Object Tracking with a Quadroter UAV

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Source Work

Computer Vision Based General Object Following for GPS-denied Multirotor Unmanned Vehicles [1]

- Goal is to reliably track and follow an object using an inexpensive GPS-denied quadrotor platform
- Uses parallel PD controllers on Parrot AR Drone 2.0 to track and follow a target

Body Reference Frame

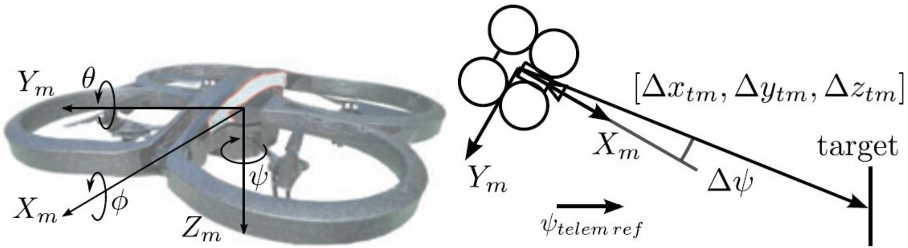


Figure 1: Orthonormal right-handed reference frame [1]

- $[X_m, Y_m, Z_m]$: Orthonormal body reference frame
- ϕ: Roll
- θ: Pitch
- ψ: Yaw

- $[\Delta x_{tm}, \Delta y_{tm}, \Delta z_{tm}]$: Target relative position
- $\psi_{telem\ ref}$: Preferred relative tracking direction
- $\Delta\psi$: Target relative yaw angle

Image Features

$$f_u = \frac{x_{bb} + (w_{bb}/2)}{w_{im}} \quad (1)$$

$$f_v = \frac{y_{bb} + (h_{bb}/2)}{h_{im}} \quad (2)$$

$$f_\Delta = \sqrt{\frac{w_{im} \cdot h_{im}}{w_{bb} \cdot h_{bb}}} \propto_\sim x_{tm} \quad (3)$$

- f_u: Horizontal position of target centroid
- f_v: Vertical position of target centroid

- f_Δ: Change of target size in the image frame
- x_{tm}: Frontal distance from the UAV to the target
- x_{bb}: Upper-left corner horizontal location of target
- y_{bb}: Upper-left corner vertical location of target
- w_{bb}: Width of target
- h_{bb}: Height of target
- w_{im}: Width of image
- h_{im}: Height of image

Decoupling Altitude and Lateral Movement Errors

$$\Delta f_{u\psi} = \Delta f_u \tag{4}$$

$$\Delta f_{uy} = \Delta f_u - \frac{\psi_{telem\ ref} - \psi_{telem}}{FOV_u} \tag{5}$$

$$\Delta f_{vz} = \Delta f_v - \frac{\theta_{centroid\ ref} - \theta_{telem}}{FOV_u} \tag{6}$$

$$\Delta f_{\Delta x} = \Delta f_{\Delta} \tag{7}$$

- $\Delta f_u, \Delta f_{u\psi}$: Horizontal position change of target centroid
- $\Delta f_{uy}, \Delta f_{vz}$: Change in centroid position decoupled from yaw and roll movement of vehicle

- Δf_v: Change in vertical position of target centroid
- $\psi_{telem\ ref}, \psi_{telem}$: Yaw reference and vehicle yaw
- $\theta_{telem\ ref}, \theta_{telem}$: Pitch reference and vehicle pitch
- FOV_u, FOV_v: Horizontal and vertical field of view of the camera
- $\Delta f_{\Delta x}, \Delta f_{\Delta}$: Change in target distance proportional to change in target size

Other Terms

- A_{exp}: Expected size of the target in the image frame
- d_{exp}: Expected distance from the UAV to the target
- α_u, α_v: Horizontal and vertical resolution of the image

System Block Diagram

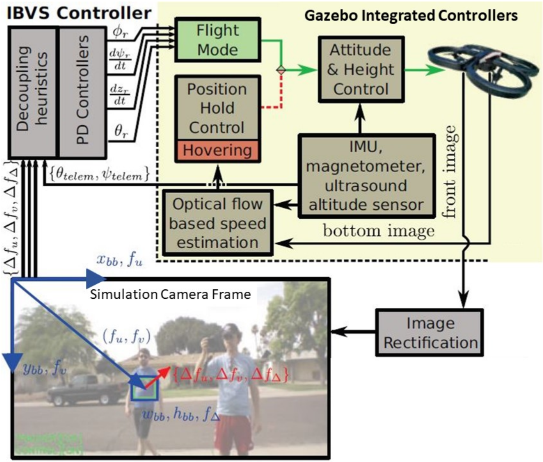


Figure 2: High-level controller block diagram [1]

