Summary of Omni-Directional Drive Choices

Gareth Cawood
Mechatronics Dep., Nelson Mandela Metropoliton University *

November 12, 2012

Abstract

This report briefly introduces the concept of an omni-directional drive. It then proceeds to give overviews of many of the the currently available and in use forms of achieving omni-directional drive. Both units which have received commercial use, and those restricted to hobby robotics have been listed. Because no specific application is in mind, no recommendation towards a specific drive method is made. The appendix includes some further information and links to a design report and video demonstration of most of the drive methods listed in the report.

1 Introduction

An omni-directional drive is defined as a drive system that permits a robot or vehicle to experience displacement in any one of three degrees of freedom. In general they are linear displacement in the x and y- horizontal planes as well as rotation around the z-axis.

There are many benefits to making a vehicle that is capable of moving in any direction. Many concepts have been developed over the years, but they are still rarely found in commercial products, bar a few exceptions. The major reason for this most likely being a cots vs. necessity view of the problem.

This report gives an overview of the various currently explored means of achieving omni-directional drive.

*Completed at Reutlingen University under supervision of Prof Dr-Ing Gruhler

(a) OmniWheel singular (b) OmniWheel Double (c) Continuous OmniWheel

Figure 1: Omni-Wheels (ANDY MARK 2012, Byun *et al.* 2001)

2 Types of Drives

This section gives an overview of various forms of omni-directional drive.

2.1 Omni-Wheels

Omni-wheels are designed on the concept of a normal wheel that has the ability to roll or 'slip' sideways. So although no drive can be applied in the lateral direction, the wheel is still able to be moved in that direction. This is accomplished be placing many smaller wheels or cylinders on the edges of the main wheel as can be seen in figure 1a. The angle of the smaller wheels relative to the main wheel also gives the wheels the name Swedish 90°Wheel.

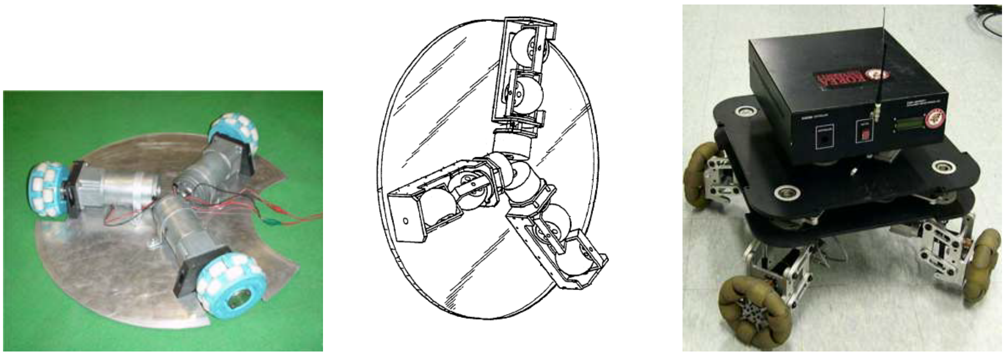
To prevent awkward situations where a roller may not be in the desired place and to minimise friction in lateral movement, two wheels are often combined to form a wheel which has a more complete surface. This can be seen in fig 1b.

The use of one Omni-wheel is said to cause vertical vibrations due to the non-continuous contact. The use of two omni-wheels to prevent this is said to create horizontal vibrations (Lee *et al.* 2001). To counter both these problems a continuous alternate wheel has been designed (Byun *et al.* 2001). The design of this wheel can be seen in figure 1c

2.1.1 3-Wheel Layout

The minimum setup, a 3-wheel layout, often called Kiwi Drive, makes use of 3 independently powered omni-wheels mounted at 120° to each other to steer the robot in any direction.

The setup is similar to the Killough Platform, the main difference that the wheels used by the Killough Platform differ slightly. The Killough Platform



(a) Three Omni-Wheels setup (b) Killough Platform (c) 4 Wheel movable layout

Figure 2: Omni-Wheels (Ribeiro *et al.* 2004, Pin en Killough 1992, Buchli 2006)

can be seen in fig 2b and the Kiwi Platform in fig 2a.

2.1.2 4-Wheel Layout

Similar to the Kiwi Drive, a 4 wheel layout can be used to improve speed and control. Four independently mounted wheels are mounted at 90° angles to each other.

