Omnidirectional Drive Systems

Ian Mackenzie

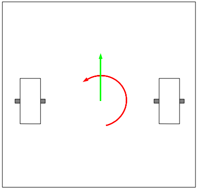
2006 FIRST Robotics Conference

Ian Mackenzie

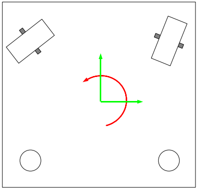
- Involved in FIRST since 1998
- High school student on Woburn Robotics (188) from 1998-2001
- University mentor for Woburn Robotics in 2002
- Recruiter/organizer for FIRST Canadian Regional in 2003
- Lead mentor for Simbotics (1114) in 2004, created SimSwerve crab drive system
- Planning committee/head referee for Waterloo Regional in 2005 and 2006
- Scheduling algorithm developer, inspector, Lego League referee...

Introduction

- Tank drive: 2 degrees of freedom



- Omnidirectional drive: 3 degrees of freedom



Advantages and Disadvantages

Advantages

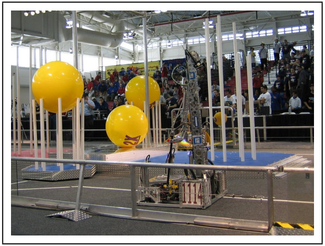
- Maneuverability

Disadvantages

- Complex
  - Heavy
  - Less robust
  - Tricky to control
- (Usually) less pushing force

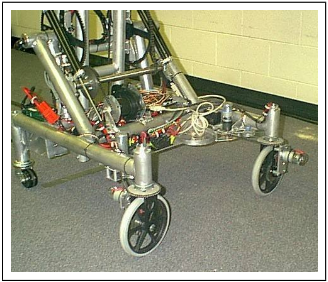
Strategies Favouring Omnidirectional Drive

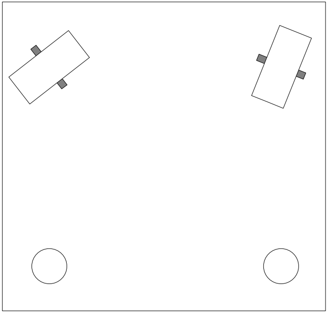
- Primarily offensive robots
  - Not good at pushing others
  - Good at avoiding defense
  - If implemented correctly, easier to align robot to targets (e.g. balls to pick up, goals to score into)
- Confined spaces on the field
  - *Raising the Bar* in 2004
  - Analogous to industrial applications



Swerve Drive

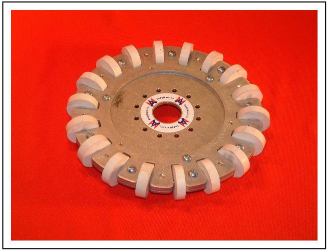
- Independently steered drive modules
- Simple conceptually
- Simple wheels
- Otherwise complex to build
- Complex to program and control
- Maximum pushing force
- Either steered gearboxes or concentric drive

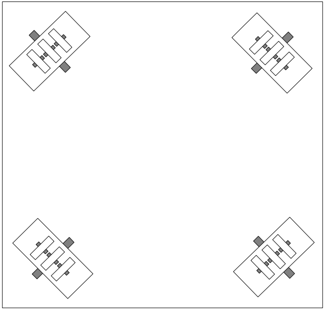




Holonomic Drive

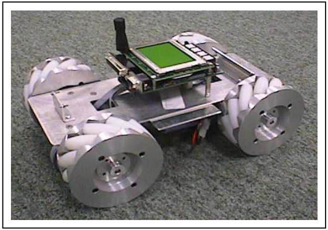
- Wheels with ‘straight’ rollers (omniwheels)
- More complex conceptually
- Fairly complex wheels
- Fairly simple to build
- Fairly simple to program and control
- (Usually) low traction
- Less speed and pushing force on when moving diagonally

