Omnidirectional Drive Systems Kinematics and Control

Presented by:

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Who?

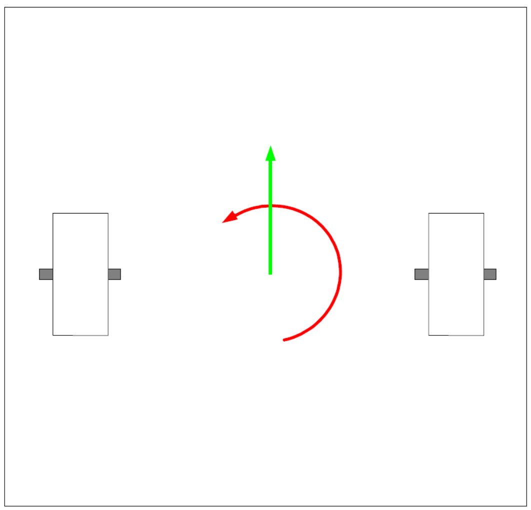
- Andy Baker
  - FRC mentor since 1998 (FRC 45, TechnoKats)
  - Designer of gearboxes, wheels, etc.
  - Started AndyMark in 2004
  - Inspector, referee, 2003 WFA winner
- Ian Mackenzie
  - FRC student: 1998-2002 (FRC 188, Woburn)
  - FRC mentor since 2004 (FRC 1114, Simbotics)
  - Waterloo Regional planning committee
  - 2008 Waterloo Regional WFFA winner

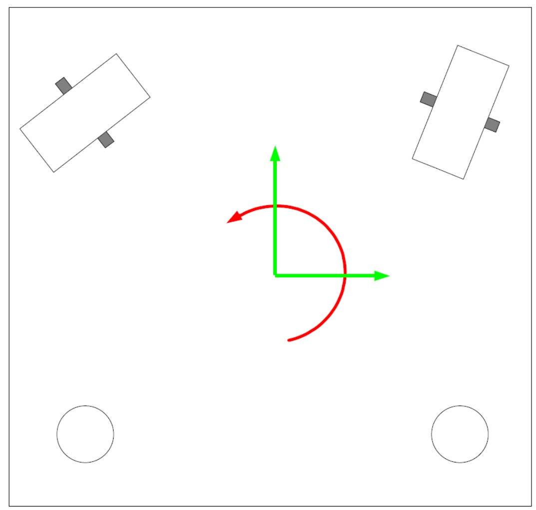
Outline

- Drive intro
- Drive types
- Kinematics
- Examples

Drive Types

- Tank drive: 2 degrees of freedom
- Omni-directional drive: 3 degrees of freedom





Omni-directional Drive History

- 1998: crab steering, FRC team 47
- 1998: Omni wheels, FRC team 67, 45
- 2002: 3-wheel Killough drive, FRC team 857
- 2003: Ball Drive, FRC team 45
- 2005: Mecanum-style “Jester Drive”, FRC team 357
- 2005: AndyMark, Inc. sells “Trick Wheels”
- 2007: AndyMark, Inc. sells Mecanum wheels

Strategy

- Primarily offensive robots
  - Not good at pushing
  - Good at avoiding defense
- Confined spaces on the field
  - *Raising the Bar* in 2004
  - Analogous to industrial applications
- Inspirational and innovative

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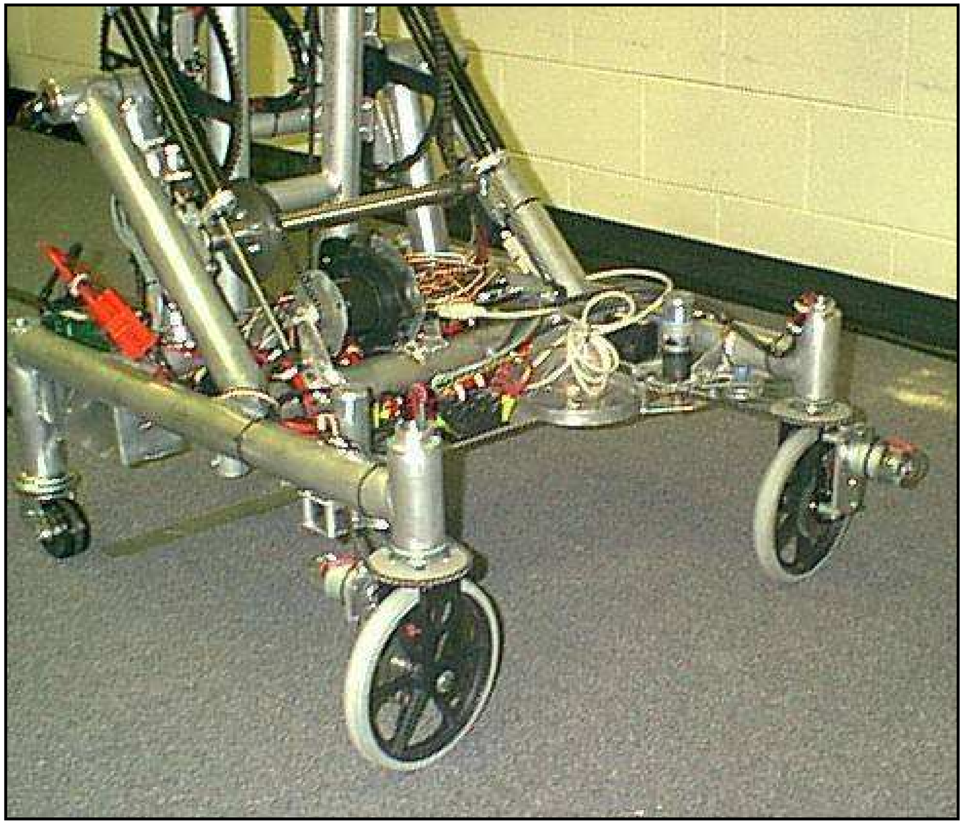
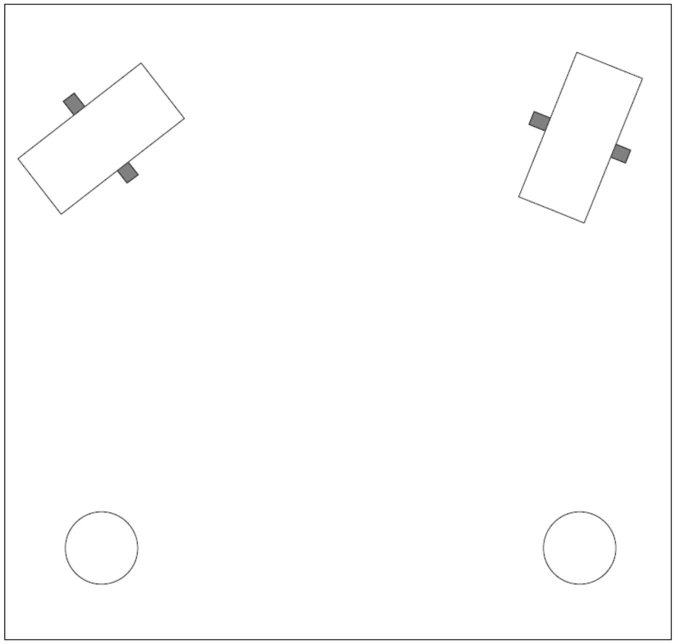
Omni-directional Drive Types

- Swerve (or Crab) Drive
- Killough Drive, using omni-wheels
- Mecanum Drive
- Ball Drive

