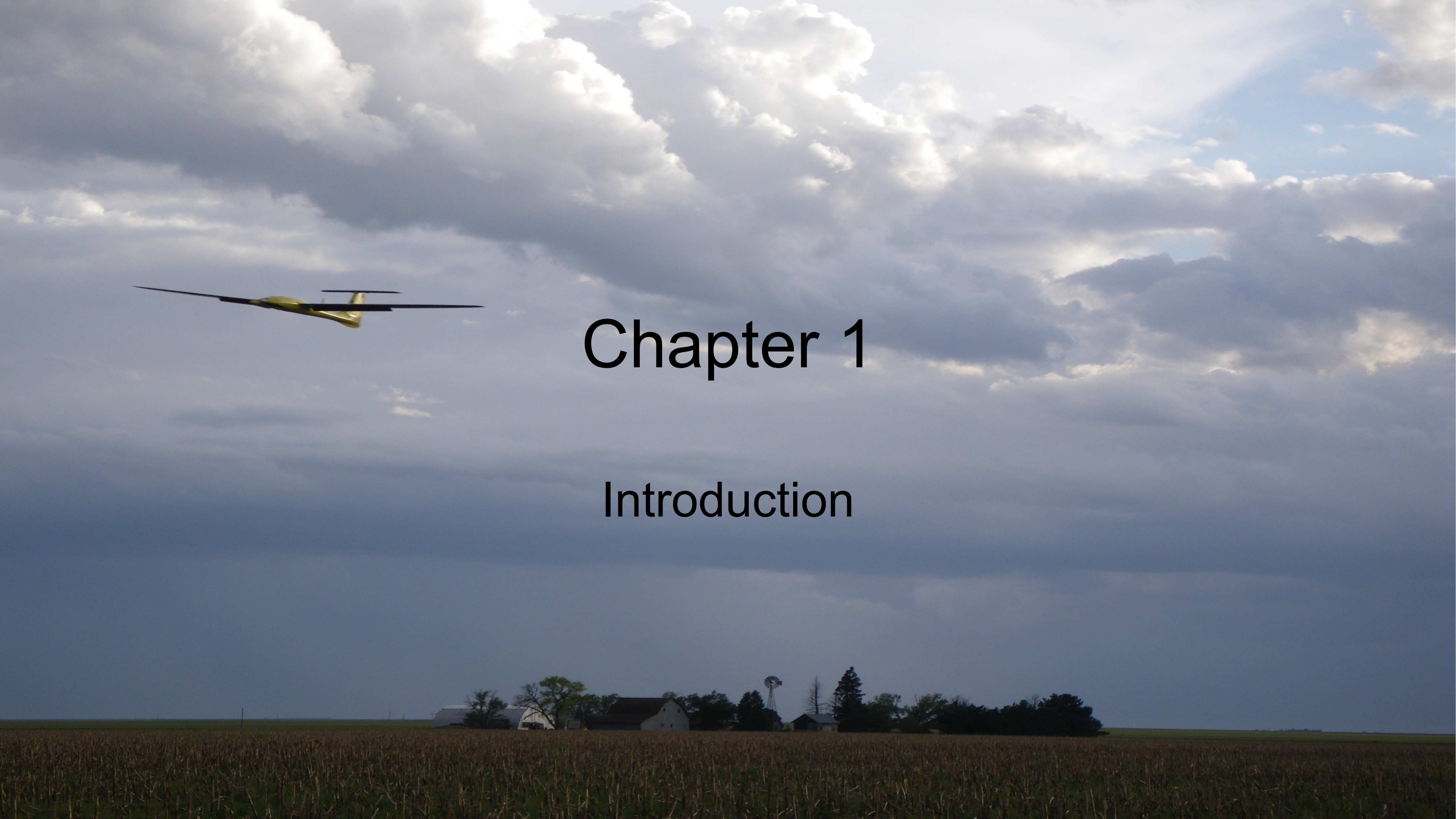


Chapter 1

Introduction

Potential Applications for Small UAVs

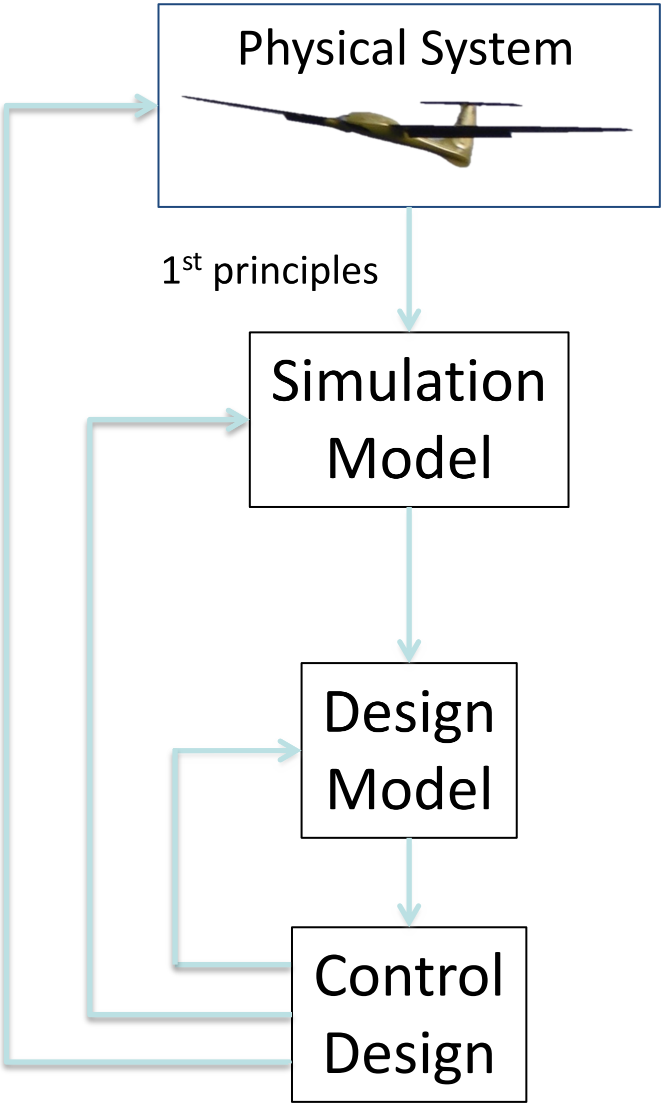
Civil and Commercial:
- Monitoring environment – meteorology, pollution, mapping, mineral exploration
- Monitoring disaster areas – forest fires, avalanches, nuclear contamination
- Communications relays – news broadcasts, disaster relief, sports events
- Law enforcement – road traffic, border patrol, drug control
- Precision agriculture – crop monitoring

Military:
- Special Operations: Situational awareness
- Intelligence, surveillance, and reconnaissance
- Communication node
- Battle damage assessment

Homeland Security:
- Border patrol
- Surveillance
- Rural/urban search and rescue

New related area:
- Air mobility of humans, goods, services

Control Design Process



The real thing

Detailed model
ODE's, nonlinear, high order
Includes everything that is feasible to model
Hi-fi representation of real physical system behavior
Too complex for control design

ODE's, linear, low order
May only consider a portion of dynamic behavior
Simpler to understand
Captures dominant behavior