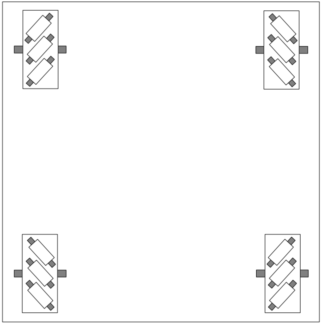




Mecanum Drive

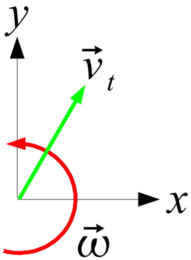
- Wheels with angled rollers
- Very complex conceptually
- Very complex wheels
- Otherwise simple to build
- Fairly simple to program and control
- (Usually) low traction
- Less speed and pushing force on when moving diagonally





Kinematics

- Mathematics describing motion
- Solid grasp of theory makes control much easier
- Great example of how real university-level theory can be applied to FIRST robots
- Three step process:
  - Define overall robot motion
    - Usually by $\vec{v}_t$, $\vec{\omega}$; can transform other forms into this form quite easily
  - Calculate velocity at each wheel
  - Calculate actual wheel speed (and possibly orientation) from that velocity



Single Wheel

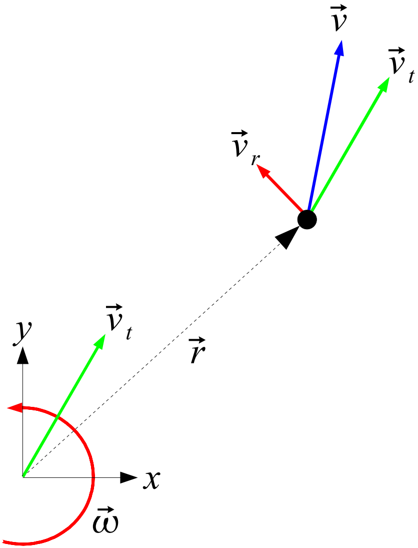
Common to all types of omnidirectional drive

Vector approach

$$\vec{v} = \vec{v}_t + \vec{\omega} \times \vec{r}$$

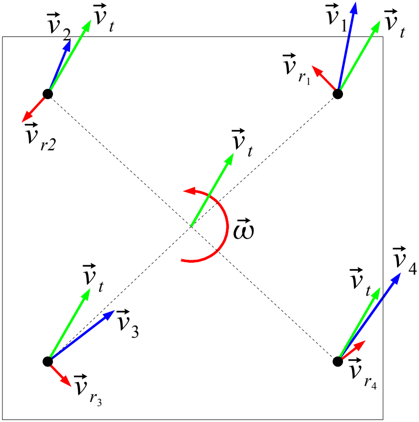
Scalar approach

$$v_x = v_{t_x} - \omega \cdot r_y$$
$$v_y = v_{t_y} + \omega \cdot r_x$$



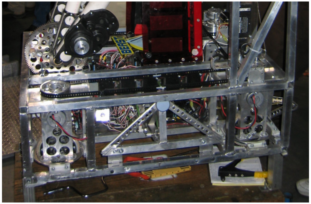
Entire base

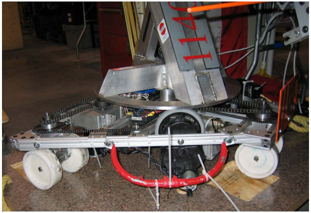
- In general, each wheel will have a unique speed and direction
  - Full swerve drive would require at least 8 motors; has been done once (Chief Delphi in 2001)
  - Swerve drive usually done with 2 swerve modules along with casters or holonomic wheels



Swerve Drive Approximations

- Some drive trains use swerve modules steered together
  - Four modules steered together (crab drive)
  - Front modules steered together, back modules steered together
  - Right modules steered together, left modules steered together
- Does not allow full freedom of motion
- Requires fewer steering motors

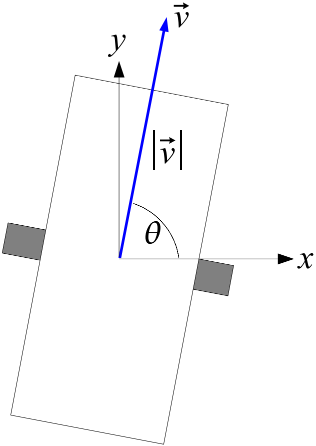




Swerve Drive

- Resolve velocity at each wheel into magnitude and angle
- Be careful with angle quadrant!

$$|\vec{v}| = \sqrt{v_x^2 + v_y^2}$$
$$\theta = \arctan\left(\frac{v_y}{v_x}\right)$$