IBVS Block Diagram

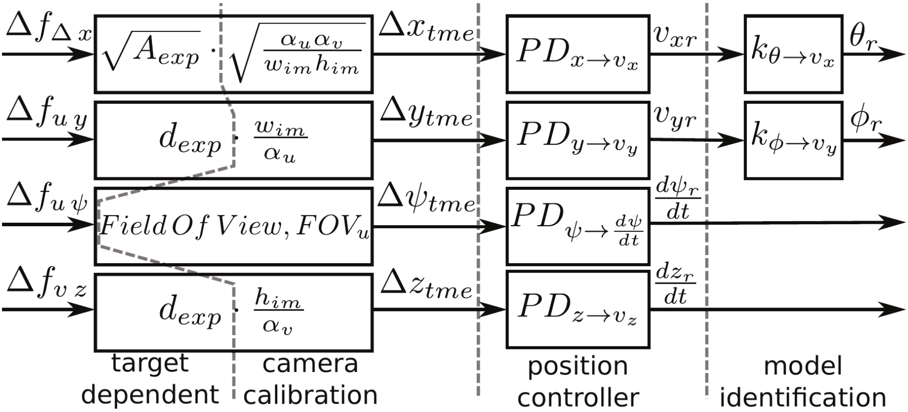


Figure 3: IBVS PD controller block diagram [1]

IBVS Depth Controller

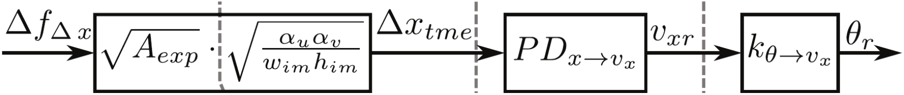


Figure 4: Depth controller block diagram [1]

Calculate the depth error based on the expected target size and image size:

$$\Delta x_{tme} = \Delta f_{\Delta x} \cdot \sqrt{A_{exp}} \cdot \sqrt{\alpha_u \alpha_x / w_{im} h_{im}} \tag{8}$$

Use a PD controller to generate a longitudinal velocity reference:

$$v_{xr} = 0.0254 \cdot \Delta x_{tme} + 0.0124 \cdot dx_{tme}/dt \tag{9}$$

Use static relation $k_{tilt} \approx 5 - 7 \dfrac{m/s}{24^\circ}$ to generate a pitch angle reference[2]:

$$\theta_r = v_{xr}/k_{tilt} \tag{10}$$

IBVS Lateral Controller

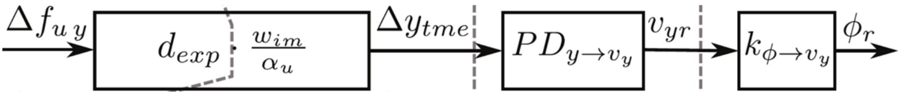


Figure 5: Lateral controller block diagram [1]

Calculate the lateral error based on the expected target depth and change of the target centroid in the horizontal image frame:

$$\Delta y_{tme} = \Delta f_{uy} \cdot d_{exp} \cdot w_{im}/\alpha_u \tag{11}$$

Use a PD controller to generate a lateral velocity reference:

$$v_{yr} = -0.298 \cdot \Delta y_{tme} - 0.145 \cdot dy_{tme}/dt \tag{12}$$

Use static relation $k_{tilt} \approx 5 - 7\frac{m/s}{24^\circ}$ to generate a roll angle reference[2]:

$$\phi_r = v_{yr}/k_{tilt} \tag{13}$$

IBVS Yaw Controller

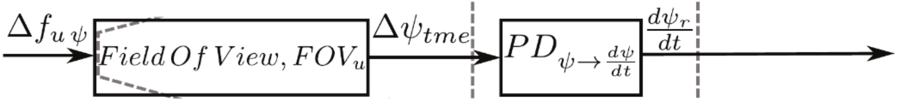


Figure 6: Yaw controller block diagram [1]

