see Figure 1). For such a wheel, there is only one kinematic constraint at the contact point with the ground, so the wheel can move freely, and without friction, along the direction orthogonal to the axle of the roller in contact with the ground. There are several realizations of robots combining such universal wheels: see, for instance, references [2], [3], and [4].The main drawback of such structures is that the load capacity and the surmountable bump height are limited by the diameter of the rollers, and not by the diameter of the wheels, as with conventional wheels.

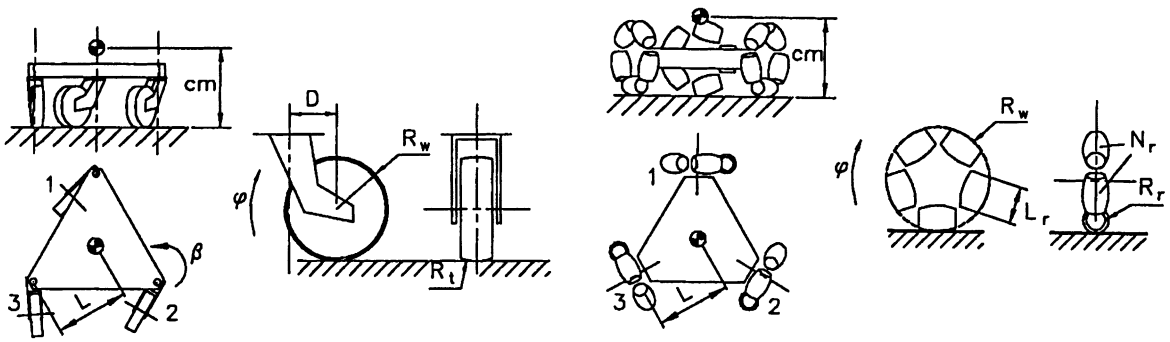


Fig. 1. Omnimobile robots equipped with off-centred wheels and universal wheels.

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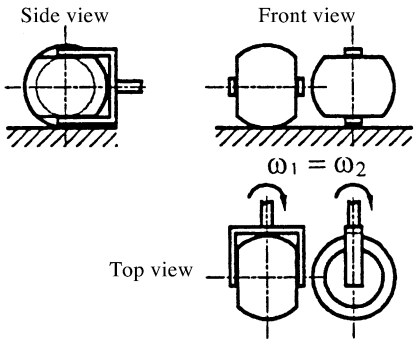


Fig. 2. Orthogonal wheel principle.

Moreover this structure induces vertical vibrations, due to the successive shocks occuring when the contact with the ground shifts from one roller to the next. Discussions on the design of robots equipped with universal wheels appear in reference [3].

A variation on this concept is proposed in reference [5] (see Figure 2). Each wheel assembly consists of two truncated spheres, placed side-by-side, and rolling around two orthogonal axes. The wheel circumference appears as continuous, thus eliminating the shocks, but the contact point with the ground shifts from one roller to the other one, inducing parasitic torques. These wheels yield good performances and smooth motion, but the bulkiness of the system is important.

Another solution consists in using spherical wheels in order to overcome the limitations inherent to the small size of the rollers. The principle of this concept is to decouple the load carrying function from the driving function. In the MIT ball mechanism,[6] each ball wheel is driven by a ring mechanism equipped with a set of freely spinning rollers. The ring drives the sphere around an axis orthogonal to the ring plane which is fixed and inclined with respect to the platform. The rollers allow the sphere to rotate freely around the directions perpendicular to this axis. It must be pointed out however that the rotation of the sphere around such a direction implies pivoting of the sphere around several of the rollers and therefore wear of the rollers. Another drawback of this structure results from the bulkiness of the ring mechanism which reduces the height of surmountable obstacles.

Our purpose in this paper is to describe and analyse another driving mechanism for ball wheels, leading to robot omnimobility. The idea is to drive the ball by an universal wheel equipped with rollers. The rotation of the roller-wheel drives the sphere around the direction parallel to the wheel axis, while the sphere rotates freely around any direction perpendicular to this axis.[7] This concept is now patented[8] and is used in the design of a new omnimobile robot ROLLMOBS.

The paper is organized as follows: in Section 2 we describe and compare different realizations of this concept, from the load carrying function as well from the driving function viewpoint. In Section 3 we discuss the performance of the system, according to several criteria such as load capacity, surmountable obstacle, maximum slope. In Section 4 we describe the prototype which has been developed in our Lab.

2. THE NEW ROLLMOBS CONCEPT

In a classical design, except for the MIT concept, universal wheels are used to drive the robot and to carry it. As a consequence, the performances of the platform, such as its load capacity, are limited by the diameter of the roller in contact with the ground. The principle of the new design is to decouple the drive and load carrying functions: a spherical wheel is placed between the universal wheel and the ground. Most of the performances of the structure now depend on the sphere diameter and no longer on the roller diameter. In this section we discuss several possible practical realisations of this concept.

2.1 Drive function

This solution is similar to the computer mouse but the rollers are replaced by universal wheels. In the case of a mobile robot, the roller should drive the sphere in order to move the structure. The driving torque is important. As a consequence, an important normal force needs to be applied between the roller and the sphere. A classical wheel is not suitable because the friction forces prevent transversel motion (see Figure 3a). However, if a universal wheel is used, the freely rotating roller in contact with the sphere allows free transverse motion, (see Figure 3b). In the plane of the wheel, the sphere has a constrained motion which is controllable by the rotation of the wheel shaft, while the motion in the direction parallel to the shaft is unconstrained.