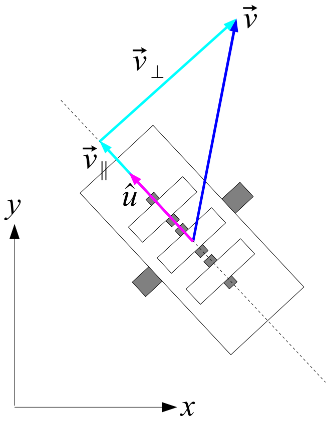
Holonomic Drive

- Resolve velocity into parallel and perpendicular components

$$\begin{aligned} \left|\vec{v}_{\|}\right| &= \vec{v} \cdot \hat{u} \\ &= (v_x \hat{\imath} + v_y \hat{\jmath}) \cdot \\ &\quad \left(-\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}\right) \\ &= -\frac{1}{\sqrt{2}} v_x + \frac{1}{\sqrt{2}} v_y \end{aligned}$$

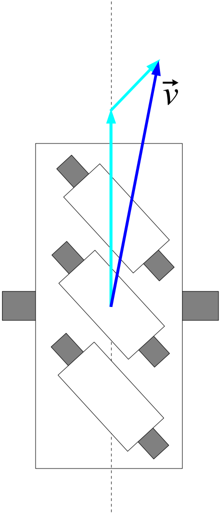
- Magnitude of $\vec{v}_{\|}$ gives wheel speed

$$\begin{aligned} |\vec{v}_w| &= \left|\vec{v}_{\|}\right| \\ &= -\frac{1}{\sqrt{2}} v_x + \frac{1}{\sqrt{2}} v_y \end{aligned}$$



Mecanum Drive

- Similar to holonomic drive
- Conceptually: Resolve velocity into components parallel to wheel and parallel to roller
- Not easy to calculate directly (directions are not perpendicular), so do it in two steps

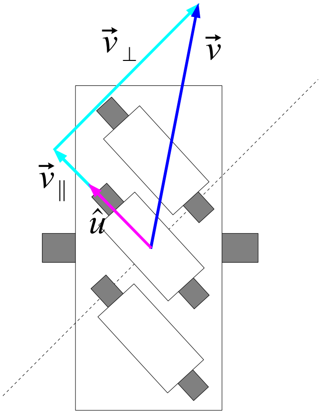


Resolve to Roller

- Resolve velocity into components parallel and perpendicular to roller axis
- Perpendicular component can be discarded

$$
\begin{aligned}
\left|\vec{v}_{\parallel}\right| &= \vec{v} \cdot \hat{u} \\
&= (v_x \hat{\imath} + v_y \hat{\jmath}) \cdot \\
&\quad \left(-\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}\right) \\
&= -\frac{1}{\sqrt{2}} v_x + \frac{1}{\sqrt{2}} v_y
\end{aligned}
$$

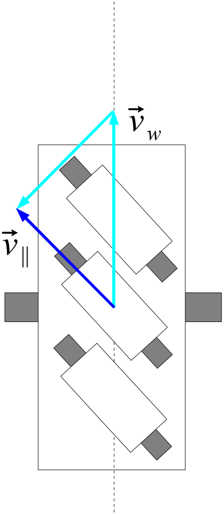
- $\hat{u}$ is not the same for each wheel!



Resolve to Wheel

- Use component parallel to roller axis and resolve it into components parallel to wheel and parallel to roller
- This does not involve simple projections like holonomic drive, so we cannot use dot products
- However, angle is known, so we can calculate $|\vec{v}_w|$ directly:

$$
\begin{aligned}
|\vec{v}_w| &= \frac{|\vec{v}_{\|}|}{\cos 45^\circ} \\
&= \sqrt{2}\left(-\frac{1}{\sqrt{2}}v_x + \frac{1}{\sqrt{2}}v_y\right) \\
&= -v_x + v_y
\end{aligned}
$$