Swerve drive, team 1114, 2004

Swerve drive, team 47, 2000





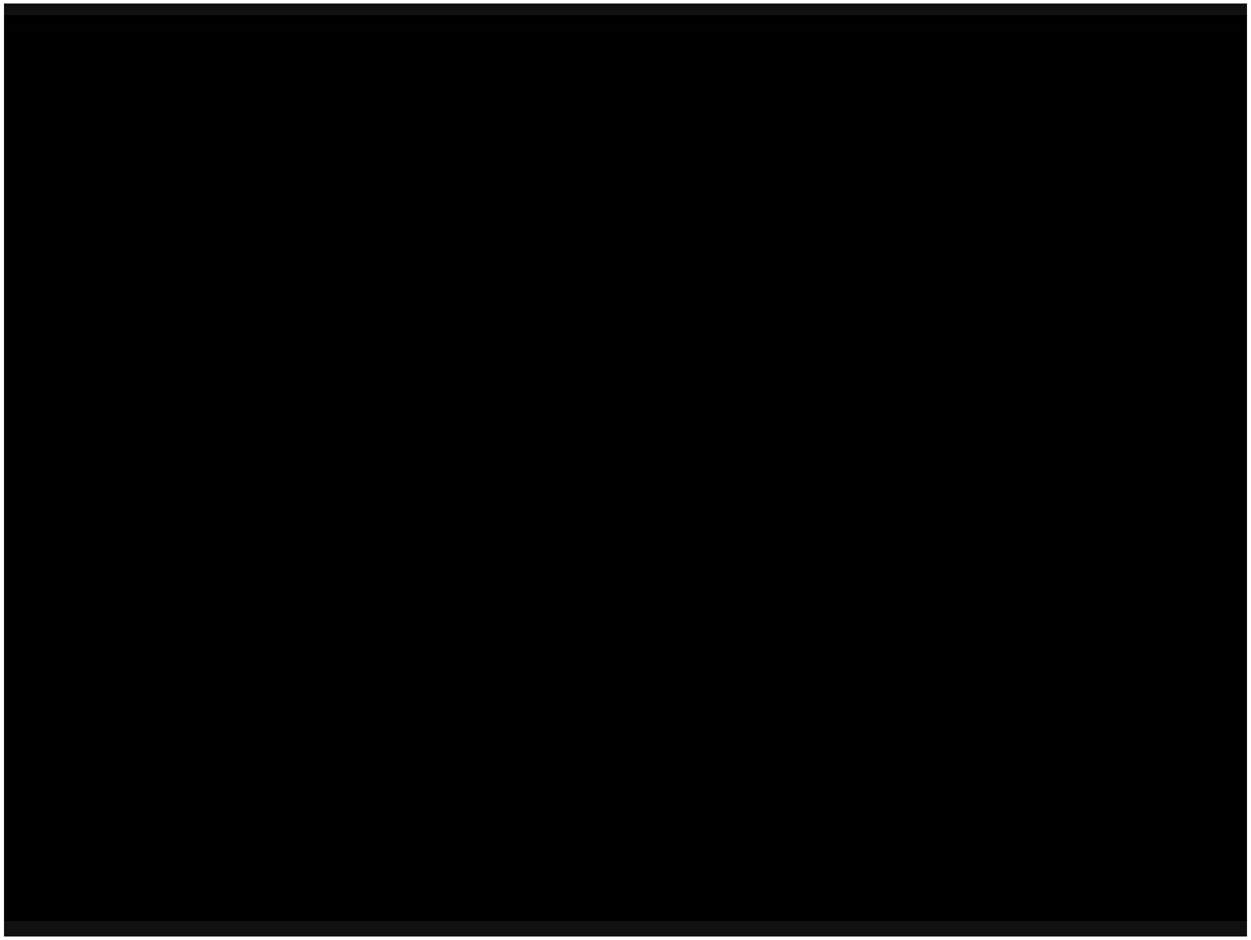
Swerve Drive

- High-traction wheels
- Each wheel rotates to steer

\+ No friction losses in wheel-floor interface
\+ Ability to push or hold position is high
\+ Simple wheels
\- Complex system to control and program
\- Mechanical and control issues
\- Difficult to drive
\- Wheel turning delay