Classical, half roller or alternate designs[7] can all be used to drive the sphere. Double wheels cannot be used alone. Indeed, the contact point between the wheel and the sphere

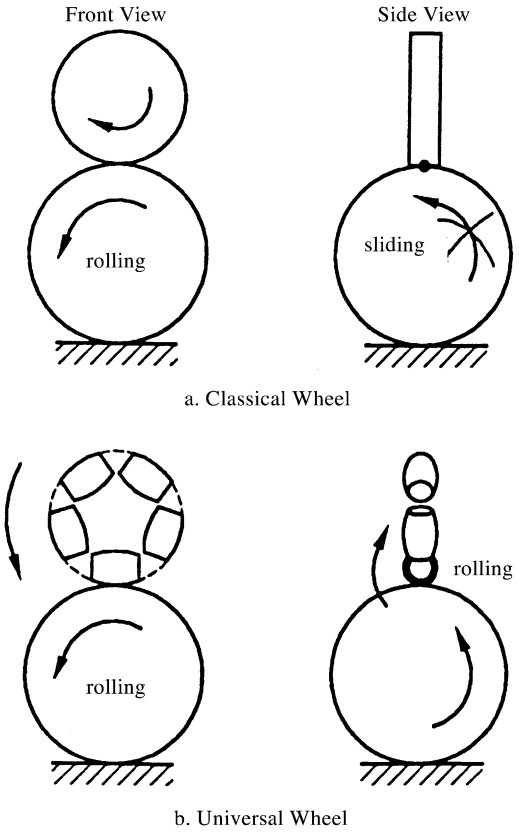


Fig. 3. Drive devices.

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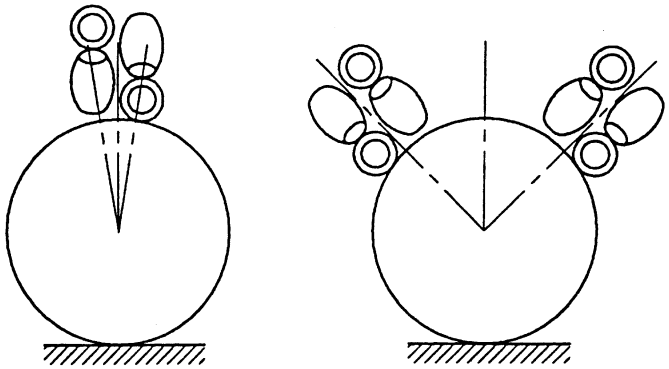


Fig. 4. Double drive wheels.

changes when the wheel shaft turns, producing undesirable vibrations in the driving direction, see Figure 4. In addition, in rare instance, the sphere may rotate such that the axis of rotation passes between the two wheels. For instance, suppose the platform is spinning such that its spin axis is the symmetry axis show in Figure 4. This axis of rotation will be vertical up causing the wheel pair to rotate in opposite directions rather than together. As a consequence, we reject this solution.

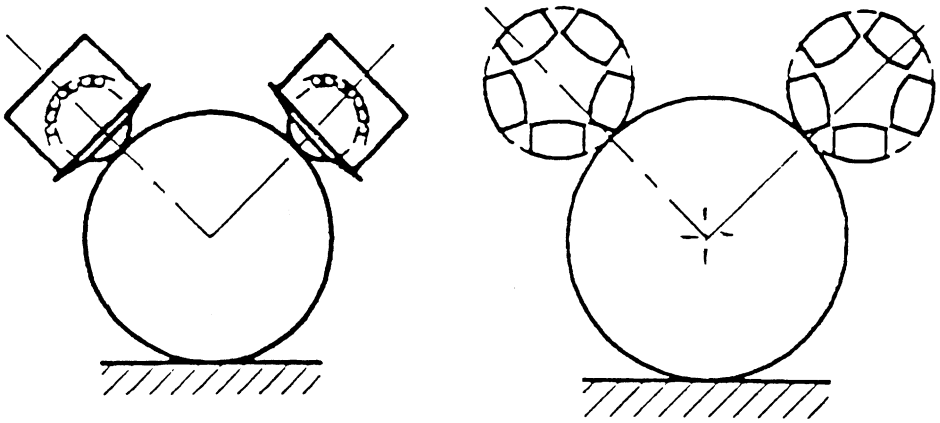
2.2 Load carrying function

The second problem to be solved is to hold the spherical wheel in place and to allow a free rotation in any direction. Clearly, the sphere should be held at at least three points. Figure 5 presents two possible solutions.

The first solution depicted in Figure 5a consists in using three standard solid balls, normally used in transfer devices. The second solution show in Figure 5b uses non-motorized universal wheels, as double wheels cannot be used for the reason presented in Section 2.1. The drawback of this solution is the problem of spurious vibration arising due to the gap between the rollers. On the other hand, it should be noted that the load capacity of available solid balls is limited. Though both solutions are possible we will in the sequel only present the solution using solid balls.