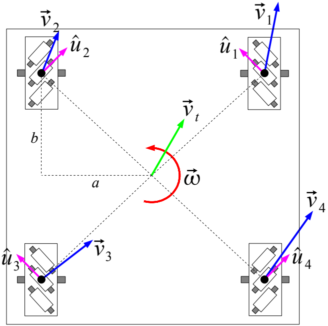


Mecanum Drive Example

Using wheel 3 as an example:

$$
\begin{aligned}
v_{3_x} &= v_{t_x} + \omega b \\
v_{3_y} &= v_{t_y} - \omega a \\
\hat{u}_3 &= -\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}
\end{aligned}
$$

$$
\begin{aligned}
|\vec{v}_{w_3}| &= \sqrt{2}\left(-\frac{1}{\sqrt{2}}v_{3_x} + \frac{1}{\sqrt{2}}v_{3_y}\right) \\
&= -v_{3_x} + v_{3_y} \\
&= -v_{t_x} - \omega b + v_{t_y} - \omega a \\
&= v_{t_y} - v_{t_x} - \omega\left(a + b\right)
\end{aligned}
$$

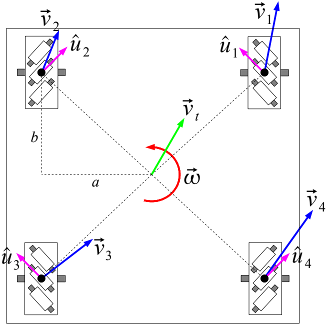


Mecanum Drive Example

Similarly,

$$\begin{aligned} |\vec{v}_{w_1}| &= v_{t_y} - v_{t_x} + \omega(a+b) \\ |\vec{v}_{w_2}| &= v_{t_y} + v_{t_x} - \omega(a+b) \\ |\vec{v}_{w_4}| &= v_{t_y} + v_{t_x} + \omega(a+b) \end{aligned}$$

Note that all speeds are linear functions of the inputs (i.e. no trigonometry or square roots necessary), so control is very fast.

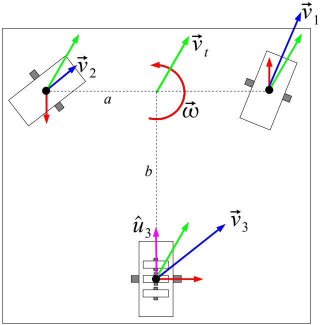


Hybrid Swerve/Holonomic Drive

$$v_{1_x} = v_{t_x}$$
$$v_{1_y} = v_{t_y} + \omega a$$

$$v_{2_x} = v_{t_x}$$
$$v_{2_y} = v_{t_y} - \omega a$$

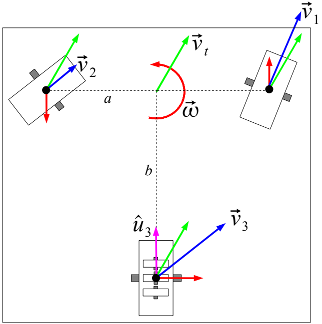
$$v_{3_x} = v_{t_x} + \omega b$$
$$v_{3_y} = v_{t_y}$$



Hybrid Swerve/Holonomic Drive

Swerve module 1:

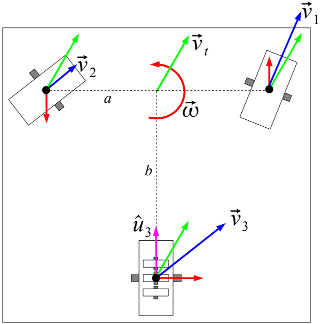
$$
\begin{aligned}
|\vec{v}_{w_1}| &= \sqrt{v_{1_x}^2 + v_{1_y}^2} \\
&= \sqrt{v_{t_x}^2 + \left(v_{t_y} + \omega a\right)^2} \\
\theta_1 &= \arctan\left(\frac{v_{1_y}}{v_{1_x}}\right) \\
&= \arctan\left(\frac{v_{t_y} + \omega a}{v_{t_x}}\right)
\end{aligned}
$$



Hybrid Swerve/Holonomic Drive

Swerve module 2:

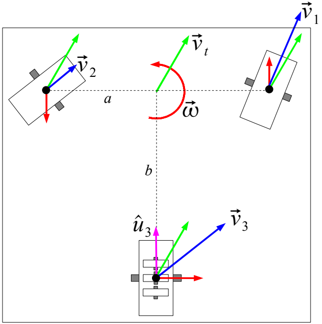
$$
\begin{aligned}
|\vec{v}_{w_2}| &= \sqrt{v_{2_x}^2 + v_{2_y}^2} \\
&= \sqrt{v_{t_x}^2 + \left(v_{t_y} - \omega a\right)^2} \\
\theta_1 &= \arctan\left(\frac{v_{2_y}}{v_{2_x}}\right) \\
&= \arctan\left(\frac{v_{t_y} - \omega a}{v_{t_x}}\right)
\end{aligned}
$$



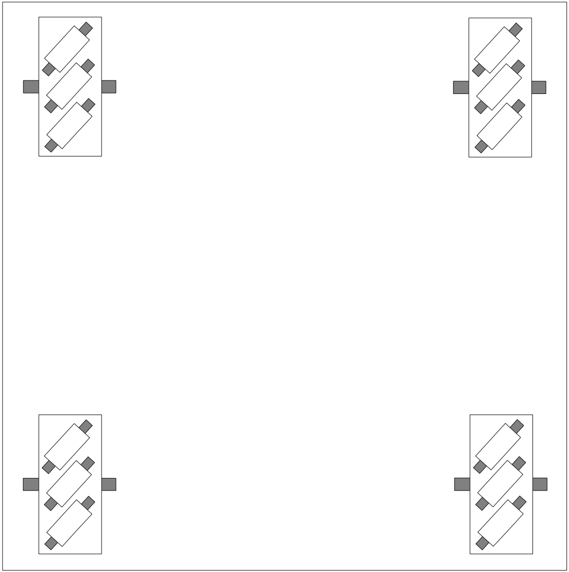
Hybrid Swerve/Holonomic Drive

Holonomic wheel:

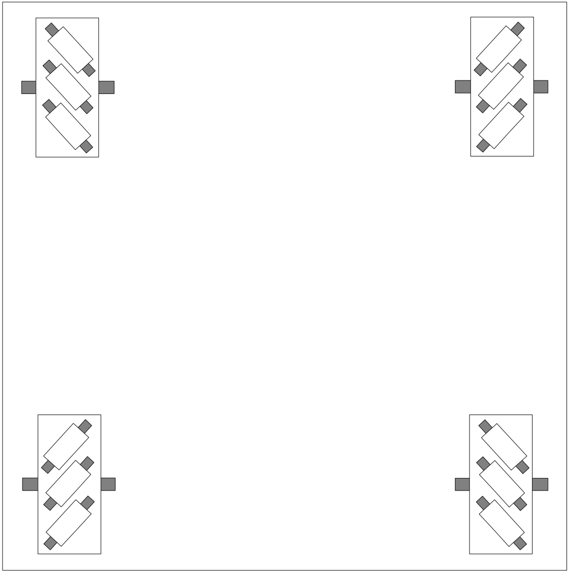
$$
\begin{aligned}
|\vec{v}_{w3}| &= \vec{v}_3 \cdot \hat{u}_3 \\
&= \left(v_{3_x}\hat{\imath} + v_{3_y}\hat{\jmath}\right) \cdot \hat{\jmath} \\
&= v_{3_y} \\
&= v_{t_y}
\end{aligned}
$$



What's Wrong With This Picture?

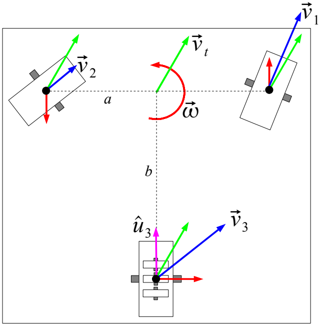


What's Wrong With THIS Picture?



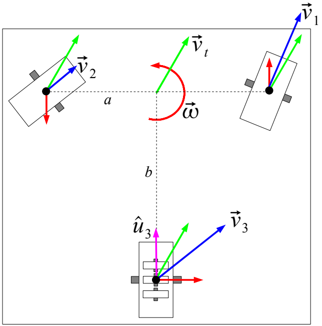
Scaling Issues

- Speed calculations may result in greater-than-maximum speeds
- Possible to limit inputs so this never happens, but this overly restricts some directions
- Better to adjust speeds on the fly