Simulation Model

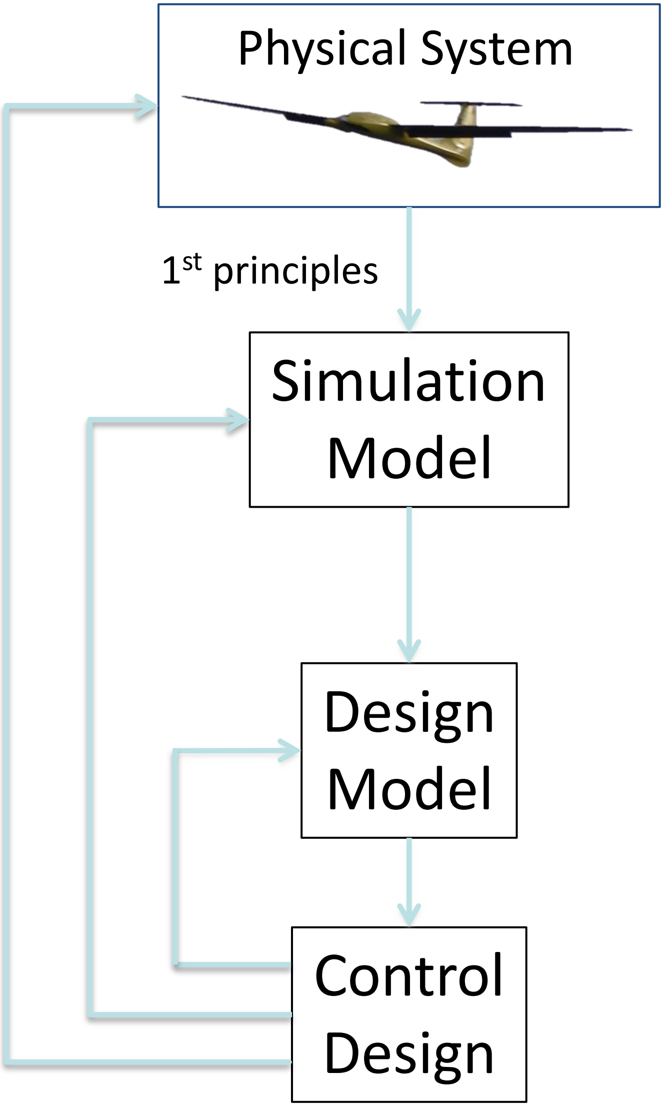
$$
\begin{aligned}
\dot{p}_n &= (\cos\theta\cos\psi)u + (\sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi)v + (\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi)w \\
\dot{p}_e &= (\cos\theta\sin\psi)u + (\sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi)v + (\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi)w \\
\dot{h} &= u\sin\theta - v\sin\phi\cos\theta - w\cos\phi\cos\theta \\
\dot{u} &= rv - qw - g\sin\theta + \frac{\rho V_a^2 S}{2\mathrm{m}}\left[C_X(\alpha) + C_{X_q}(\alpha)\frac{cq}{2V_a} + C_{X_{\delta_e}}(\alpha)\delta_e\right] + \frac{\rho S_{\text{prop}} C_{\text{prop}}}{2\mathrm{m}}\left[(k_{\text{motor}}\delta_t)^2 - V_a^2\right] \\
\dot{v} &= pw - ru + g\cos\theta\sin\phi + \frac{\rho V_a^2 S}{2\mathrm{m}}\left[C_{Y_0} + C_{Y_\beta}\beta + C_{Y_p}\frac{bp}{2V_a} + C_{Y_r}\frac{br}{2V_a} + C_{Y_{\delta_a}}\delta_a + C_{Y_{\delta_r}}\delta_r\right] \\
\dot{w} &= qu - pv + g\cos\theta\cos\phi + \frac{\rho V_a^2 S}{2\mathrm{m}}\left[C_Z(\alpha) + C_{Z_q}(\alpha)\frac{cq}{2V_a} + C_{Z_{\delta_e}}(\alpha)\delta_e\right] \\
\dot{\phi} &= p + q\sin\phi\tan\theta + r\cos\phi\tan\theta \\
\dot{\theta} &= q\cos\phi - r\sin\phi \\
\dot{\psi} &= q\sin\phi\sec\theta + r\cos\phi\sec\theta \\
\dot{p} &= \Gamma_1 pq - \Gamma_2 qr + \frac{1}{2}\rho V_a^2 Sb\left[C_{p_0} + C_{p_\beta}\beta + C_{p_p}\frac{bp}{2V_a} + C_{p_r}\frac{br}{2V_a} + C_{p_{\delta_a}}\delta_a + C_{p_{\delta_r}}\delta_r\right] \\
\dot{q} &= \Gamma_5 pr - \Gamma_6(p^2 - r^2) + \frac{\rho V_a^2 Sc}{2J_y}\left[C_{m_0} + C_{m_\alpha}\alpha + C_{m_q}\frac{cq}{2V_a} + C_{m_{\delta_e}}\delta_e\right] \\
\dot{r} &= \Gamma_7 pq - \Gamma_1 qr + \frac{1}{2}\rho V_a^2 Sb\left[C_{r_0} + C_{r_\beta}\beta + C_{r_p}\frac{bp}{2V_a} + C_{r_r}\frac{br}{2V_a} + C_{r_{\delta_a}}\delta_a + C_{r_{\delta_r}}\delta_r\right]
\end{aligned}
$$

Simulation Model

$$
\begin{aligned}
C_{p_0} &= \Gamma_3 C_{l_0} + \Gamma_4 C_{n_0} \\
C_{p_\beta} &= \Gamma_3 C_{l_\beta} + \Gamma_4 C_{n_\beta} \\
C_{p_p} &= \Gamma_3 C_{l_p} + \Gamma_4 C_{n_p} \\
C_{p_r} &= \Gamma_3 C_{l_r} + \Gamma_4 C_{n_r} \\
C_{p_{\delta_a}} &= \Gamma_3 C_{l_{\delta_a}} + \Gamma_4 C_{n_{\delta_a}} \\
C_{p_{\delta_r}} &= \Gamma_3 C_{l_{\delta_r}} + \Gamma_4 C_{n_{\delta_r}} \\
C_{r_0} &= \Gamma_4 C_{l_0} + \Gamma_8 C_{n_0} \\
C_{r_\beta} &= \Gamma_4 C_{l_\beta} + \Gamma_8 C_{n_\beta} \\
C_{r_p} &= \Gamma_4 C_{l_p} + \Gamma_8 C_{n_p} \\
C_{r_r} &= \Gamma_4 C_{l_r} + \Gamma_8 C_{n_r} \\
C_{r_{\delta_a}} &= \Gamma_4 C_{l_{\delta_a}} + \Gamma_8 C_{n_{\delta_a}} \\
C_{r_{\delta_r}} &= \Gamma_4 C_{l_{\delta_r}} + \Gamma_8 C_{n_{\delta_r}}
\end{aligned}
$$

