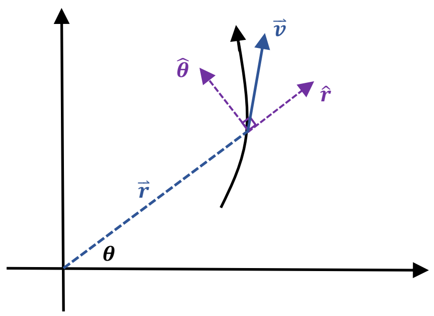
Kinematics Particles

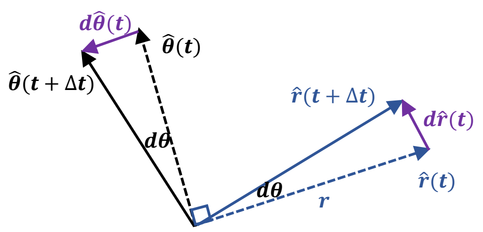
$2D$ Polar Coordinate System



$\hat{r}$ is unit vector parallel to $\vec{r}$ (radial)

$\hat{\theta}$ is unit vector vertical to $\vec{\theta}$ (tangential)

Velocity in $2D$ polar coordinates



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

$$\vec{v} = \frac{d\vec{r}}{dt} = \frac{d(r\cdot\hat{r})}{dt} = \frac{dr}{dt}\hat{r} + r\frac{d\hat{r}}{dt}$$

$$d\hat{r} \cong |\hat{r}|d\theta\hat{\theta} = d\theta\hat{\theta}$$

$$\frac{d\hat{r}}{dt} = \frac{d\theta}{dt}\hat{\theta}$$

$$\vec{v} = \underbrace{\dot{r}}_{v_r}\hat{r} + \underbrace{r\dot{\theta}}_{v_\theta}\hat{\theta} = v_r\hat{r} + v_\theta\hat{\theta}$$

$$\Rightarrow \boxed{\vec{v} = v_r\hat{r} + v_\theta\hat{\theta}}$$

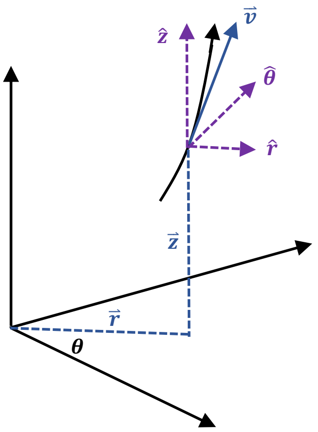
Acceleration in $2D$ polar coordinates

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d\left(v_r\hat{r} + v_\theta\hat{\theta}\right)}{dt} = \frac{d^2r}{dt^2}\hat{r} + \frac{dr}{dt}\frac{d\hat{r}}{dt} + \frac{dr}{dt}\frac{d\theta}{dt}\hat{\theta} + r\frac{d\theta}{dt}\frac{d\hat{\theta}}{dt} + r\frac{d^2\theta}{dt^2}$$

$$d\hat{\theta} \cong \left|\hat{\theta}\right|d\theta(-\hat{r}) = -d\theta\hat{r}$$

$$\Rightarrow \boxed{\vec{a} = \left(\ddot{r} - r\dot{\theta}^2\right)\hat{r} + \left(r\ddot{\theta} + 2\dot{r}\dot{\theta}\right)\hat{\theta}}$$

$3D$ Cylindrical Coordinate System



$$\vec{r} = r\hat{r} + z\hat{z}$$
$$\vec{v} = v_r\hat{r} + v_\theta\hat{\theta} + \dot{z}\hat{z}$$
$$\vec{a} = \left(\ddot{r} - r\dot{\theta}^2\right)\hat{r} + \left(r\ddot{\theta} + 2\dot{r}\dot{\theta}\right)\hat{\theta} + \ddot{z}\hat{z}$$