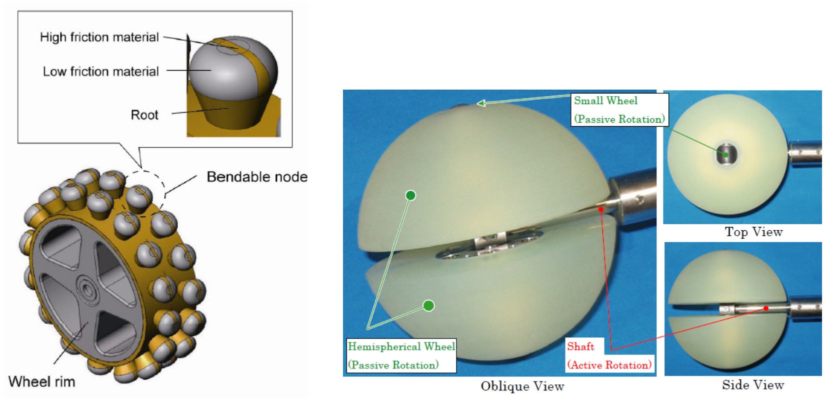
An alternative to this also exists, where the angle between the motors is not fixed. The motors can be angled in a slightly steeper X pattern which can allow higher speeds in certain directions. An example of such a platform can be seen in fig 2c.

2.1.3 Anisotropic wheels

Anisotropic means that something is directionally dependent. That is it has different properties depending on the orientation of the force on the wheels. In theory these wheels respond in the same manner as the omni-wheels, having traction in one direction, and having the ability to roll or 'slip' in the perpendicular.

Anisotropic wheels have been manufactured and used in a prototype (Ishigami *et al.* 2010), but are not commercially available. A model of these wheels can be seen in fig 3a. The wheel comprosises of a rim with multiple bendable nodes.

The nodes are made up of two materials, a high friction material that has traction in the same plane as the wheel rotates, and a low friction material



(a) Anisotropic Wheel (b) Different views of an Omniball

Figure 3: Omni-Wheels (Ishigami *et al.* 2010, Tadakuma 2007)

which is located on the sides. When driving forwards the wheels have traction, as the wheel would try to move sideways, the nodes bends slightly and only the low friction material makes contact with the ground allowing it to slip.

2.1.4 Omni-Ball

An omniball is very similar to the Omni-wheel in the way it moves. The main difference being that the ball is completely spherical, so is able to roll in any direction easier than the Omni-Wheel. The Omni-wheel can be seen in fig 3b. It can be used in the same three and four wheel setups as the omni-wheel.

2.1.5 Control

With all of these drive methods, the way to calculate the desired motor speeds is to work with the sum of the velocities of each motor. Each motor only applies a force in one direction, by starting with a vector of the speed and direction you want to move in, one can calculate the desired speed for each individual motor.

2.2 Mecanum Wheels

Mecanum wheels look rather odd, especially when moving at non 90°angles. Originally modelled on Omni-wheels, the 'loose' roller wheels are patterned at a 45°angle to the main axis of the wheel, similar to a screw's thread. This angle gives them the alternative name Swedish 45°Wheel. An arrangement

(a) Mecanum Wheel (b) Fork lift that uses Mecanum Wheels

Figure 4: Omni-Wheels (VEX ROBOTOICS DESIGN SYSTEM 2012, Airtax 2012)

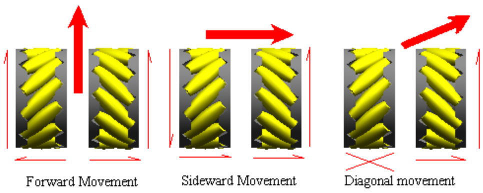


Figure 5: Mecanum Wheel Control (McCandless 2001)

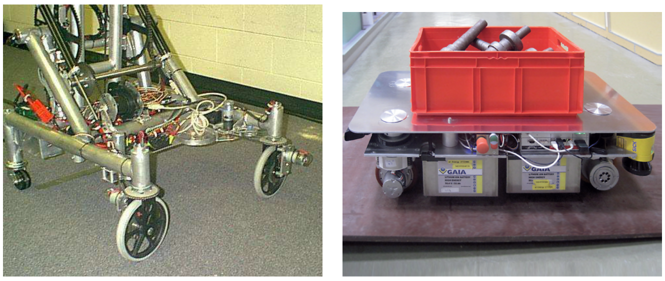
of 4 independently driven Mecanum wheels allows a robot to move in any direction and rotate on the spot. The way this happens is similar to the model of a corkscrew turning.