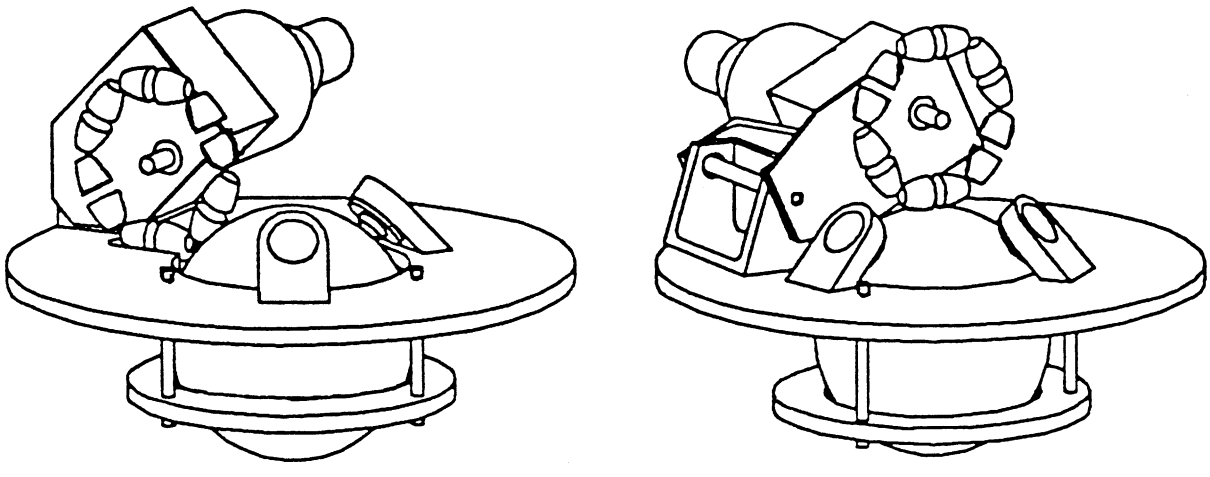
2.3 Combination

The simplest design consists in combining solid balls as bearing elements and simple universal wheels as driving elements. We will concentrate on the two most attractive solutions. In case ROL1, presented in Figure 6a, the sphere is held in place by two passive bearing elements and one classical driven universal wheel. The drive and load carrying



a. Solid balls b. Universal wheels

Fig. 5. Load carrying devices.



a.ROL1 b.ROL2

Fig. 6. New wheel designs.

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functions are thus coupled. Vertical vibrations are not completely eliminated but strongly reduced thanks to the use of small rollers which interpenetrate efficiently. This solution does not require the use of a suspension.

For solution ROL2 presented in Figure 6b, the two functions are decoupled : three (or more) solid balls are used to carry the load and the universal wheel ensures only the drive function. However, this structure is hyperstatic and the force between the universal wheel and the sphere needs to be provided by a spring for example. In this case, the vertical vibration problem is eliminated. These two solutions will be discussed in Section 3.

2.4 Robot Kinematics

In order to discuss the kinematics we consider the robot as an equilateral triangle trolley whose frame is equipped with 3 spheres placed at the vertices of an equilateral triangle. The sphere axis parallel to the wheel axis points toward the centre of the robot. This description corresponds to the Rollmobs prototype (see Section 4). According to reference [9], this configuration provides the robot with isotropic properties. Let us consider an inertial base ($\boldsymbol{i}_1$, $\boldsymbol{i}_2$) in which the position of the frame centre of the robot (g) is described by coordinates *x* and *y*. The angular position of a moving frame base ($\boldsymbol{j}_1$, $\boldsymbol{j}_2$) attached to the robot centre is characterized by the angle θ (see Figure 7). Let (ω_1, ω_2, ω_3) be the angular velocities of the three motors and (Ω_1, Ω_2, Ω_3) those of the spheres around an axis passing through the sphere centre and parallel to the wheel shaft.

Let us define:

$$q^T = [x \;\; y \;\; \theta]^T$$
$$\dot{\xi}^T = [\omega_1 \;\; \omega_2 \;\; \omega_3]^T \qquad (1)$$
$$\dot{\psi}^T = [\Omega_1 \;\; \Omega_2 \;\; \Omega_3]^T$$

The kinematic constraints for each wheel correspond to a non-slipping condition between the wheel and the sphere in the plane of the wheel, and to a non-slipping condition between the sphere and the ground. These constraints relate the angular velocities of the universal wheels ($\dot{\xi}$) to the angular position (θ) and velocity ($\dot{q}$) of the trolley. Taking L as the distance between the sphere and the frame centres, R_s as sphere radius and R_w as wheel radius, the kinematic constraints for wheel i are written as:

$$\text{sphere–ground contact: } [-\sin(\alpha_i) \;\; \cos(\alpha_i) \;\; L]\, R(\theta)\dot{q} + R_s\, \Omega_i = 0 \qquad (2a)$$

$$\text{wheel–sphere contact: } R_s\, \Omega_i = -R_W\, \omega_i \qquad (2b)$$

with

$$R(\theta) = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\alpha_i = (i-1)\frac{2\pi}{3}$$