Calculate the yaw error based on the change of the target centroid in the horizontal field of view:

$$\Delta\psi_{tme} = \Delta f_{u\psi} \cdot FOV_u \tag{14}$$

Use a PD controller to generate a yaw rate reference:

$$\frac{d\psi_r}{dt} = -0.990 \cdot \Delta\psi_{tme} - 0.119 \cdot \frac{d\psi_{tme}}{dt} \tag{15}$$

IBVS Height Controller

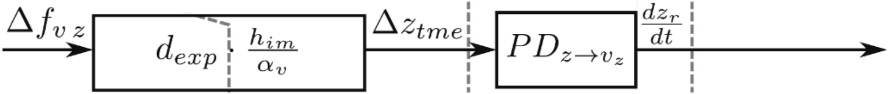


Figure 7: Height controller block diagram [1]

Calculate the height error based on the change of the target height in the image frame:

$$\Delta z_{tme} = \Delta f_{vz} \cdot d_{exp} \cdot \frac{h_{im}}{\alpha_v} \tag{16}$$

Use a PD controller to generate a height velocity reference:

$$\frac{dz_r}{dt} = 1.430 \cdot \Delta z_{tme} + 0.371 \cdot \frac{dz_{tme}}{dt} \tag{17}$$

Complications

- The original gains did not work unless they were all positive
- Unable to simultaneously control the attitude and velocity using the MAVSDK package
- There is an unknown amount of video latency from the camera view in the simulation to the controller, which affects the accuracy of the controller
- Image resolution is not well defined; do not know the focal length, nor scaling factor of the camera used

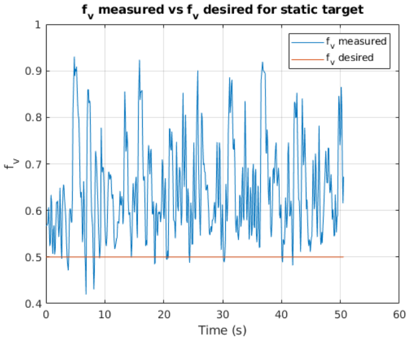
Changes from Source Paper

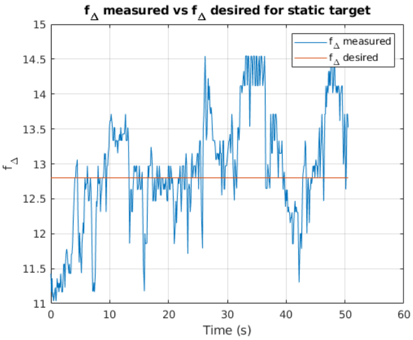
- Made all gains positive
- Directly fed velocity setpoints to flight controller instead of setting roll and pitch angles
- Ran simulations in place of physical experiments
- Focus is on controls rather than computer vision