The Mecanum wheel is is one of the most common Omni-directional drives, and is found in several commercial products such as the Airtrack Forklift seen in fig 4b

2.2.1 Control

The control of Mecanum wheels is slightly more difficult than with Omni-wheels. Because the wheels are mounted in the same manner as in a car, with two pairs of wheels fixed on either side pointing in the same direction. The angle of the rollers is mirrored on the left and right side.

To achieve forward motion all the wheels go forward. To move sideways, the wheels on the one side go forward, and the wheels on the other side go backwards. To achieve other angles combinations of motor movements are required. An example can be seen in fig 5



(a) Example of a swerve drive (b) Fraunhofer Compact Drive

Figure 6: Swerve Drives (Baker en Mackenzie 2008, FRAUNHOFER IPA 2012)

2.3 Swerve-Drive

One of the earliest solutions to the omni-directional drive problem, was the use of a castor wheel that is powered, but also steerable. This system is more commonly known as swerve-drive (or Crab drive) due to the manner in which the system moves. While it's possible to get movement in any direction with only one drive, normal resistance from the supporting wheels generally require at least two individually driven and steered wheels. An example of a swerve drive can be seen in fig 6a.

This type of product has received some commercial success. The company Fraunhofer has developed several products for use in the manufacturing and automation industries making use of their custom 'Compact Drive Module' (FRAUNHOFER IPA 2012) an example of which can be seen in fig 6b.

One of the negative aspects of this drive is that before the robot can move, the wheels have to be rotated to the correct angle. This can add delays to the movement.

2.3.1 Control

As with the Omni-Wheel, one makes use of the sum of the speed vectors for each wheel to determine total speed and direction. There are generally only two driven wheels, so one need only point them in the desired direction and at the correct speed. When rotation is required the angles of the wheels will differ.

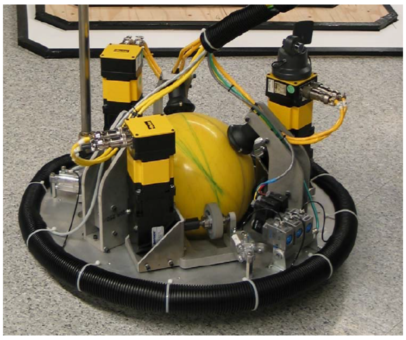


Figure 7: Human-assist Proof of Concept (Lee *et al.* 2001)

2.4 Ball drive

2.4.1 Supported system

A ball drive comprises of a large ball driven by at least two (usually three) motors with rollers attached. A platform consists of a centred driven ball along with (usually) three rolling supports, such as castor wheels or other ball rollers.

By choosing different speeds for the driving motors, the ball can be made to rotate in any direction at different speeds. This movement is then translated to the ground by the ball and the system is moved in the desired direction.

An example of this can be seen in fig 7 which was used as a proof of concept for the development of a human-assist device for lifting (Lee *et al.* 2001)

This same system is what has been used in a project at Reutlingen University (Weiß 2009).

2.4.2 Inverse Pendulum

The inverse pendulum problem is one that has been solved many times. It comprises of a long arm mounted vertically on a pivot. As the arm would fall to one side, the base responds by moving in the same direction to counter the moment. By continuously monitoring the position of the arm, the base can control it and keep it upright.

This is the kind of system that the popular Segway makes use of to stay upright and drive. This same system can be applied in two dimensions. By using a ball as the base as opposed to conventional wheels, thus two dimensional control can be achieved.

By using two motors which have the ability to rotate the 'pendulum'

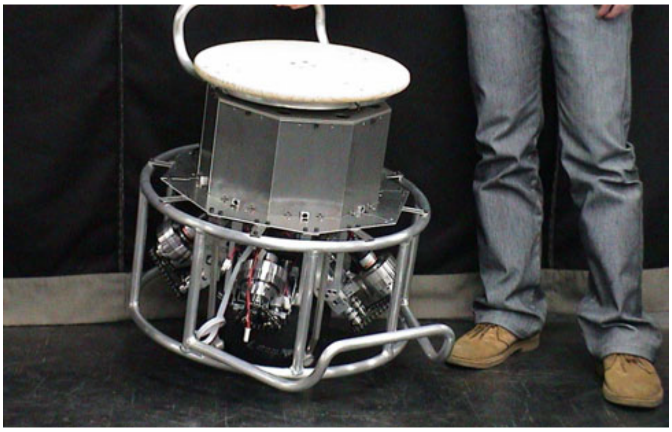


Figure 8: Basketball Rider (Endo en Nakamura 2005)

relative to the ball one can get omni-directional control. A third motor is required to obtain on the spot rotation and to aid the control process.

This system has already been successfully implemented in several prototypes such as the BB Rider, see figure 8.