Swerve drive pictures

Killough drive, team 857, 2003



Holonomic

- Stephen Killough, 1994

\+ Simple Mechanics

\+ Immediate Turning

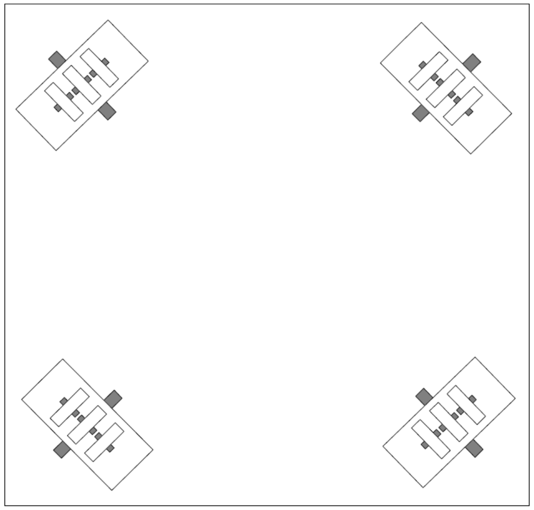
\+ Simple Control – 4 wheel independent

\- No brake

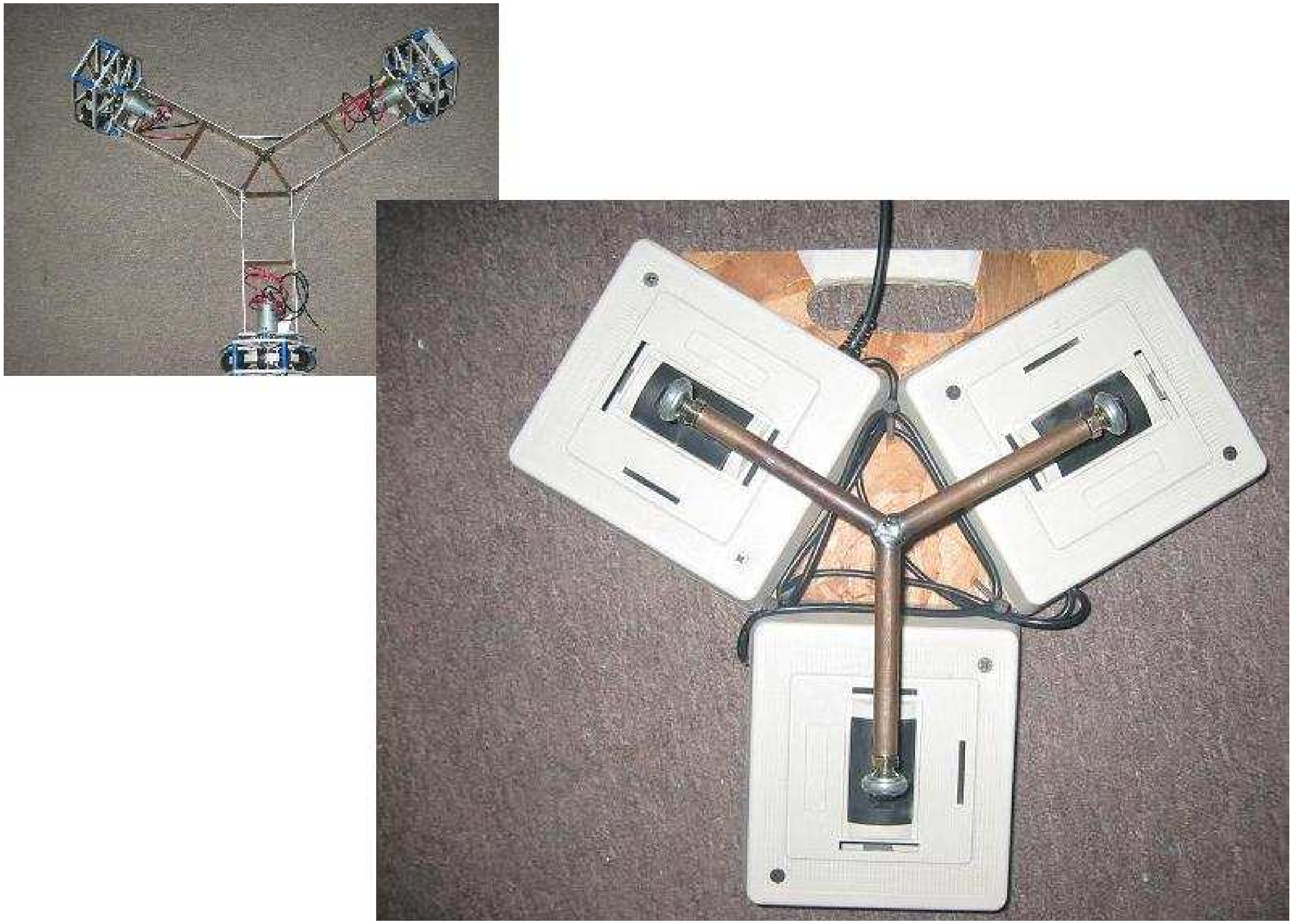
\- Minimal pushing power

\- Jittery ride, unless using dualies

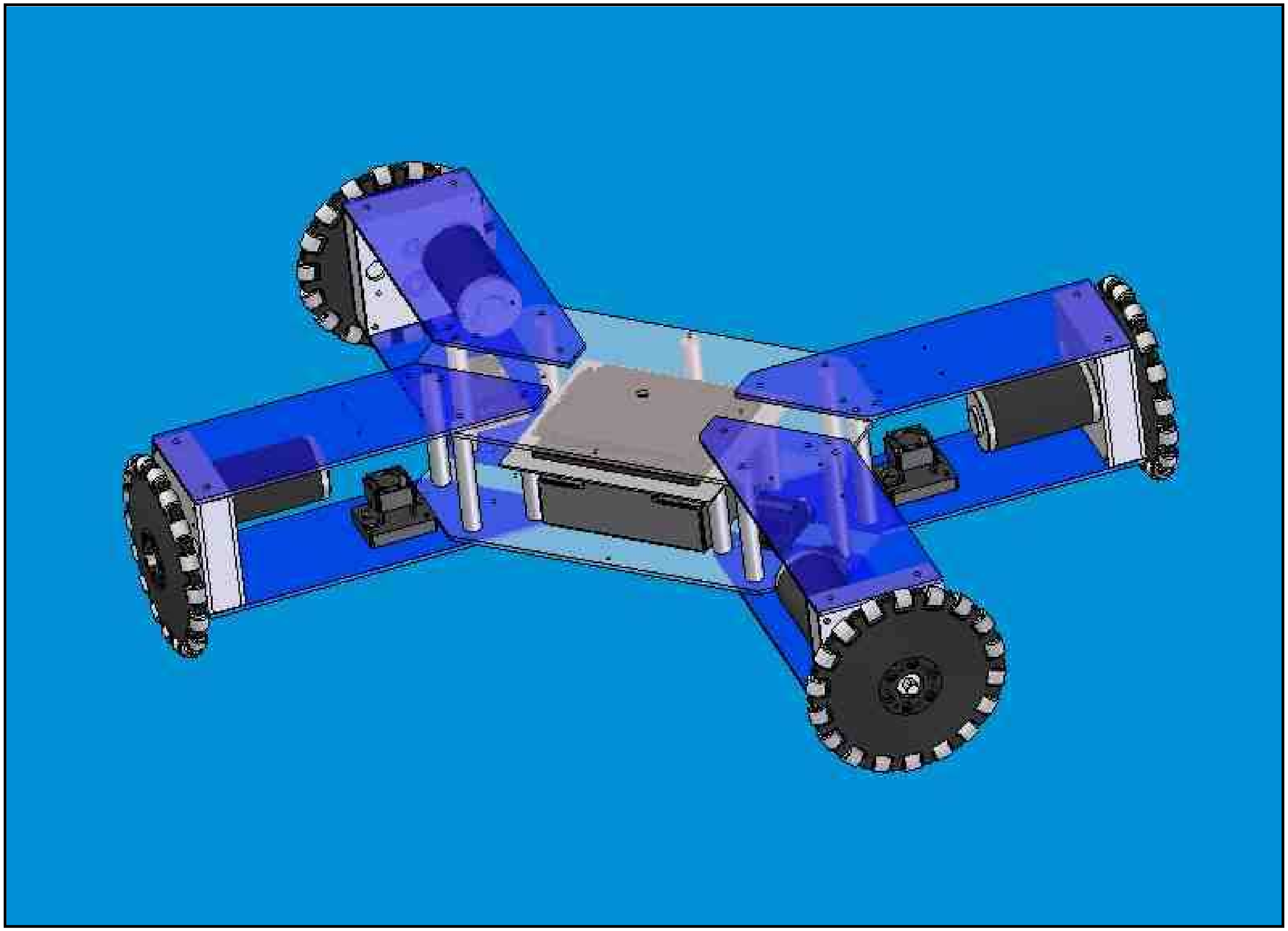
\- Incline difficulty



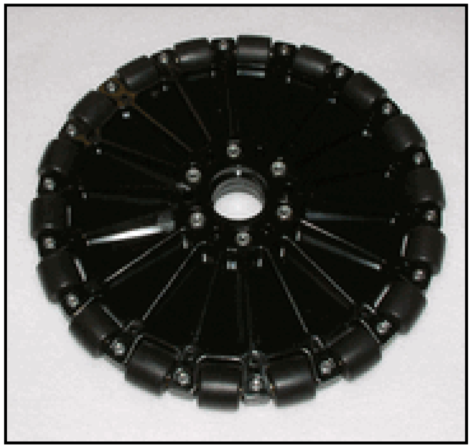
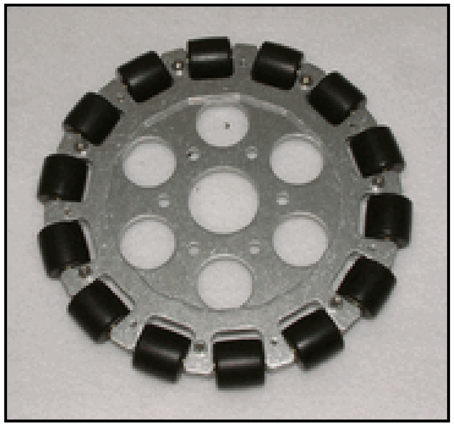
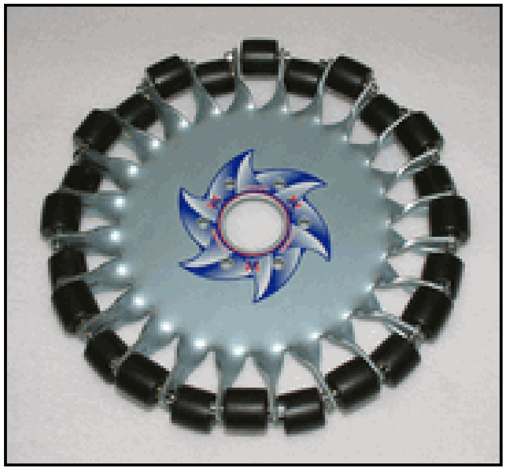
857 Kiwi Drive