The complete kinematic model of the three wheeled robot can then be written as

$$J_1 R(\theta)\dot{q} + J_2 \dot{\psi} = 0 \qquad (3a)$$

$$J_3 \dot{\xi} = \dot{\psi} \qquad (3b)$$

with

$$J_1 = \begin{bmatrix} 0 & -1 & -L \\ \sqrt{3}/2 & 1/2 & -L \\ -\sqrt{3}/2 & 1/2 & -L \end{bmatrix} \qquad (4)$$

$$J_2 = R_s,\; J_3 = -\frac{R_w}{R_s}$$

Considering equations (2), (3) and (4), we have:

$$\dot{\xi} = \frac{1}{R_w} J_1 R(\theta)\dot{q} \qquad (5)$$

Equation (5) shows that the kinematic relationships of the ROLLMOBS robot are similar to those of a robot equipped with classical universal wheels. Therefore, the two robots present the same kinematic properties. One can see that constraints (5) are not completely integrable: there is no analytical relation between ξ and q. This means that, at a given time t, q(t) and $\dot{q}$(t) do not depend only on ξ(t) and $\dot{\xi}$(t) but also upon the complete evolution of ξ(τ) and $\dot{\xi}$(τ) for τ<t. A control algorithm processing only ξ and $\dot{\xi}$ can provide only the regulation of the velocity ($\dot{q}$, θ) but not of the position x and y. Any error on ξ implies an irreversible position error on x and y.

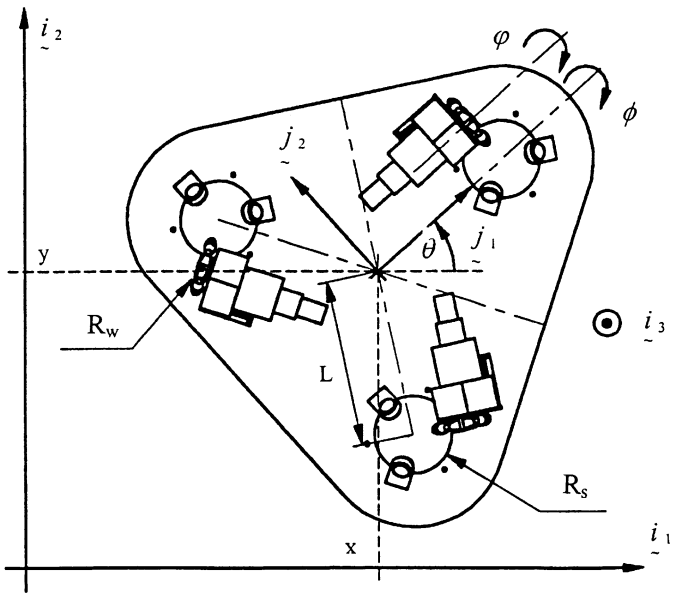


Fig. 7. Robot coordinates.

3. DISCUSSION

In this section we discuss the advantages and disadvantage of the new concept in general and of combinations ROL1 and ROL2 in particular. The comparison with “classical universal wheels” is based on the three main functionalities: the load capacity, the maximum slope the robot is able to climb and the obstacle height surmountable by the robot

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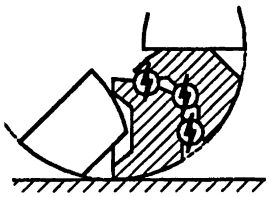


Fig. 8. Example of geometrical constraints on universal wheels.

wheel, e. g. door sill or electrical cable. It should be noted that, independently from these required functionalities, design constraints need to be verified, e.g. the minimal dimension of the door that the robot may cross and geometrical constraints on universal wheels in order to avoid contact between the rollers (see Figure 8). The first constraint is called a common constraint because it does not depend on the chosen solution. On the other hand, the second is a specific constraints that may be applied only to a particular physical solution. In the example, this constraint will impose some internal relation on the wheel dimensions such as a typical ratio between the roller radius and wheel radius e.g. $R_r/R_w < 5$.

Though these constraints have a very important effect on the design and thus on the comparison, they will not be discussed in this paper; they are developed in reference [7].

3.1 Load capacity

The theoretical contact between curved surfaces is a point or a line. However, when curved elastic bodies are pressed together, finite contact areas develop because of deflection. The shape of this area depends on the radius of the curved bodies; in the general case it forms an ellipse. These contacts areas are so small that corresponding compressive stresses tend to be extremely high. According to the Hertz theory, the maximum pressure between two contacting bodies (noted a and b) depends on the materials (Young's modulus E, Poisson's coefficient ν), the load W and the two radii (noted x and y) of the two bodies.[10] Hertz made the assumption that no tangential forces are induced between the solids. This is obviously not the case for our problem, but this theory will give us a first evaluation of the load capacity. The classical Hertz theory requires use of tables of data. Hamrock and Brew[11] proposed a simplified equation using a linear regression to fit these data, the maximum pressure can be expressed by:

$$P_{\max} = \frac{6W}{\pi D_x D_y} \tag{6}$$

$$D_x = 2\left(\frac{6\xi WR}{\pi k_e E'}\right)^{1/3} \text{ and}$$

$$D_y = 2\left(\frac{6k_e^{\,2}\xi WR}{\pi E'}\right)^{1/3} \text{ the values of ellipse axii} \tag{7}$$

$$k_e = \alpha^{2/\pi},\ E' = \frac{2}{\frac{1-\nu_a^2}{E_a}+\frac{1-\nu_b^2}{E_b}},\ \frac{1}{R} = \frac{1}{R_x}+\frac{1}{R_y} \tag{8}$$

$$\frac{1}{R_x} = \frac{1}{r_{ax}}+\frac{1}{r_{bx}},\ \frac{1}{R_{yx}} = \frac{1}{r_{ay}}+\frac{1}{r_{by}},\ \alpha = \frac{R_y}{R_x},\ \xi = 1+\frac{\pi/2-1}{\alpha} \tag{9}$$