Scaling Algorithm

- Calculate wheel speeds for each wheel
- Find maximum wheel speed
- If this is greater than the maximum possible wheel speed, calculate the scaling factor necessary to reduce it to the maximum possible wheel speed
- Scale all wheel speeds by this factor



Robots to Check Out

Team 148 in Curie has mecanum drive with two control modes; tank steering and full 3 degree of freedom steering

Team 16 in Galileo has two swerve modules steered together but driven seperately at the front, and then a third swerve module at the back; drive is either in crab mode or tank mode

Team 71 in Newton has 4 swerve modules steered together but powered seperately, driven in a hybrid crab/tank system

Team 118 in Newton has 4 swerve modules steered *and* driven together (pure crab steering)

Team 830 in Galileo has a pure holonomic drive system with full 3 degree of freedom motion

References I

Swerve

- SimSwerve: http://www.chiefdelphi.com/media/papers/1552
- Swerve module: http://www.chiefdelphi.com/forums/showthread.php?t=46817
- Concentric crab drive: http://www.chiefdelphi.com/forums/showthread.php?t=24135
- Concentric drive: http://www.chiefdelphi.com/forums/showthread.php?t=23034
- Concentric crab module: http://www.chiefdelphi.com/forums/showthread.php?t=22708
- Concentric crab drive: http://www.chiefdelphi.com/media/photos/16091
- Swerve module: http://www.chiefdelphi.com/forums/showpost.php?p=195859&postcount=3

References II

- Concentric lego crab drive: http://www.chiefdelphi.com/forums/showthread.php?t=22552
- Swerve drive approximations: http://www.chiefdelphi.com/forums/showthread.php?t=22386
- Concentric crab module: http://www.chiefdelphi.com/forums/showthread.php?t=20242
- Crab drive steering: http://www.chiefdelphi.com/media/papers/1599
- Lego crab drive: http://www.chiefdelphi.com/forums/showthread.php?t=28251
- Swerve drive approximations: http://www.chiefdelphi.com/forums/showthread.php?t=28195

References III

- Team 111 (2003): http://www.wildstang.org/gallery2/v/2003/2003_Build/2003_Robot_Build/2003_Robot_Proto/
- Team 114 (2005): http://engineer.la.mvla.net/robotics/images.php?showCollection=2005%20Inventor
- Crab drive base: http://www.chiefdelphi.com/media/photos/22005
- Swerve with unpowered omni wheels: http://www.chiefdelphi.com/media/photos/14646
- Crab module: http://www.chiefdelphi.com/media/photos/14556

Mecanum

- Mecanum drive: http://robotics.ee.uwa.edu.au/eyebot/doc/robots/omni.html
- Airtrax: http://www.airtrax.com

References IV

- (Even more) complex Mecanum wheels: http://www.chiefdelphi.com/forums/showthread.php?t=39885
- Mecanum wheel design: http://www.chiefdelphi.com/forums/showthread.php?t=46175
- Mecanum wheel: http://www.chiefdelphi.com/media/photos/22128
- Mecanum drive: http://www.chiefdelphi.com/media/photos/20664

Holonomic

- AndyMark: http://www.andymark.biz/
- Omni tracks: http://www.chiefdelphi.com/forums/showthread.php?t=46501
- Tilted omniwheels: http://www.chiefdelphi.com/forums/showthread.php?t=41723

References V

- Omniwheel position: http://www.chiefdelphi.com/forums/showthread.php?t=38839
- Holonomic drive: http://www.chiefdelphi.com/forums/showthread.php?t=28168
- Holonomic drive: http://www.chiefdelphi.com/media/photos/22831
- Holonomic drive: http://www.chiefdelphi.com/media/photos/22800
- Dual omniwheel: http://www.chiefdelphi.com/media/photos/21966
- Advanced omniwheels: http://www.chiefdelphi.com/media/photos/19483

General

- Steering control: http://www.chiefdelphi.com/forums/showthread.php?t=27022

References VI

- General discussion: http://www.chiefdelphi.com/forums/showthread.php?t=20434
- Strategies: http://www.chiefdelphi.com/forums/showthread.php?t=45967
- Good general discussion: http://www.chiefdelphi.com/forums/showthread.php?t=20434

Questions?

- ian.e.mackenzie@gmail.com
- "Ian Mackenzie" on Chief Delphi