AndyMark X-drive

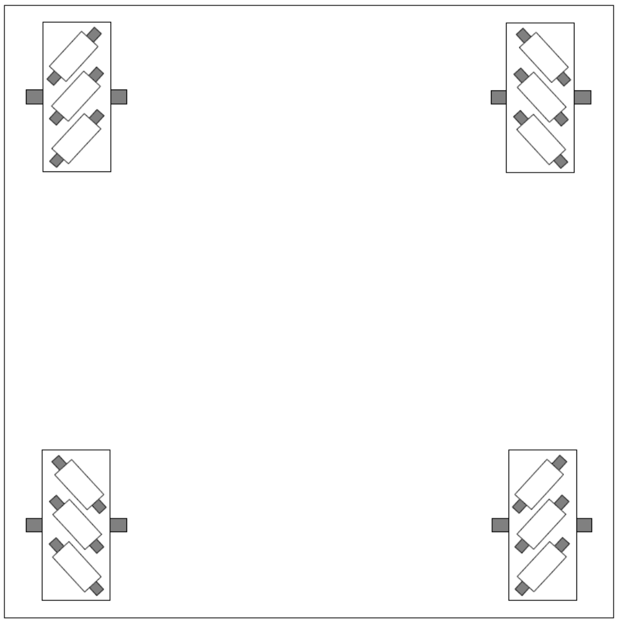


Omni wheels

Mecanum drive

+ Simple mechanisms
+ Immediate turn
+ Simple control – 4 wheel independent
- Minimal brake
- OK pushing power
- Needs a suspension
- Difficulty on inclines



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Mecanum wheels

Mecanum wheel chair, team 357

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Mecanum drive system, team 488

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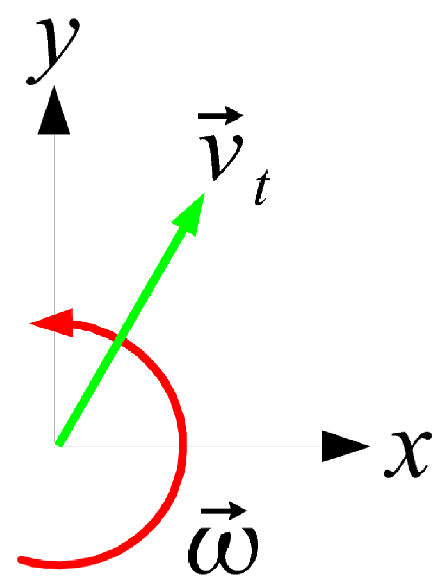
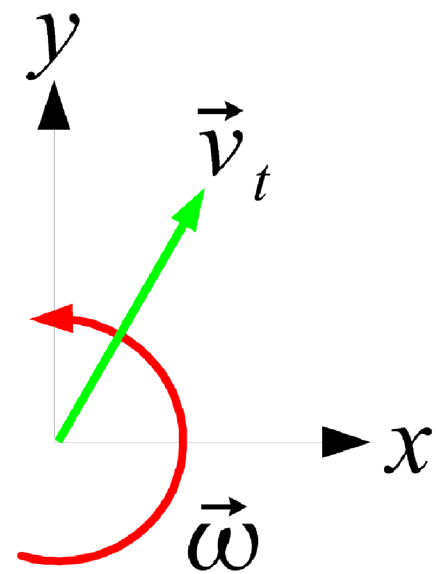
Kinematics

- 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 translation velocity $\vec{v}_t$, rotational velocity $\vec{\omega}$
  - Calculate velocity at each wheel
  - Calculate actual wheel speed (and possibly wheel orientation) from each wheel's velocity



Overall Robot Motion

- Break robot motion down into $\vec{v}_t$ (translational velocity of the center of the robot) and $\vec{\omega}$ (rotational velocity) and express as scalar components
  - v_{t_y} is forward-back motion (positive forward)
  - v_{t_x} is sideways motion (positive to the right)
  - ω is angular speed (positive counter-clockwise)



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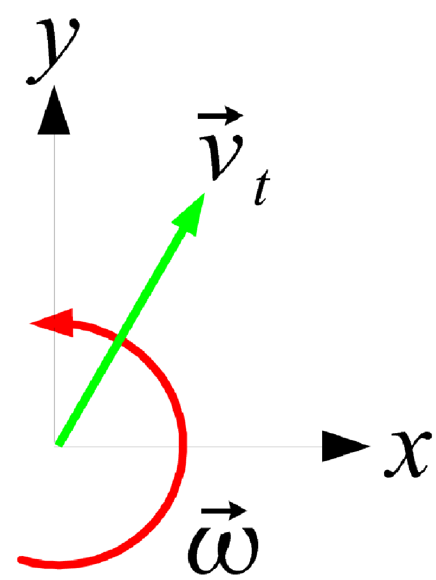
Overall Robot Motion

- Examples
  - Drive forward:
    $v_{t_y} = 10$ ft/s, $v_{t_x} = 0$,
    $\omega = 0$
  - Spin in place counterclockwise:
    $v_{t_y} = 0$, $v_{t_x} = 0$,
    $\omega = 5$ rad/s
  - Drive forward while turning to the right:
    $v_{t_y} = 10$ ft/s, $v_{t_x} = 0$,
    $\omega = -1$ rad/s
  - 'Circle strafe' to the right:
    $v_{t_y} = 0$ ft/s, $v_{t_x} = 5$ ft/s,
    $\omega = 2$ rad/s



Defining Robot Motion

- How to get v_{t_y}, v_{t_x}, ω? A few ideas…
  - Joystick + knob: Y and X axes of joystick give v_{t_y} and v_{t_x}, knob twist gives ω
    - Direct but not very intuitive to use
  - Two joysticks, crab priority: Y and X axes of first joystick give v_{t_y} and v_{t_x}, -X axis of second joystick gives ω
    - Normally drive in crab mode, moving second joystick adds rotation motion (like playing a first-person computer game with arrow keys and a mouse)
  - Two joysticks, tank priority: Y and –X axes of first joystick give v_{t_y} and ω, X axis of second joystick gives v_{t_x}
    - Normally drive in tank mode, moving second joystick adds sideways motion ('strafing' or 'dekeing')

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Velocity at a Point

- Common to all types of omnidirectional drive
- Given $\vec{v}_t$ (translational velocity of the center of the robot) and $\vec{\omega}$, determine the velocity $\vec{v}$ of some other point on the robot (e.g., the velocity at a particular wheel)
- Once the velocity at a wheel is known, we can calculate the speed at which to turn that wheel (and possibly the orientation of that wheel)

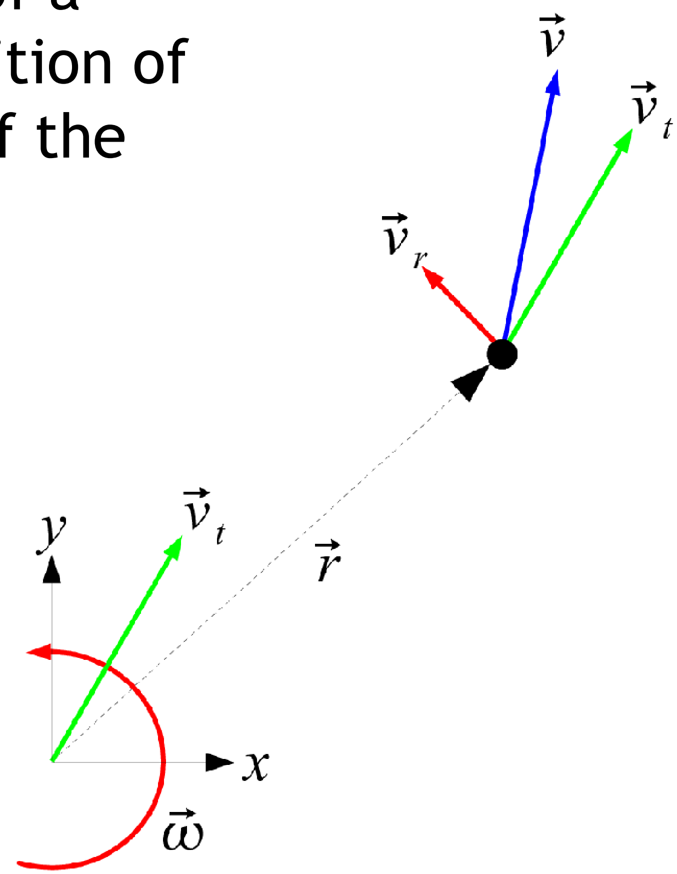
Velocity at a Point

- $\vec{r}$ is a vector giving the position of a point on the robot (e.g., the position of a wheel) relative to the center of the robot
- Vector approach:

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

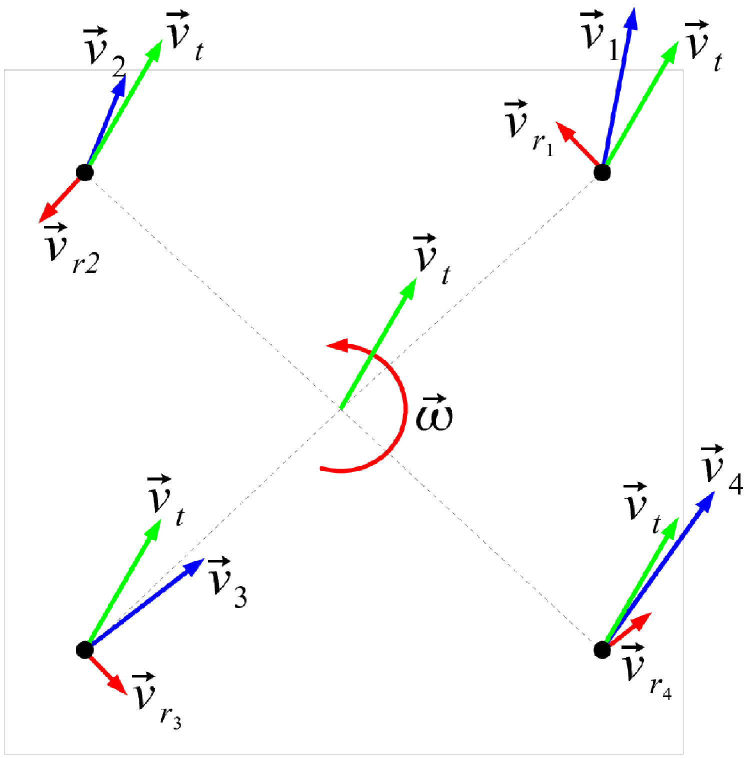
- Scalar approach:

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



Velocities of Multiple Points

- 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

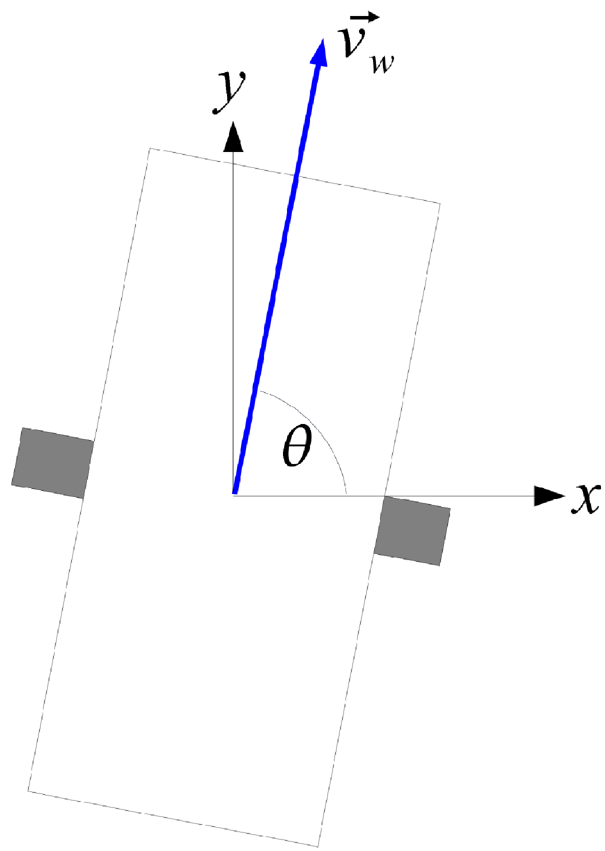


Swerve Drive

- Resolve velocity at each wheel into magnitude v_w (wheel speed) and angle θ (steering angle)
- Note that v_w is a translational speed (e.g., ft/s) and will have to be transformed into a rotational speed (e.g., wheel RPM)
- Be careful with angle quadrants!

$$v_w = \sqrt{v_x^2 + v_y^2}$$

$$\theta = \text{arctan}\left(\frac{v_y}{v_x}\right)$$



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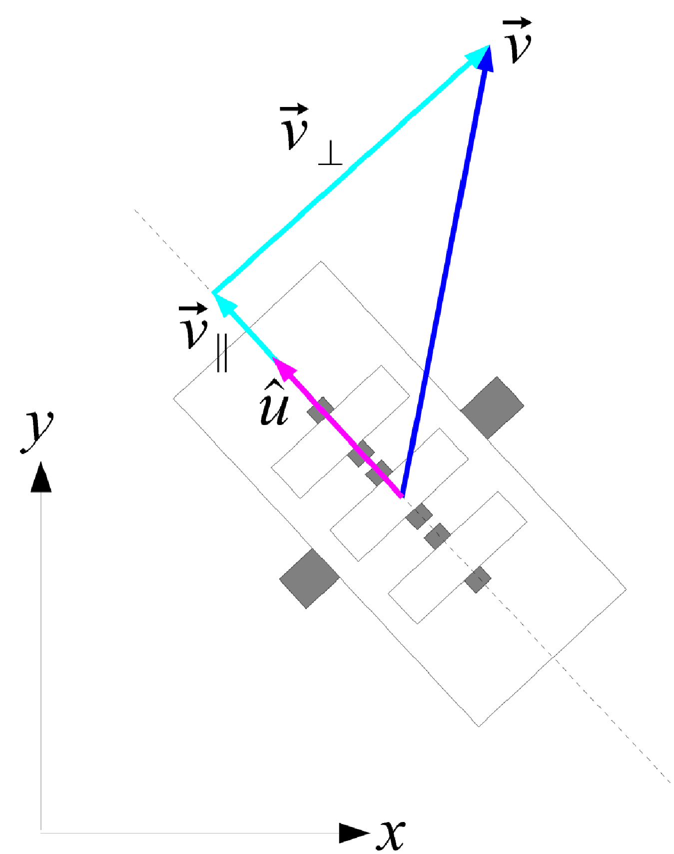
Holonomic Drive

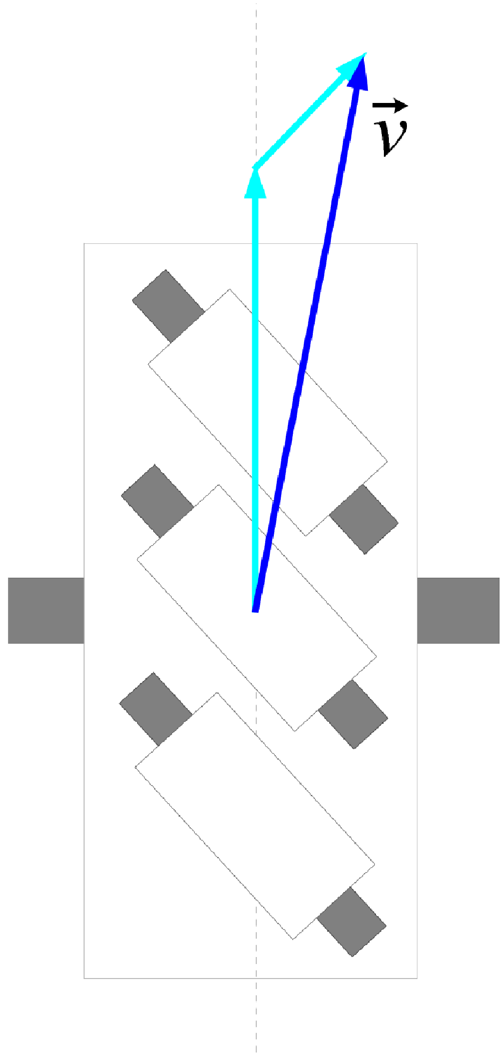
- Resolve velocity into parallel and perpendicular components; magnitude $v_{||}$ of parallel component is wheel speed v_w
- $\hat{u}$ is a unit vector in the direction of the wheel (whichever direction is assumed to be forwards)