For the classical universal wheel, we should consider only the contact between the wheel and the ground. On the other hand, for the new concept, we should also discuss the contact between the sphere and the solid ball as well as the sphere and the universal wheel.

Wheel-ground contact. Considering the contact between the wheel (or the roller) and the ground, we shall assume that the ground is horizontal, perfectly plane and undeformable, i.e. $\nu_g = 1$, $E_g = \infty$ and curve radii of the ground $R_g = R_g' = \infty$. In the case of the ROLLMOBS concept the principal radii of the wheels are identical: R_s. On the other hand, for the universal wheel, the principal radii are that of the wheel R_w and the roller R_r. Using relations (6) to (9), it is easy to compare the load capacity.

For example, a spherical wheel with $R_s = 150$ mm and made of polyurethane ($E_p = 50$ Mpa, $\nu_p = 0.5$ and $\sigma_{LE} = 5$ MPa) has a load capacity of 3250N. On the other hand, a universal wheel with same radius ($R_w = R_s = 150$mm) with a roller radius 5 time smaller than the wheel radius ($R_W/R_r = 5$), has a load capacity of only 780N. This means that for the same load capacity, say for example 1000 N, the spherical wheel will be smaller than the universal wheel, 85 mm as compared with 170 mm (see the first and second lines of Table 1).

Sphere-universal wheel and sphere-solid ball contacts. The load capacity depends on the solid ball radius R_b (or the roller radius R_r) and on the position of the roller (or ball), relative to the sphere. Figure 9 presents the two cases ROL1 and ROL2.

In the case ROL1, the radial forces between the sphere and the roller F_r^r or the solid ball F_b^r are:

$$F_r^r = F_b^r = \frac{W}{3\cos\gamma} \tag{10}$$

For the case ROL2 we have:

$$F_r^r = cons\tan t,\ F_b^r = \frac{W - F_r^r}{n\cos\gamma} \tag{11}$$

Table I. Possible minimal values of the design parameters for a 1000 N load.

	Universal wheel	ROLLMOBS ROL1	ROLLMOBS ROL2
R_s	-	85 mm	85 mm
R_w	170 mm	60 mm	60 mm
R_r	50 mm	11 mm	5 mm
R_b (steel)	-	60 mm	30 mm
R_b (polyurethane)	-	23 mm	17 mm

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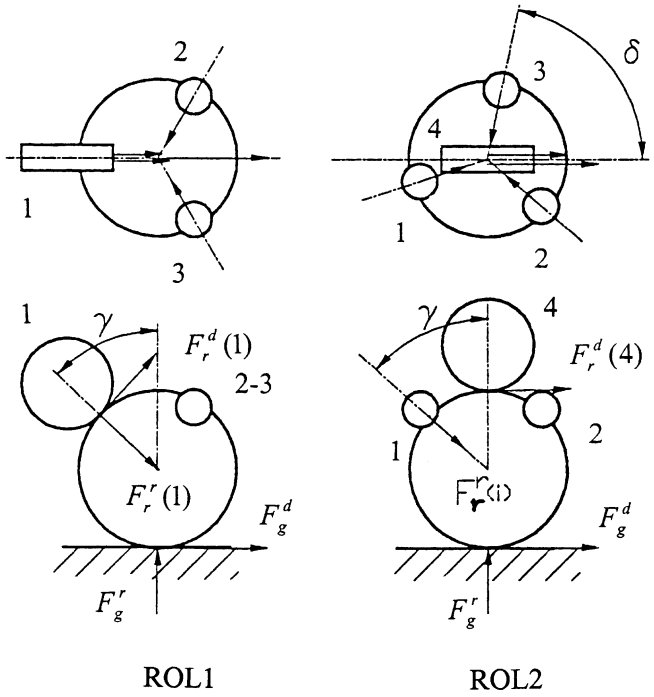


Fig. 9. Forces equilibrium.

with n the number of solid balls (greater than or equal to 3).

The second and third lines of Table I give possible universal wheel characteristics that drive the sphere for a load capacity of 1000 N and assuming an angle γ equal to 60°, and for ROL2 a radial force F_r^r equal to 450 N, these two values being determined in order to avoid slipping in the driving direction (see Section 3.2). Lines four and five give the minimal radius of the solid ball. It is interesting to note that it should be recommended to use solid balls made of polyurethane. In fact, a solid steel ball has a greater capacity but will lead important deformation of the sphere.