$$
\begin{aligned}
C_X(\alpha) &\stackrel{\triangle}{=} -C_D(\alpha)\cos\alpha + C_L(\alpha)\sin\alpha \\
C_{X_q}(\alpha) &\stackrel{\triangle}{=} -C_{D_q}\cos\alpha + C_{L_q}\sin\alpha \\
C_{X_{\delta_e}}(\alpha) &\stackrel{\triangle}{=} -C_{D_{\delta_e}}\cos\alpha + C_{L_{\delta_e}}\sin\alpha \\
C_Z(\alpha) &\stackrel{\triangle}{=} -C_D(\alpha)\sin\alpha - C_L(\alpha)\cos\alpha \\
C_{Z_q}(\alpha) &\stackrel{\triangle}{=} -C_{D_q}\sin\alpha - C_{L_q}\cos\alpha \\
C_{Z_{\delta_e}}(\alpha) &\stackrel{\triangle}{=} -C_{D_{\delta_e}}\sin\alpha - C_{L_{\delta_e}}\cos\alpha
\end{aligned}
$$

Control Design Process



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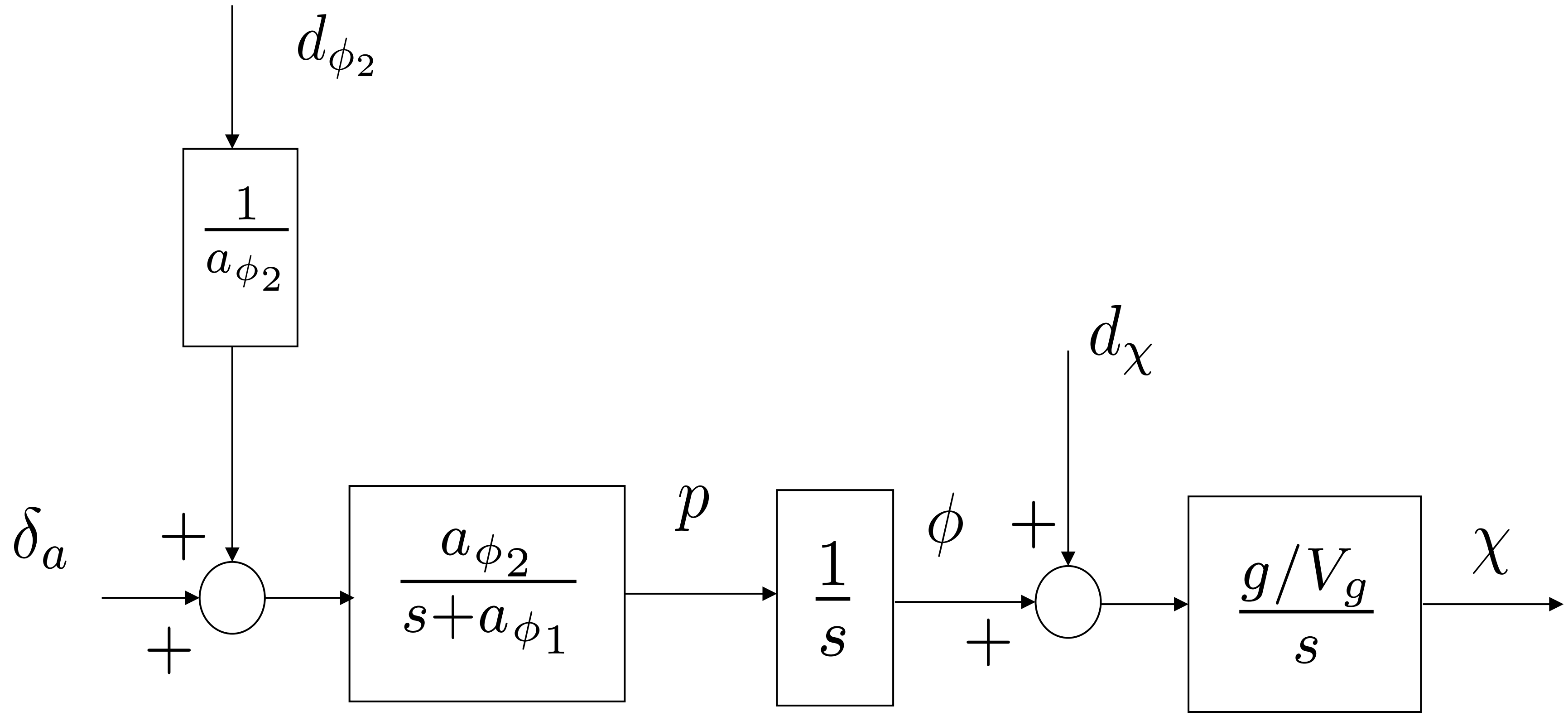
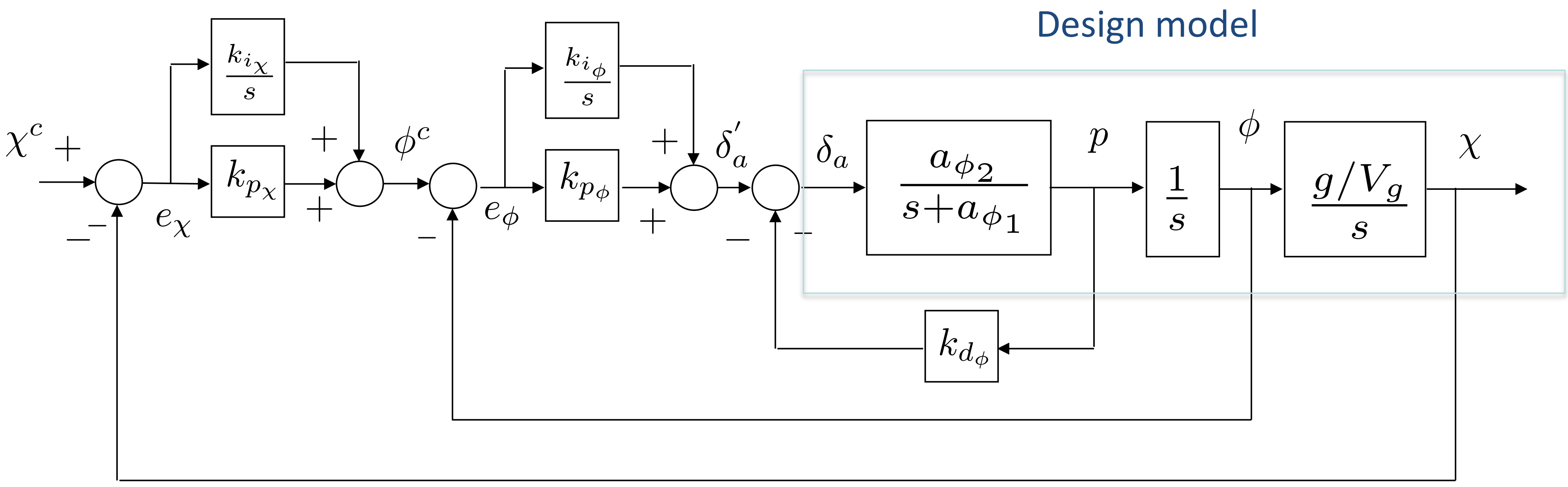
Design Model