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



Mecanum Drive

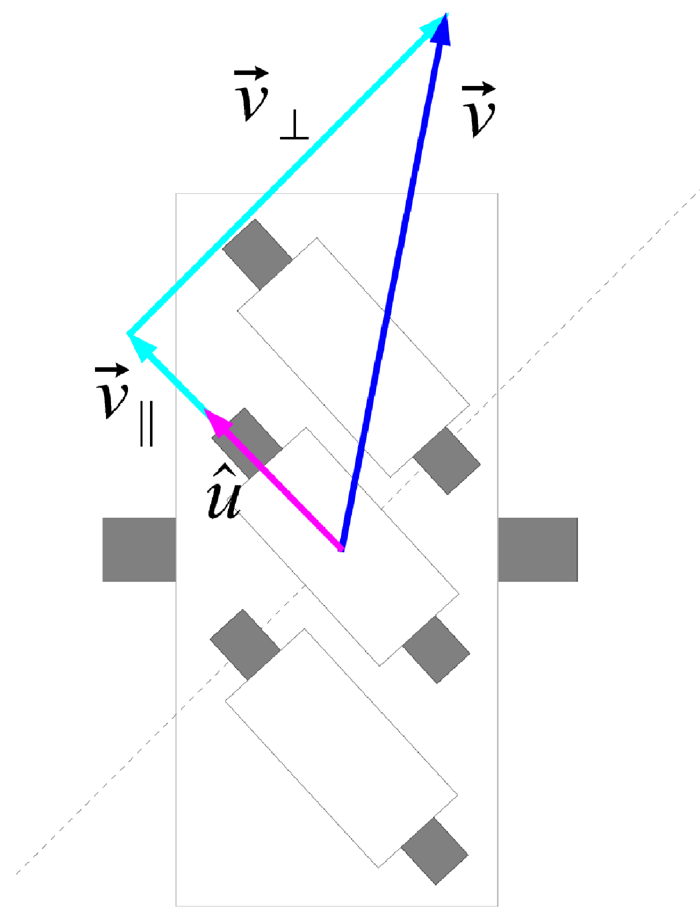
- Similar to holonomic drive
- Conceptually: Resolve velocity into components parallel to wheel and parallel to roller
- Not easy to calculate directly (directions are not perpendicular), so do it in two steps



Resolve to Roller

- Resolve velocity into components parallel and perpendicular to roller axis
  - $\hat{u}$ is not the same for each wheel; pick direction parallel to roller axis, in forwards direction
- Perpendicular component can be discarded

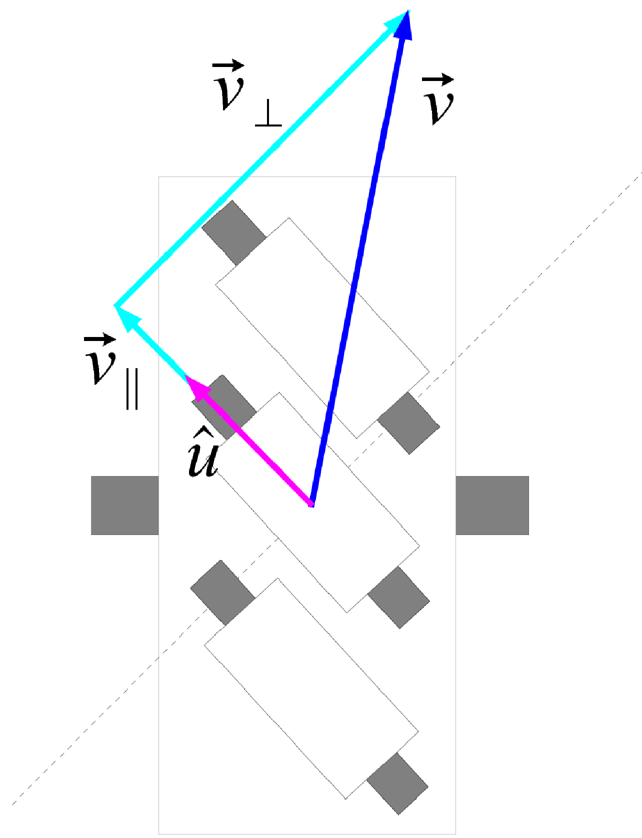
$$\begin{aligned} v_{\|} &= \vec{v} \cdot \hat{u} \\ &= (v_x \hat{\imath} + v_y \hat{\jmath}) \cdot \\ &\quad \left(-\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}\right) \\ &= -\frac{1}{\sqrt{2}} v_x + \frac{1}{\sqrt{2}} v_y \end{aligned}$$



Resolve to Wheel

- Use component parallel to roller axis and resolve it into components parallel to wheel and parallel to roller
- The component parallel to the wheel is v_w
- In this case, the angle is known, so we can calculate v_w directly:

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



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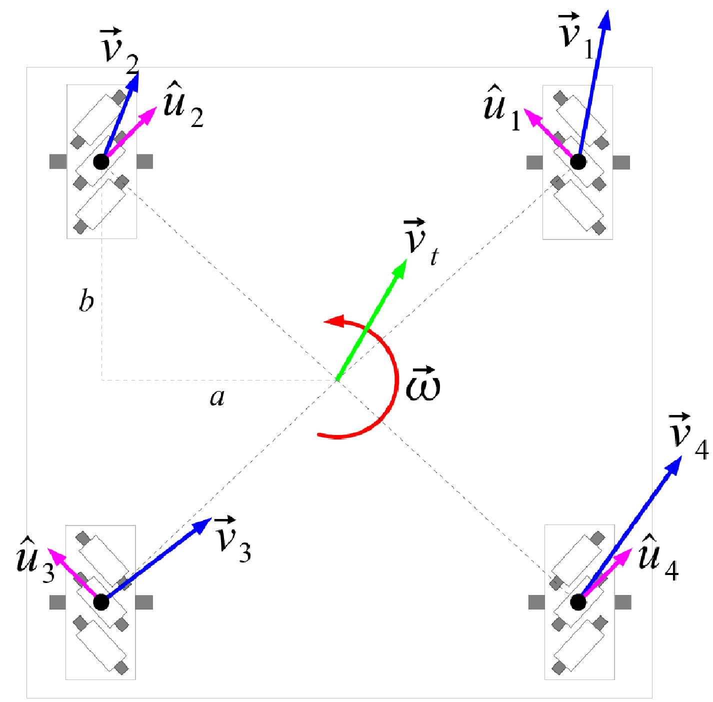
Mecanum Drive Example

- Using wheel 3 as an example:

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

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

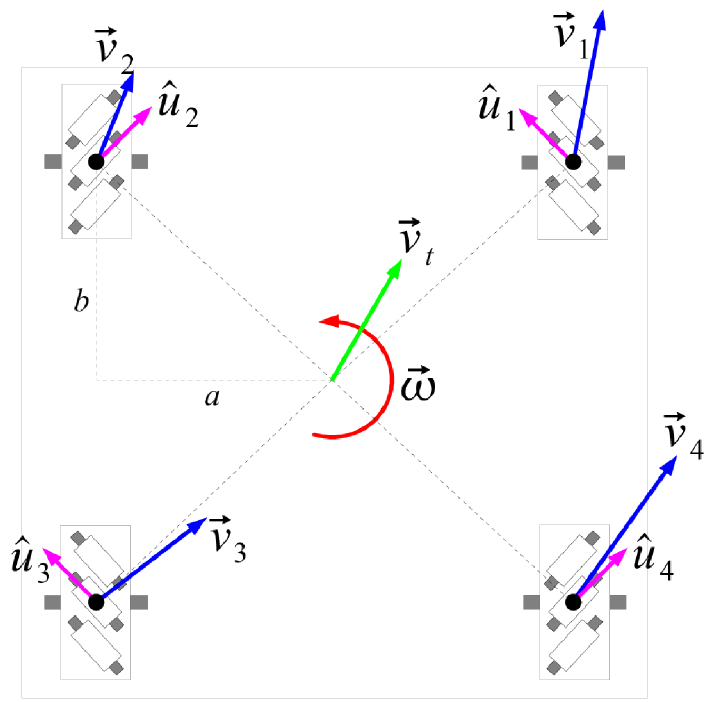


Mecanum Drive Example

- Similarly,

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

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

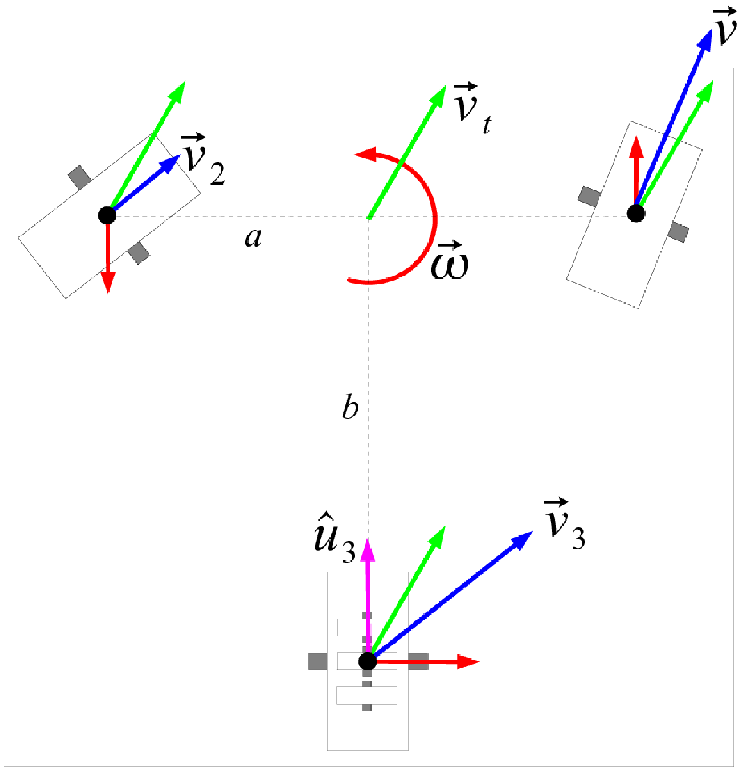


Hybrid Swerve/Holonomic Drive

$$\begin{aligned} v_{1_x} &= v_{t_x} \\ v_{1_y} &= v_{t_y} + \omega a \end{aligned}$$

$$\begin{aligned} v_{2_x} &= v_{t_x} \\ v_{2_y} &= v_{t_y} - \omega a \end{aligned}$$

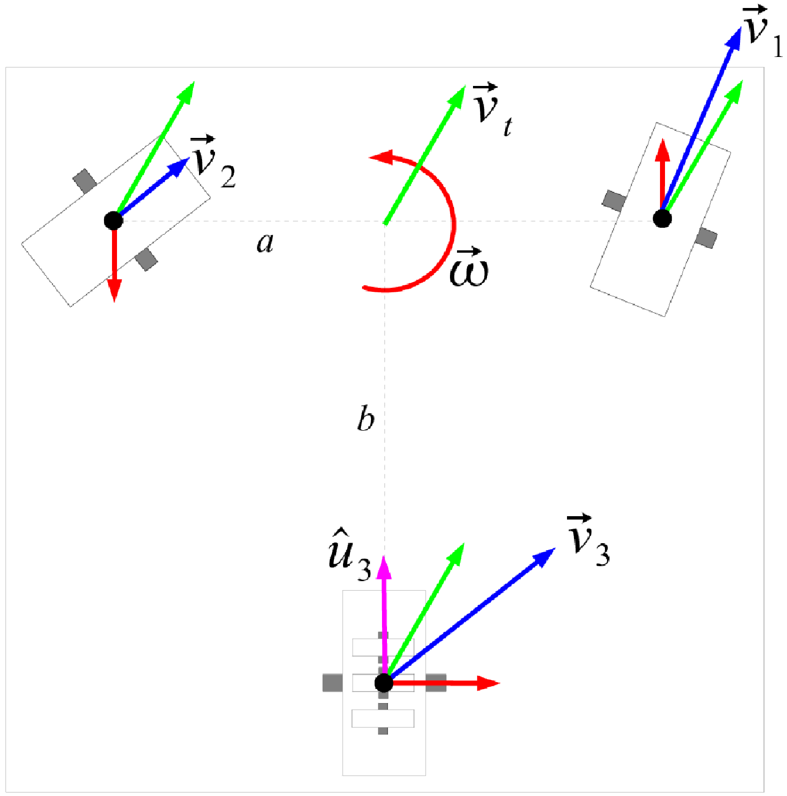
$$\begin{aligned} v_{3_x} &= v_{t_x} + \omega b \\ v_{3_y} &= v_{t_y} \end{aligned}$$



Hybrid Swerve/Holonomic Drive

- Swerve module 1:

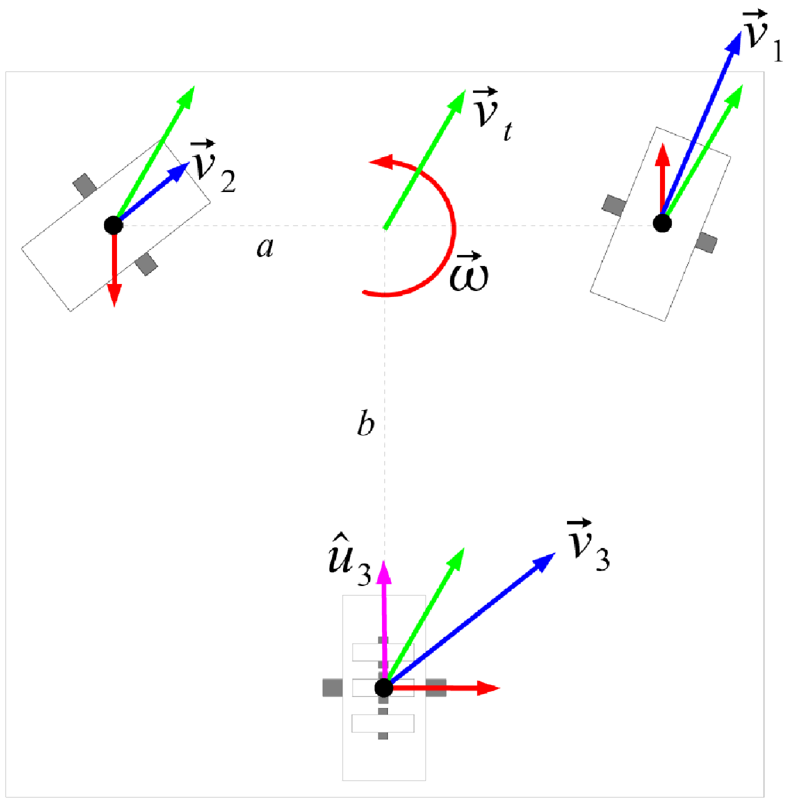
$$
\begin{aligned}
v_{w_1} &= \sqrt{v_{1_x}^2 + v_{1_y}^2} \\
&= \sqrt{v_{t_x}^2 + \left(v_{t_y} + \omega a\right)^2} \\
\theta_1 &= \arctan\left(\frac{v_{1_y}}{v_{1_x}}\right) \\
&= \arctan\left(\frac{v_{t_y} + \omega a}{v_{t_x}}\right)
\end{aligned}
$$



