Shooting While Moving

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1 Notes

- **Outputs**
  - Required angle for robot to face (deg or rad).
  - Required magnitude of ball exit velocity (m/s).
  - Required magnitude of flywheel speed (m/s)

- $\vec{V}$ denotes a Velocity Vector. This is used for math in the **2D horizontal plane** (the top-down view of the field). It includes both direction (yaw/heading) and magnitude.
- S denotes a Total Speed. This represents the **total magnitude** of the ball's exit velocity in 3D space. This is the actual value we need to control the flywheel motor.

2 Summary for Implementation

1. Get distance to Hub.
2. Look up static speed.
3. Decompose static speed into a field-centric velocity vector pointing at the Hub.
4. Subtract the robot's field-centric velocity vector from the static vector.
5. The result is the "aiming vector".
6. Turn the robot to the angle of the aiming vector.
7. Set the flywheel speed based on the magnitude of the aiming vector (adjusted for hood angle).

3 Constraints

1. **Hood Angle (ϕ):** The vertical angle of the shooter is constant.
2. **Control Variables:** We can only control the robot's heading (yaw) and the speed of the ball leaving the shooter.
3. **Motion:** The robot has a velocity vector $\vec{V}_{robot}$ in the xy-plane (field-centric).

4 Vectors

We analyze the problem primarily in the 2D horizontal plane (top-down view of the field). The z-axis (vertical) behavior is constant relative to the shooter's frame of reference because the robot does not move vertically (or, at least, we hope so).

We define four velocity vectors:

1. $\vec{V}_{static}$: The ideal velocity vector of the ball relative to the ground. This is an unchanging vector derived from the lookup table as if the robot were standing still.
2. $\vec{V}_{ground}$: The actual, physical velocity of the ball relative to the ground after it has been shot.
3. $\vec{V}_{robot}$: The current velocity vector of the robot relative to the field.
4. $\vec{V}_{shot}$: The velocity vector the shooter imparts to the ball relative to the robot.

We want the sum of the robot's velocity and the shot's velocity to yield the ideal velocity of the ball relative to the ground:

$$\vec{V}_{robot} + \vec{V}_{shot} = \vec{V}_{static} \tag{1}$$

In practice, we want the actual velocity of the ball relative to the ground to match our ideal static shot:

$$\vec{V}_{ground} = \vec{V}_{static} = \vec{V}_{robot} + \vec{V}_{shot} \tag{2}$$

5 Math

5.1 Step 1: Determine the Ideal Static Vector

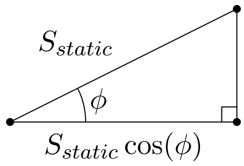
First, we calculate the distance d to the Hub using field coordinates:

$$d = \underbrace{\sqrt{(x_{target} - x_{robot})^2 + (y_{target} - y_{robot})^2}}_{\text{Pythagorean Theorem}}$$

Now, using the lookup table[1], find the required total launch speed S_{static} for this distance.

Since we are working in the horizontal plane, we must extract the horizontal component of this speed. Because the hood angle ϕ is fixed, the relationship is:

$$V_{static\_horizontal} = S_{static}\cos(\phi) \tag{3}$$



The direction of this vector is simply the angle directly towards the target, θ_{target}:

$$\theta_{target} = \text{atan2}^{[2]}(y_{target} - y_{robot}, x_{target} - x_{robot})$$

Now we can write the Static Vector in Cartesian coordinates:

$$\vec{V}_{static} = \begin{bmatrix} V_{static\_horizontal}\cos(\theta_{target}) \\ V_{static\_horizontal}\sin(\theta_{target}) \end{bmatrix}$$

[1] This lookup table might instead be a calculation that interpolates a set of empirical data, so this math will simply assume that the ideal velocity $\vec{V}_{static}$ is given.

[2] The atan2 function is a two-argument arctangent function that computes the angle θ (in radians) between the positive x-axis and a point (x, y) in a 2D plane. Unlike standard $\arctan(y/x)$, it returns a four-quadrant angle between $-\pi$ and π, properly handling all quadrant signs and avoiding division-by-zero errors.

5.2 Step 2: Vector Subtraction

We rearrange Equation (2) to solve for the shot vector:

$$\vec{V}_{shot} = \vec{V}_{static} - \vec{V}_{robot}$$

Broken down into x and y components:

$$V_{shot\_x} = (V_{static\_horizontal} \cos(\theta_{target})) - V_{robot\_x}$$

$$V_{shot\_y} = (V_{static\_horizontal} \sin(\theta_{target})) - V_{robot\_y}$$

5.3 Step 3: Calculating Outputs

Now that we have the required shot vector $\vec{V}_{shot}$ relative to the robot, we convert it back into polar coordinates to get our control inputs.

1. Robot Heading (Lead Angle): The robot must face the direction of the shot vector.

$$\theta_{lead} = \text{atan2}(V_{shot\_y}, V_{shot\_x})$$

2. Shot Speed: First, calculate the horizontal magnitude of the shot:

$$V_{shot\_horizontal} = \sqrt{V_{shot\_x}^2 + V_{shot\_y}^2}$$

Finally, convert this horizontal velocity back to the total flywheel exit velocity by dividing by the cosine of the fixed hood angle:

$$S_{new} = \frac{V_{shot\_horizontal}}{\cos(\phi)}$$

See next page for all important formulae.

1. Ideal Horizontal Velocity

Isolates the horizontal component of the ideal lookup speed (S_{static}) using the fixed hood angle (ϕ).

$$\boxed{V_{\text{static\_horizontal}} = S_{\text{static}} \cos(\phi)}$$

2. Target Angle

Determines the ideal angle to the target if the robot were stationary.

$$\boxed{\theta_{\text{target}} = \text{atan2}(y_{\text{target}} - y_{\text{robot}}, x_{\text{target}} - x_{\text{robot}})}$$

3. Shot Vector Components (Vector Subtraction)

Calculates the x and y velocity components the shooter must provide by subtracting the robot's current velocity from the ideal static velocity.

$$\boxed{\begin{aligned} V_{\text{shot\_x}} &= (V_{\text{static\_horizontal}} \cos(\theta_{\text{target}})) - V_{\text{robot\_x}} \\ V_{\text{shot\_y}} &= (V_{\text{static\_horizontal}} \sin(\theta_{\text{target}})) - V_{\text{robot\_y}} \end{aligned}}$$

4. New Robot Heading (Lead Angle)

Calculates the actual direction the robot must face to land the shot while moving.

$$\boxed{\theta_{\text{lead}} = \text{atan2}(V_{\text{shot\_y}}, V_{\text{shot\_x}})}$$

5. New Flywheel Speed

Combines the horizontal shot components back into a total 3D magnitude to set the final flywheel speed.

$$\boxed{S_{\text{new}} = \frac{\sqrt{V_{\text{shot\_x}}^2 + V_{\text{shot\_y}}^2}}{\cos(\phi)}}$$