

In polar coordinates, the position vector is:

$$\vec{r} = s\hat{s}$$

To find the velocity, take a time derivative:

$$\begin{aligned}\vec{v} &= \frac{d}{dt}(s\hat{s}) \\ &= \dot{s}\hat{s} + s\dot{\hat{s}}\end{aligned}$$

But what is $\dot{\hat{s}}$?

Start by writing \hat{s} and $\hat{\phi}$ using Cartesian basis vectors:

$$\begin{aligned}\hat{s} &= \cos\phi\hat{x} + \sin\phi\hat{y} \\ \hat{\phi} &= -\sin\phi\hat{x} + \cos\phi\hat{y}\end{aligned}$$

Now, take the time derivative:

$$\begin{aligned}\frac{d}{dt}\hat{s} &= -\sin\phi\dot{\phi}\hat{x} + \cos\phi\dot{\hat{x}} + \cos\phi\dot{\phi}\hat{y} + \sin\phi\dot{\hat{y}} \\ &= \dot{\phi}\hat{\phi} \\ \frac{d}{dt}\hat{\phi} &= -\cos\phi\dot{\phi}\hat{x} - \sin\phi\dot{\hat{x}} - \sin\phi\dot{\phi}\hat{y} + \cos\phi\dot{\hat{y}} \\ &= -\dot{\phi}\hat{s}\end{aligned}$$

So, plugging back into the velocity:

$$\begin{aligned}\vec{v} &= \dot{s}\hat{s} + s\dot{\hat{s}} \\ \vec{v} &= \dot{s}\hat{s} + s\dot{\phi}\hat{\phi}\end{aligned}$$

Now, I can find the acceleration the same way:

$$\begin{aligned}\vec{a} &= \frac{d}{dt}(\dot{s}\hat{s} + s\dot{\phi}\hat{\phi}) \\ &= \ddot{s}\hat{s} + \dot{s}\dot{\hat{s}} + \dot{s}\dot{\phi}\hat{\phi} + s\ddot{\phi}\hat{\phi} + s\dot{\phi}\dot{\hat{\phi}} \\ &= \ddot{s}\hat{s} + \dot{s}(\dot{\phi}\hat{\phi}) + \dot{s}\dot{\phi}\hat{\phi} + s\ddot{\phi}\hat{\phi} + s\dot{\phi}(-\dot{\phi}\hat{s}) \\ &= (\ddot{s} - s\dot{\phi}^2)\hat{s} + (s\ddot{\phi} + 2s\dot{\phi})\hat{\phi}\end{aligned}$$

How can I interpret these acceleration terms?

$$\vec{a} = (\text{acceleration of radial coordinate} \quad \overbrace{\ddot{s}}^{\text{centripetal acceleration}} \quad)\hat{s} + (\text{tangential acceleration} \quad \overbrace{s\ddot{\phi}}^{\text{Coriolis acceleration}} \quad + \quad \overbrace{2\dot{s}\dot{\phi}}^{\text{Coriolis acceleration}})$$

- The first term tells me the **second derivative of the radial coordinate**.
- The second term is pointing toward the center (it has a minus sign) and is proportional to the square of the angular velocity. This is like $a_c = r\omega^2 = \frac{v^2}{r}$. This is the **centripetal acceleration**. When something moves in a circle, in order to keep turning (and move in a straight line with constant speed), there needs to be an acceleration towards the center.
- The third term is the **tangential acceleration**, like $a_T = r\alpha$.
- The fourth term is a **Coriolis acceleration**. This is an acceleration that arises from the radial coordinate changing while the angular coordinates changes (e.g., the object moves away from the center while also moving around the center).