3.2 Slope

In order to climb a slope we should check that the wheel will not slip on the ground and for the ROLLMOBS concept that the universal wheel will not slip on the sphere. The condition between the wheel and the ground is identical for both concepts and it impose only to select a material with a good friction coefficient. Table II presents these coefficients for some specific materials. But, one can easily demonstrate that for ROLLMOBS the risk of slipping is more important between universal wheel and sphere than between sphere and ground.[7] However, this risk can be considerably lowered using a good design.[7,12] To avoid slipping, the following condition must hold:

$$\frac{F_r^d}{F_r^r}(\alpha, \theta, \gamma) \leq \mathrm{f} \qquad (12)$$

with F_r^r the radial force between the roller and the sphere and F_d^r the driving force.

The ratio between the driven force F_r^d and the radial force F_r^r on the roller depends on the slope angle α, robot orientation θ and wheel position angle γ on the sphere while the friction coefficient f depends on the materials. This means that, for a given slope angle and for a given friction coefficient f, it is possible to determine the minimal value of γ that verifies the inequality (12), whatever the robot's orientation on the slope. For example, in the case ROL1, for a wheel and a sphere made of polyurethane (the friction coefficient is estimated to be f = 0.5) and for a slope angle $\alpha = 8°$, the minimal value of γ is 60°. For ROL2 it has been evaluated[7,12] that γ should be 68° and that F_r^r should be around 450 N.

Table II. Friction coefficients.

Materials	Friction coefficient
concrete-steel	0.4
concrete-rubber	0.6
concrete-polyurethane	0.5
polyurethane-polyurethane	0.4 . . . 0.5
steel-polyurethane	0.35 . . . 45

3.3 Surmountable bump height

From the user's point of view it is important to evaluate the maximum bumps surmountable by a wheel (e.g. door sill or electric cable). This value is function of the wheel type and diameter as well as the robot speed. We will consider only the case of a solid tire because the rollers are usually made of or covered with polyurethane or other materials which may be considered as hard material (hardness > 90 Shore). Two cases may be considered. In the first, it is assumed that the problem is static i.e. the platform may cross the obstacle at a very low speed. Assuming that the wheel is undeformable, static equilibrium shows that a wheel can cross the step only if the roller does not slide at the contact point.[7,12] Hence, the crossing condition depends on the friction coefficient. For example, for a typical value of 0.5 for the friction coefficient, the maximum bump that the roller can cross is about 20% of the roller radius i.e. $H/R_w < 0.2$ with H the bump height and R_W the wheel radius.

On the other hand, if we cross the obstacle at a normal speed, e.g. 4 km/h, smaller values of this ratio should be respected in order to satisfy comfort requirements and to assure acceptable lifetime of the rollers. For example the European Federation of Handling Industry[13] recommends that ratios H/R_W should be below 0.06.

For the ROLLMOBS, from a geometric point of view the maximum surmountable bump height is the same in all directions and is limited by the height of the retaining ring which should therefore be placed as height as possible, but of course below the centre of the sphere. Thus, for example, according to the above discussion for a 120 mm wheel radius the static surmountable height is 24 mm and the dynamic 7.2 mm.

For universal wheels, this value depends on the wheel orientation with respect to the obstacle. If the wheel axle is parallel to the step, the maximum surmountable obstacle height is a function of the diameter of the wheel. On the other hand, if the roller axle is parallel to the step, the

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surmountable obstacle height is now a function of the roller radius R_r. For a ratio $R_r/R_W = 1/5$ this means that the roller capability is 5 times smaller than for the wheel. For example, in the worst case for a 120 mm wheel radius, the static surmountable height is only 4.8 mm and the dynamic one 1.44 mm.

3.4 Miscellaneous

- The problem of vibrations is not completely solved for ROL1 but may be improved by ROL2. At this stage only simple preliminary experiment were conducted on an experimental set up.[7] Only vibrations resulting from wheel circumference discontinuity were measured. Vibration amplitudes were found to be important. Indeed, the problem of the wheel circumference discontinuity increases with the load applied to the wheel. The structure undergoes a shock each time the contact point passes from a deformed roller to an undeformed one. This problem may be reduced using more rigid rollers but vibrations will still be present, particularly in the case of ROL1. If ROL2 is used, vibrations are transmitted to the robot chassis through a suspension which tends to reduce the vibration amplitude. Some simulations were also conducted in order to evaluate the vibration induced by one wheel alone but it is very difficult to evaluate the vibration induce by the robot composed of three wheel.[14]
- It should also be pointed out that the main problem of the concept is that the contact condition between the wheel and the sphere may changed depending on the nature of the ground. If the robot rolls through dust or water, a wheel may slip since the value of the friction coefficient may vary. Such a malfunction has not been detected on the prototype (see Section 4), but clearly this risk is real and certainly limits the application domain of the new concept to indoor applications in a clean environment: hospital corridor, house, . . . This restriction however also holds when using universal wheels.
- Another problem is that weight of the wheel. A polyurethane sphere may be relatively heavy, however such a wheel can be made hollow to reduce the weight. It is true that the mechanics of our concept is much more complex than a "simple" universal wheel and that a relatively extensive structure is needed to support the sphere and bearings.

3.5 Conclusions

Comparing the new concept to the "classical" universal wheel, it appears that the new design improves surmountable bump height and load bearing capacity, and the slope angle is identical if a proper design has been made. Using these functionalities and constraints the design of the structures were optimized.[7] Figure 10 gives, on the same scale a view of the three solutions for a robot load capacity of 3000 N.