Static Target Video

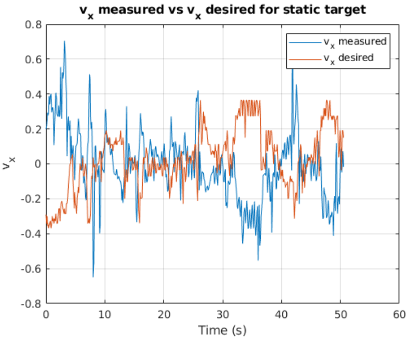
https://youtu.be/lV7pVpNrT4s

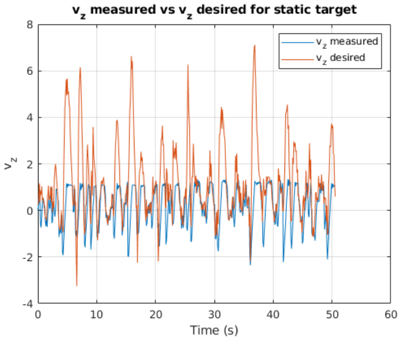
Static Target: Camera Results





Static Target: Flight Results

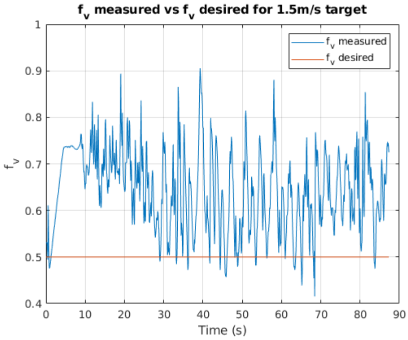


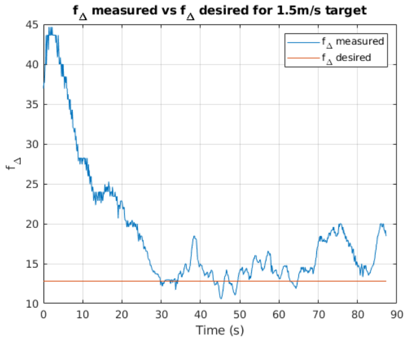


1.5 m/s Target Video

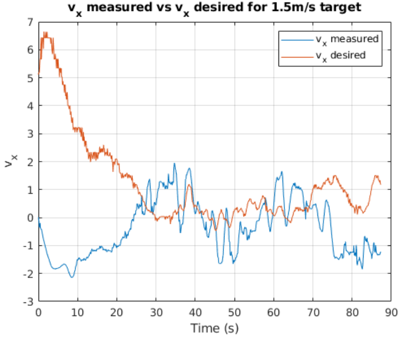
Video

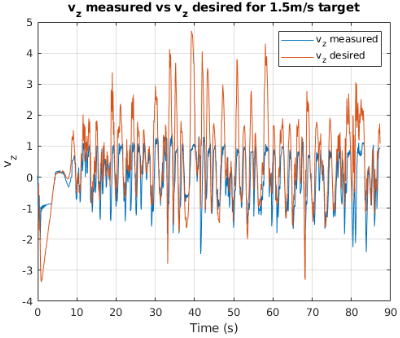
1.5 m/s Target: Camera Results





1.5 m/s Target: Flight Results

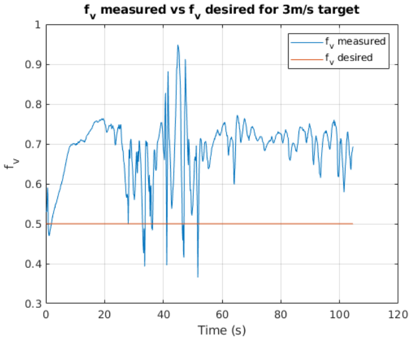


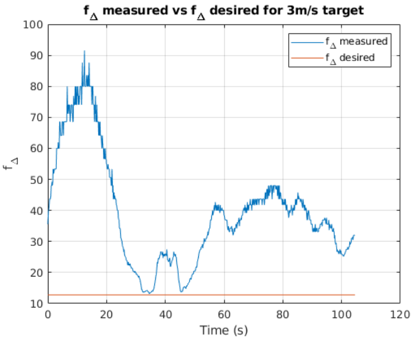


3 m/s Target Video

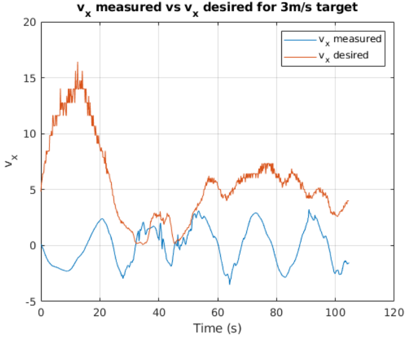
Video

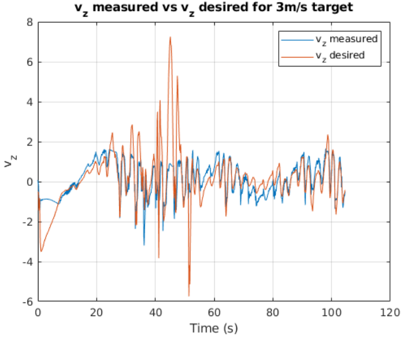
3 m/s Target: Camera Results





3 m/s Target: Flight Results





Future Work

- Find proper resolution values based on the correct focal length
- Measure flight data accurately
- Run more simulations
- Analyze/compare data with previous tests
- Complete final report

Bibliography

[1] J. Pestana, J. L. Sanchez-Lopez, S. Saripalli, and P. Campoy, "Computer vision based general object following for GPS-denied multirotor unmanned vehicles," in *2014 American Control Conference*, pp. 1886–1891, 2014.
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[2] J. Pestana, "On-board control algorithms for quadrotors and indoors navigation," *Master's thesis, Universi-dad Politécnica de Madrid, Spain*, 2012.