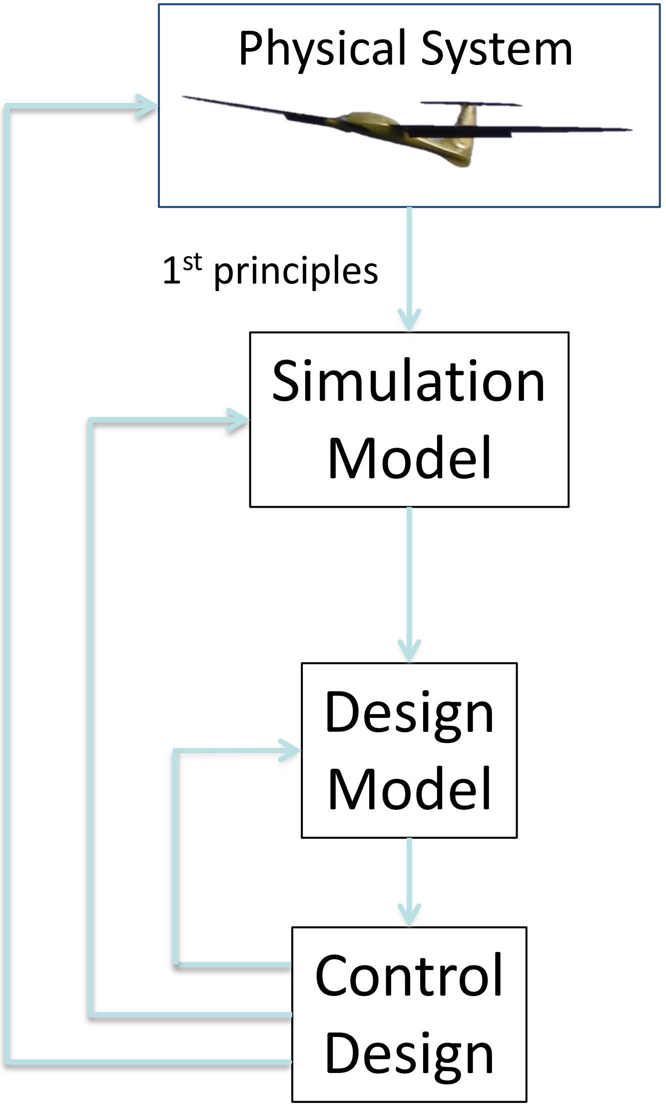
Course from aileron transfer function:



Control Design



Control Design Process



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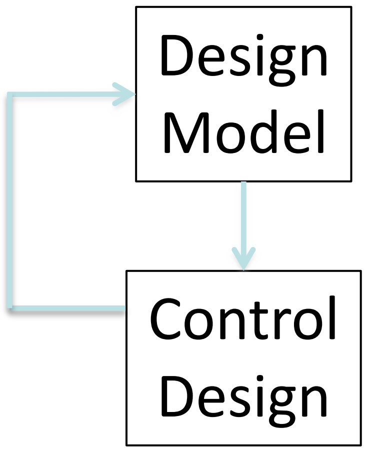
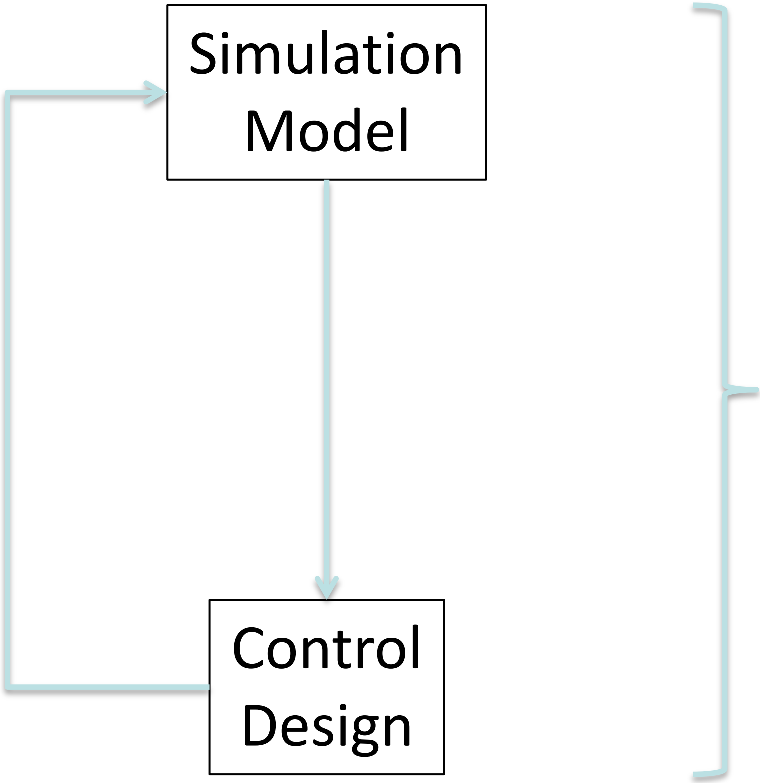


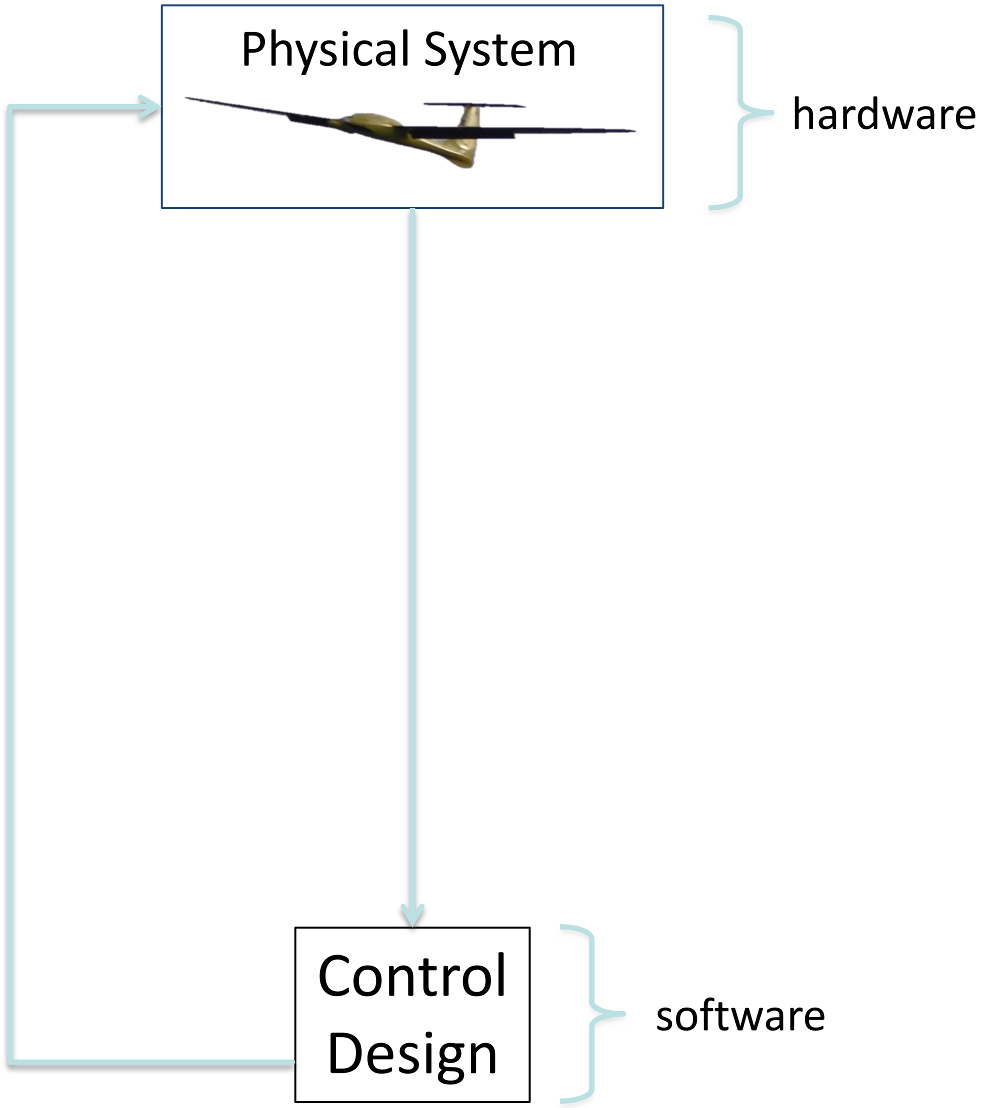
Step 1:
Linear, low-order model
Control design and system model implemented in software