Hybrid Swerve/Holonomic Drive

- Swerve module 2:

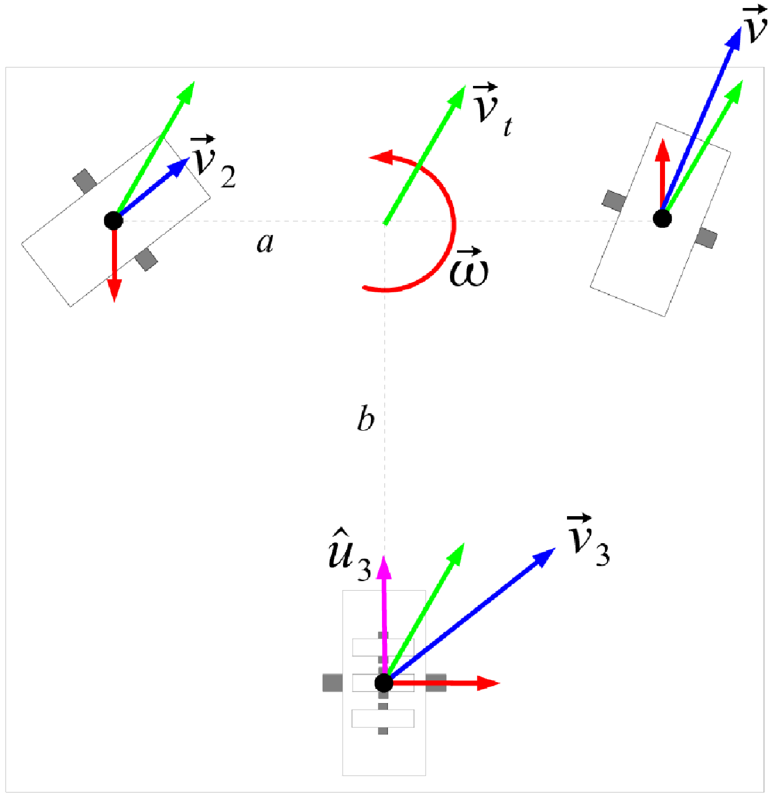
$$v_{w_2} = \sqrt{v_{2_x}^2 + v_{2_y}^2}$$
$$= \sqrt{v_{t_x}^2 + \left(v_{t_y} - \omega a\right)^2}$$
$$\theta_1 = \arctan\left(\frac{v_{2_y}}{v_{2_x}}\right)$$
$$= \arctan\left(\frac{v_{t_y} - \omega a}{v_{t_x}}\right)$$



Hybrid Swerve/Holonomic Drive

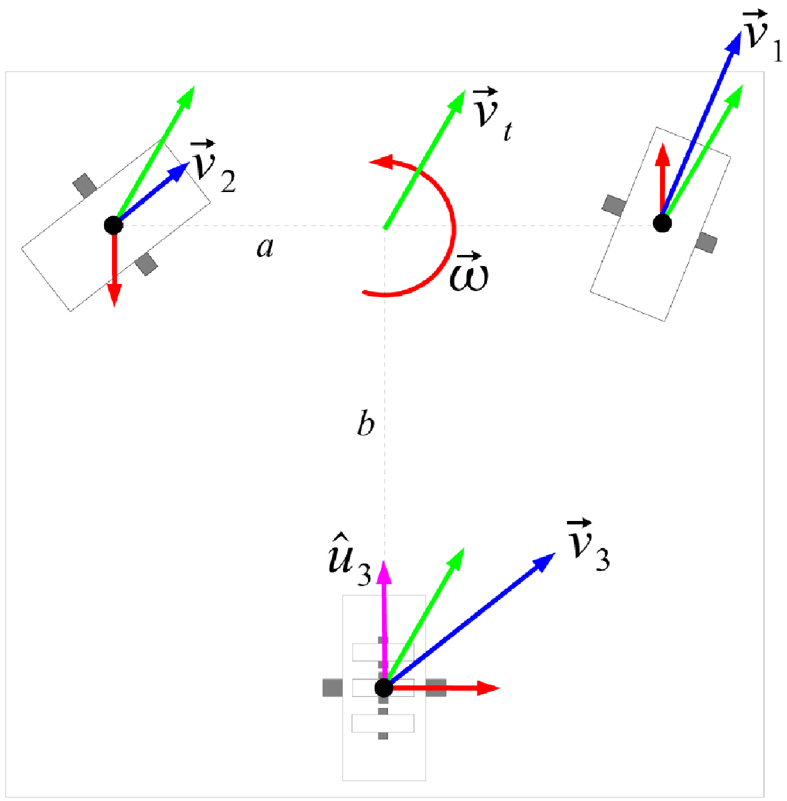
- Holonomic wheel:

$$
\begin{aligned}
v_{w_3} &= \vec{v}_3 \cdot \hat{u}_3 \\
&= \left(v_{3_x}\hat{\imath} + v_{3_y}\hat{\jmath}\right) \cdot \hat{\jmath} \\
&= v_{3_y} \\
&= v_{t_y}
\end{aligned}
$$



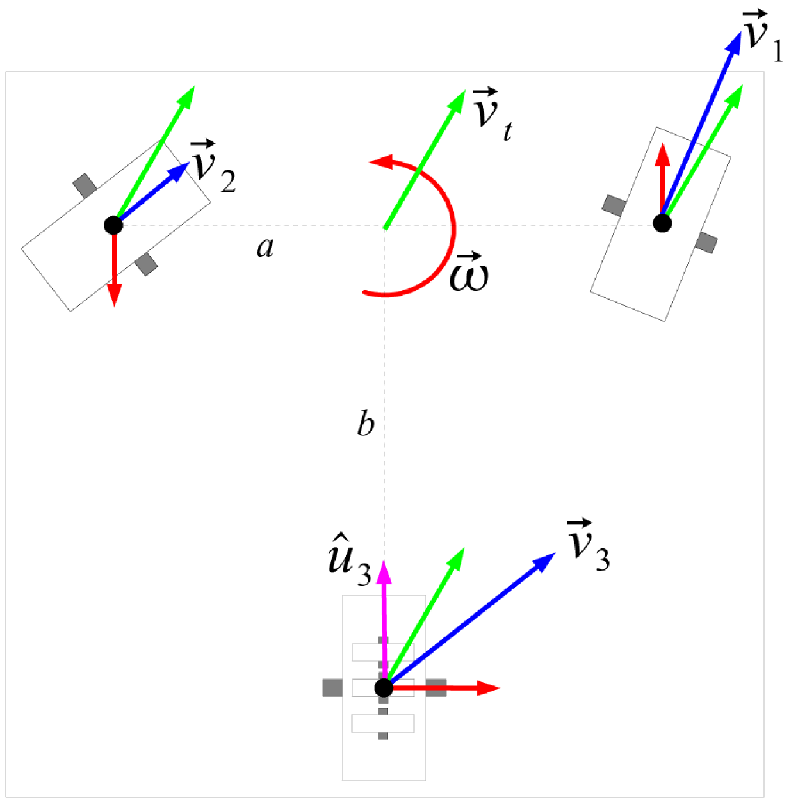
Scaling Issues

- 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



Questions?

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