2.4.3 Control

The control for Inverse Pendulum setup can be fairly complicated. The more work that is put in to developing an appropriate control system, the better the system will respond. The system would generally be designed to monitor an accelerometer, and to always return the system to the upright position. Once that is developed the system will move in whatever direction one tips the pendulum.

For the supported system the control is fairly easy, again needing only to use the speed of two of the motors to achieve the correct speed and direction. A third motor can be used entirely for rotation.

2.5 Other of interest

Other methods of drive besides those listed above do exist, very often making use of a combination of the ones listed in this report.

2.5.1 Vuton Tracks

A Vuton track is very similar to an Omni-Wheel, just as opposed to having a wheel with cylinders mounted on it, the Vuton track makes use of tank tracks with cylinders mounted perpendicularly to the track. The main benefit of

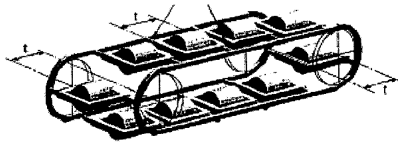


Figure 9: Example of one Vuton Track (Damoto *et al.* 2001)

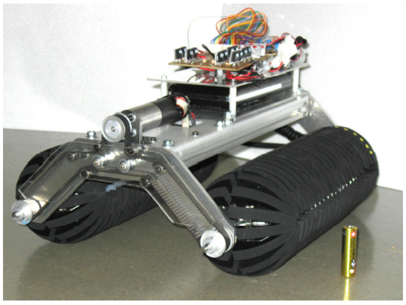


Figure 10: Omni-Crawler (Tadakuma *et al.* 2008)

the Vuton track over Omni-Wheels is the increased load bearing capacity when using Vuton tracks. An image of one of the vuton tracks can be seen in figure 9.

Mounting 4 of these tracks in a square configuration gives one the ability to travel in any direction. Good control can also be achieved with only three units. That together with the benefits of a track system, such as good traction and ease of control make this a fairly sturdy choice.

2.5.2 Omni-Crawler

The Omni-Crawler is a unique idea, it makes use of a set of circular tracks to provide motion in any direction. It is to the Omni-Ball as the Vuton Track is to the Omni-Wheel. Enclosed within the tracks is a motor and drives which rotate the tracks in the normal direction providing forward and reverse motion as well as rotation. The entire track mechanism is also pivoted to be able to roll sideways. Motors mounted on the centre of the Omni-Crawler drive a gear that rotates the tracks sideways providing left and right motion.

The negatives being that such a system would be relatively complicated from a mechanical point of view and the high cost that generally goes along with mechanically complicated systems. An image of a prototype of the system can be seen in 10.

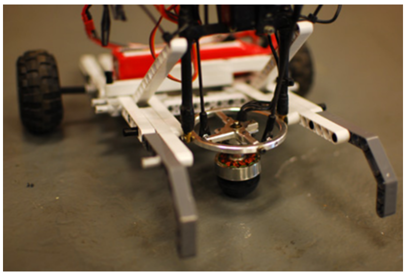


Figure 11: Basketball Rider (Ackerman 2011)

2.5.3 Hemispherical Omnidirectional Gimbaled Drive

In 2011 an old design was revisited (Ackerman 2011). It makes use of a hemispherical wheel which spins, much like a spinning top to move in various directions.

When upright the sphere spins on the spot, not inducing movement in any direction. As the sphere is made to lean sideways, a point of the sphere that has angular velocity is in contact with the ground, thus propelling the object forward. By altering the angle of contact of the sphere one can achieve motion in any direction. The prototype can be seen in fig 11

Although it is possible to get motion with only one of these devices, to get true and controlled omnidirectional drive, at least two of these devices are required. Much like the supported ball drive (sec 2.4.1) extra castor wheels or ball bearings are required to support the structure.

Although this design may seem very similar to that of the Ball drive, the main difference with this is that only one motor is required to spin the wheel. Two other actuators are required to tilt the wheel in the correct orientation. The example model makes use of two servos from a model plane in a gimbal setup to easily set the orientation of the sphere.

The idea has been suggested before. It was proposed to be used as propulsion for a car, and was illustrated in the 1938 edition of Mechanics and Handicraft Magazine /citeackerman.

2.5.4 Donut Swerve Drive

In 1985 a patent was filed for the design of an omni-directional drive unit (Shiraishi 1985). The design made use of two motors per driving 'wheel' to allow drive in any direction. One of the motors gave rotary movement to the 'wheel' while the other altered the orientation of the wheel. Much like in the swerve drive system in section 2.3.