Control Design Process



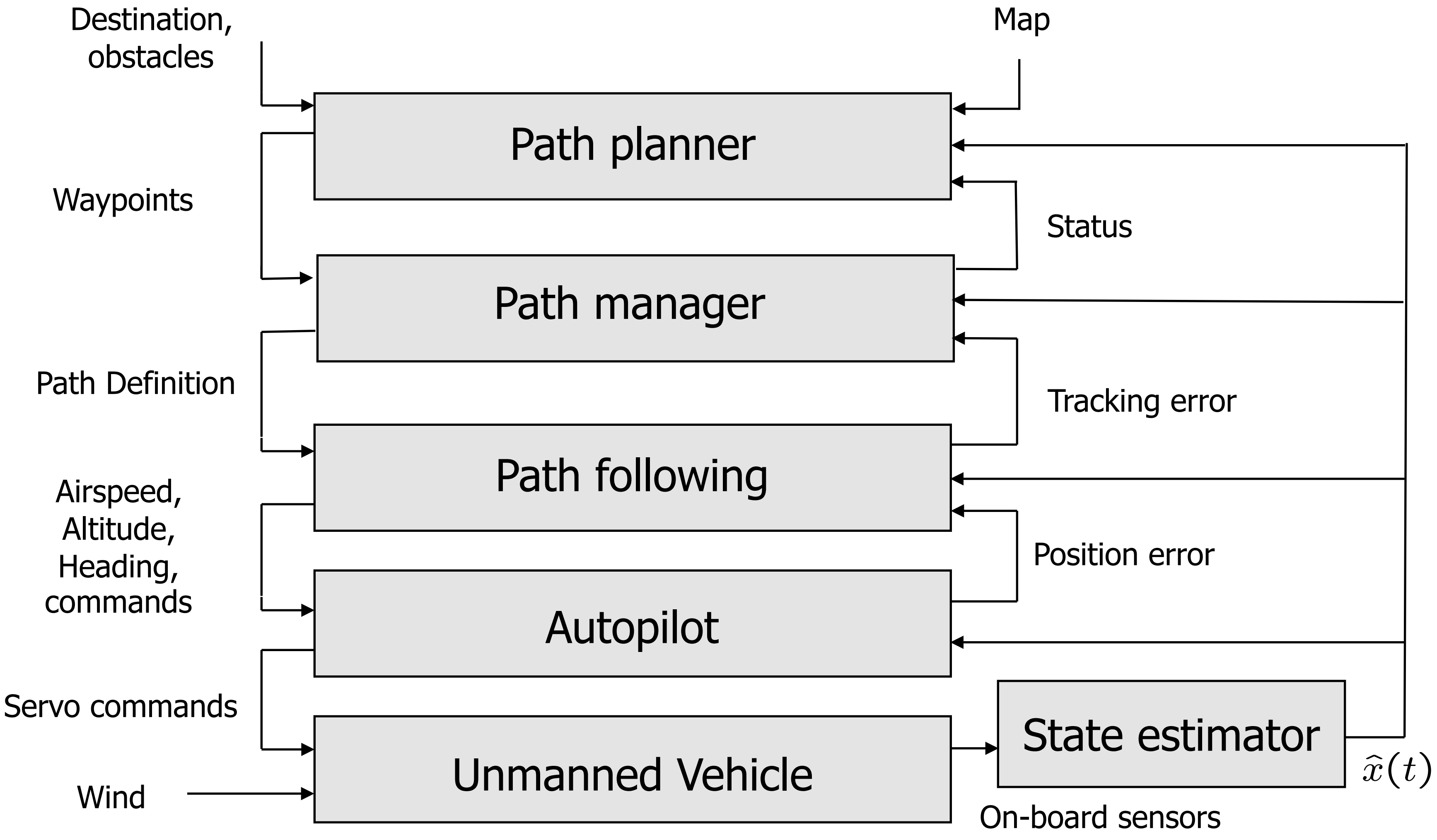
Step 2:
Detailed system model
Control design and system model implemented in software