4. PROTOTYPE

A prototype has been built in order to validate the ROLLMOBS principle. A small platform has been manufactured, based on the ROL1 drive principle (Figure 11).

4.1 Robot components

The robot is equipped with 3 spheres made of polyurethane and universal wheels oriented at 120° from each other. The sphere is held between 2 balls and 1 universal wheel. The driven wheel is made up of 12 half rollers. The chosen design is not optimal in the sense that spurious vibrations are not minimized but the wheel is easy to build. A list of the robot elements is summarized in Table III.

The power supplies and the computer that drives the robot are linked to the vehicle through a cable. For future structures both elements will be implemented on the robot. Typical DC motors drive the wheels, and tachometers are included on the main shafts. A controller sends its instructions to each motor at a rate of 5 ms (200 Hz). There is currently no feedback to the controller (see Figure 12). The position and orientation of the robot are calculated by dead reckoning only.

4.2 First experiments

In order demonstrate the validity of the ROLLMOBS mechanical concept, a series of experiments were performed. It was not intended to optimize the performances of the structure using closed-loop control algorithm, but simply to conduct a first experiment based on a preprogrammed trajectory. The experimental set up is very simple: a light is fixed on the structure and a camera takes a long exposure photo allowing to depict the actual path of the vehicle such as presented in Figure 13. Figure 13a presents a 360° spin turn motion at a speed of 0.5 rad/s.

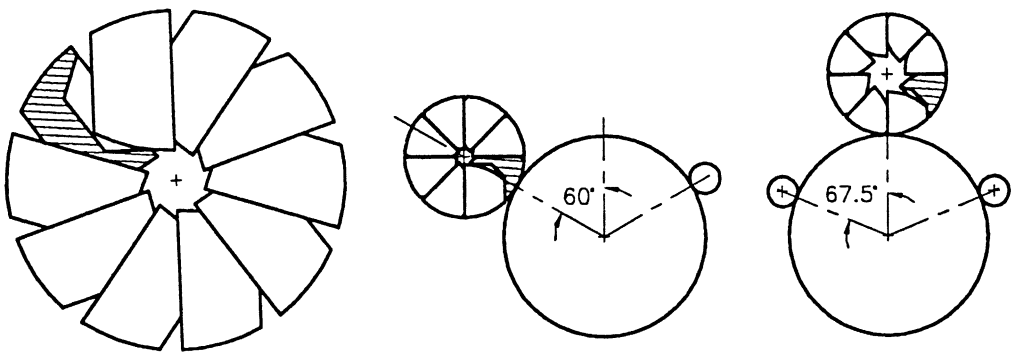


Fig. 10. Comparison of the three concepts.
(for: robot load capacity = 3000N, slope = 8° and bump = 10mm)

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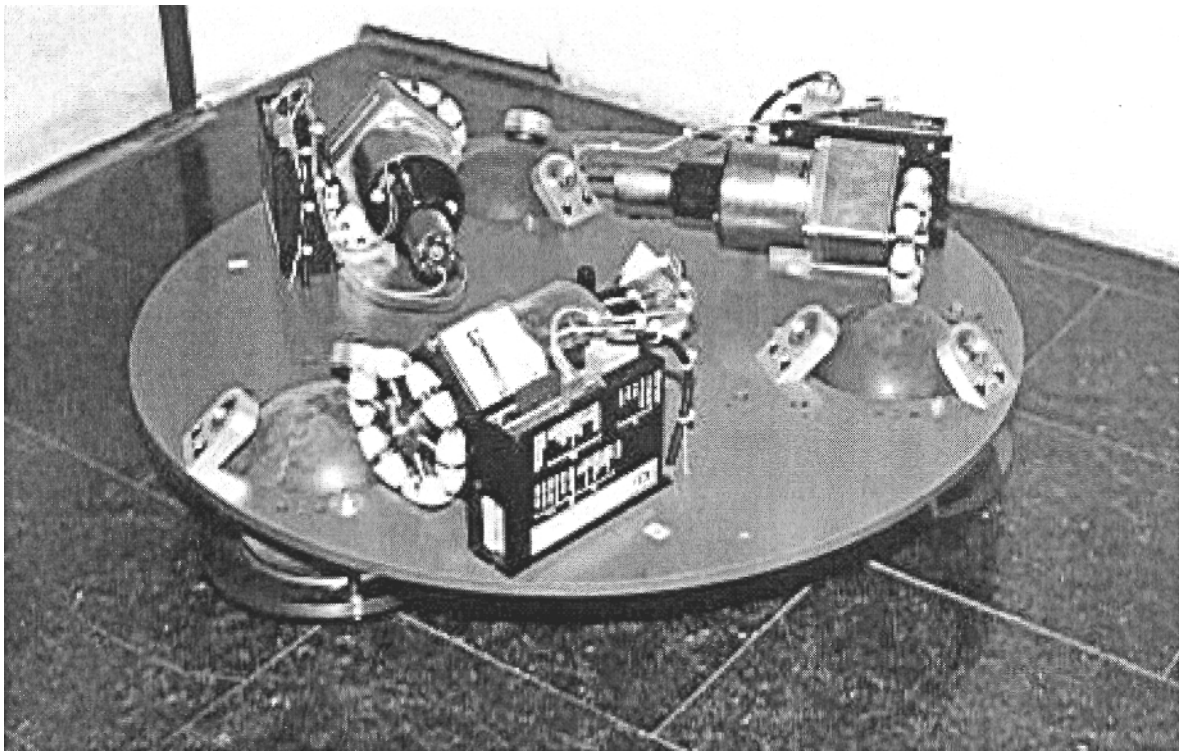


Fig. 11. ROLLMOBS prototype.