The difference in this design is that instead of using a conventional wheel, it made use of a donut shaped wheel angled at 45° to the floor. An alternative suggestion was made to use half a sphere as the wheel instead, similar to what is seen section 2.5.3.

Further suggestions were made to achieve steering instead by altering the angle of attack of the wheel, like in section 2.5.3

2.5.5 Hovercraft

Mention can also be found of omni-directional hovercraft. This is fairly straight forward as once lift is gained, one can travel in any direction by simply directing the propelling fans in the correct direction, similar to that of the drivable castor wheels in Section 2.3, or one can make use of three fans placed at 120°to each other, similar to the omni-wheel setup in Section 2.1.1.

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A Further Reading

If you would like to find out more about the respective methods of movement and how to control them, here is a list of useful documents.

A.1 Omni-Wheels

A.1.1 3-Wheel Layout

To see a video of this type of drive go here: http://www.youtube.com/watch?feature=endscreen&v=mNy09kuIdzs&NR=1 or here http://www.youtube.com/watch?v=FGKdiTPj_sc

A report covering the design of such a system can be seen here: http://alexandria.tue.nl/repository/books/612987.pdf

A.1.2 4-Wheel Layout

To see a video of this type of drive go here: http://www.youtube.com/watch?v=5vJCucpVdX0&feature=related

A paper covering control of such a unit can be seen here: http://www.mech.chuo-u.ac.jp/~osumilab/papers/iros2008-2.pdf

A.1.3 Anisotropic Wheels

5-page report covering a brief overview of inspiration and overview of alternatives. Explains process to manufacture: http://web.mit.edu/mobility/publications/Iagnemma_ICAM_10.pdf

A.1.4 Omni-Ball

Mechanical design of an Omni-Ball: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04341852

Development of a vehicle using four omni-balls: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=4399560&contentType=Conference+Publications

A.2 Mecanum Wheels

Short video describing how Mecanum Wheels work: http://www.youtube.com/watch?v=o-j9TReI1aQ

A video with a fairly impressive demonstration of a forklift which makes use of Mecanum Wheels: http://www.youtube.com/watch?v=_f_x0RgVzfc

This document covers the design of a robot using mecanum wheels, looks at alternatives and shows some of the calculations performed: `http://cdn.intechopen.com/pdfs/465/I...ementation.pdf`

A.3 Swerve-Drive

Video demonstrating the ability of a swerve drive: `http://www.youtube.com/watch?v=p9WHMssEF4U&feature=relmfu` To better see the workings of a swerve-drive look here: `http://www.youtube.com/watch?v=q9uck-wRa_8` A patent document covering a design for a swerve drive unit can be seen here `http://www.google.com/patents/US6491127`

A.4 Ball Drive

A.4.1 Supported Drive

Hanna Weiß of the Hochschule Reutlingen wrote a bachelor's thesis entitled Konzeption und Implementierung von Steuerprogrammen für eine mobile Roboterplattform hoher Beweglichkeit sowie Optimeierung des Gesamtsystems (Weiß 2009) which covers the design and some of the control for a supported ball drive.

A.4.2 Inverse Pendulum

A fairly nice video example of an inverse pendulum on a ball: `http://www.youtube.com/watch?v=bI06lujiD7E&feature=related`

This document covers the design of the BasketBall Unit, as well as covering some of the maths involved in control: `http://ftp.mi.fu-berlin.de/Rojas/omniwheel/icar2005.pdf`

A.5 Other of Interest

A.5.1 Vuton Tracks

Video's and short write up on the Vuton Track: `http://www-robot.mes.titech.ac.jp/robot/special/vuton/vuton_e.html`

A.5.2 Omni-Crawler

Paper describing the design process of the Omni-Crawler: `http://web.mit.edu/mobility/publications/IROS08_1351_MS.pdf` and another such document: http://web.mit.edu/mobility/publications/WA2-4.pdf

This video shows off the mobility of the device: http://www.youtube.com/watch?v=BTp2UAaihaI

A.5.3 Spinning-top Design

You can see a video of the device in use as well as a description of how it works: http://www.youtube.com/watch?v=uaT7M3Nwj7c&feature=youtu.be

Unfortunately there is no documentation covering the operation of the design.

A.5.4 Donut Swerve Drive

A patent covering the design of such a system can be found here: http://www.google.com/patents/US4519466

A.5.5 Hovercraft

A page demonstrating several different hovercraft setups for omni-directional drive: http://cse.unl.edu/~carrick/wordpress/?p=6