Control Design Process

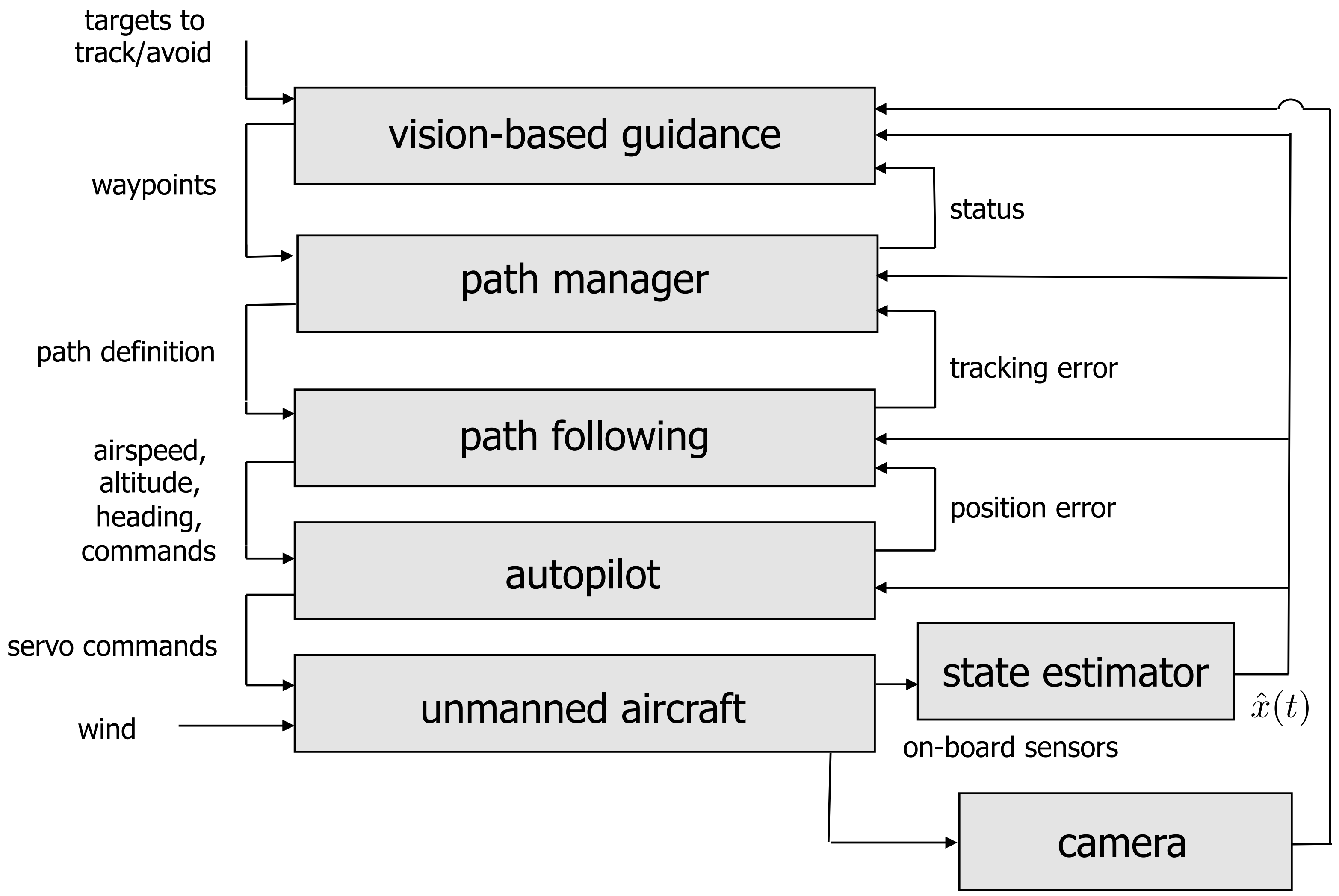


Step 3:
Real system hardware
Control design implemented in software

Architecture



Architecture w/ Camera



Course Project Ideas

- Implement autopilot components on hardware using ROSflight, PixHawk, or another autopilot
- Develop learning modules for the African Drone and Data Academy in Malawi (e.g., Jupyter notebooks)
- Integrate our course simulator into the AirSim simulator (https://github.com/microsoft/AirSim)
- Extend existing autopilot components to do something in a different way (e.g., perform path following using MPC)
- Extend existing autopilot to do something new (e.g., use machine vision to land on a target)
- Something of your own creation that builds on the concepts of this course