Table III. System characteristics.

–	Platform dimension: Ø500 mm
–	Spheres: Ø120 mm; weight: 1 kg; polyurethane
–	Ball bearings: Ø15 mm; steel
–	DC motors: 15 W; 24 VDC; tachogenerator
–	Gearhead: 25:1 gear ratio; 65% efficiency
–	rated torque 1.45 Nm; rated speed 60 rpm
–	Universal wheels: 6 classical rollers
–	Total weight: 15 kg

Figure 13b illustrates the "crab-motion" capability of the robot. The robot follows a square (1 by 1 meter) at a speed of 0.2 m/s. Figure 13c shows the robot following a circle (Ø1 m) with a linear speed of 0.3 m/s. Orientation is maintained during the rotation. Finally, Figure 13d shows a combination of transverse motion and rotation.

The final position of the robot centre is compared to the initial one. In repeated experiments, the position error of the platform was found to be less than 5% of the length of the trajectory. Further experiments should be carried out using more accurate measuring devices and implementing a feedback control on the robot.

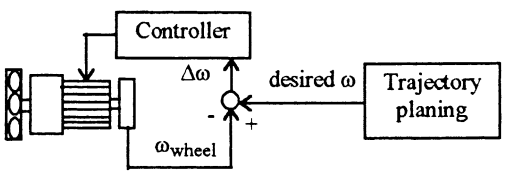


Fig. 12. Current control block diagram.

5. CONCLUSIONS

An original spherical wheel has been presented. It is based on the computer mouse concept providing the robot with full mobility. Simultaneous longitudinal, transverse and rotational motions are possible. The structure does not present any singular configurations as does an omnimobile robot equipped with off centred wheels. The new concept has the same mobility as robots equipped with classical universal wheels, but for indoor application performances are enhanced: the maximum surmountable bump height and load capacity are improved whereas spurious vibrations may be reduced.

A prototype of such a platform has been built using three spherical wheels driven by a classical universal wheel. The mobile robot performs well and proves its omnimobility. Trajectories are quite accurate despite lack of feedback control. The small prototype has proved its performance in terms of accuracy and comfort (smooth motions).

Further work will implement new features on the prototype such as optic encoders mounted on passive universal wheels. Two other prototypes are being built: the first one is an autonomous platform (embarked batteries, on-board PC) with a load capacity of 150 kg. The second prototype is a wheelchair for disabled people.

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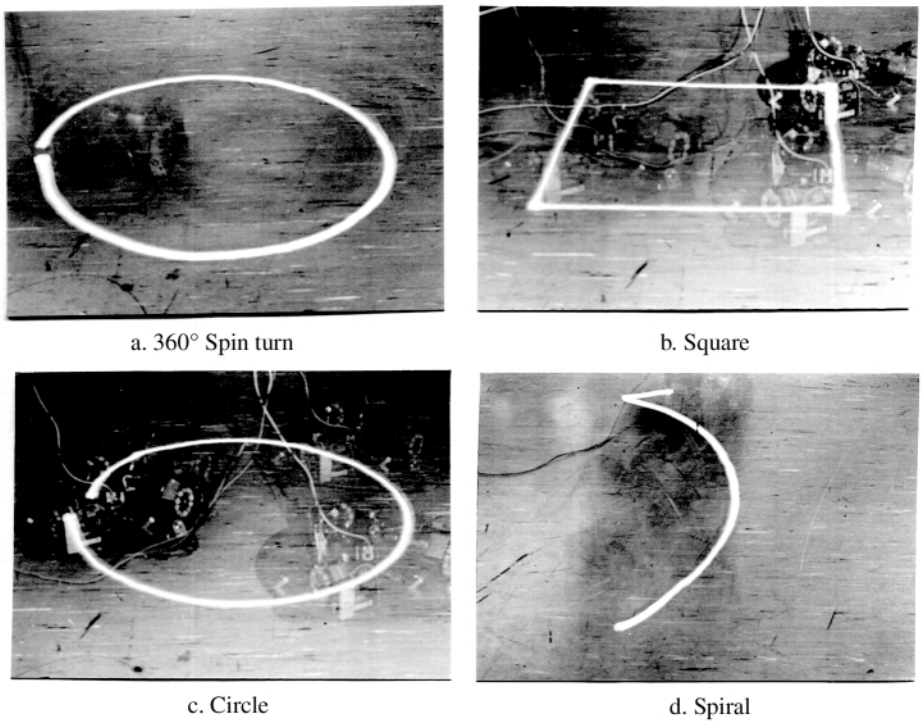


Fig. 13. Robot motion capabilities.

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