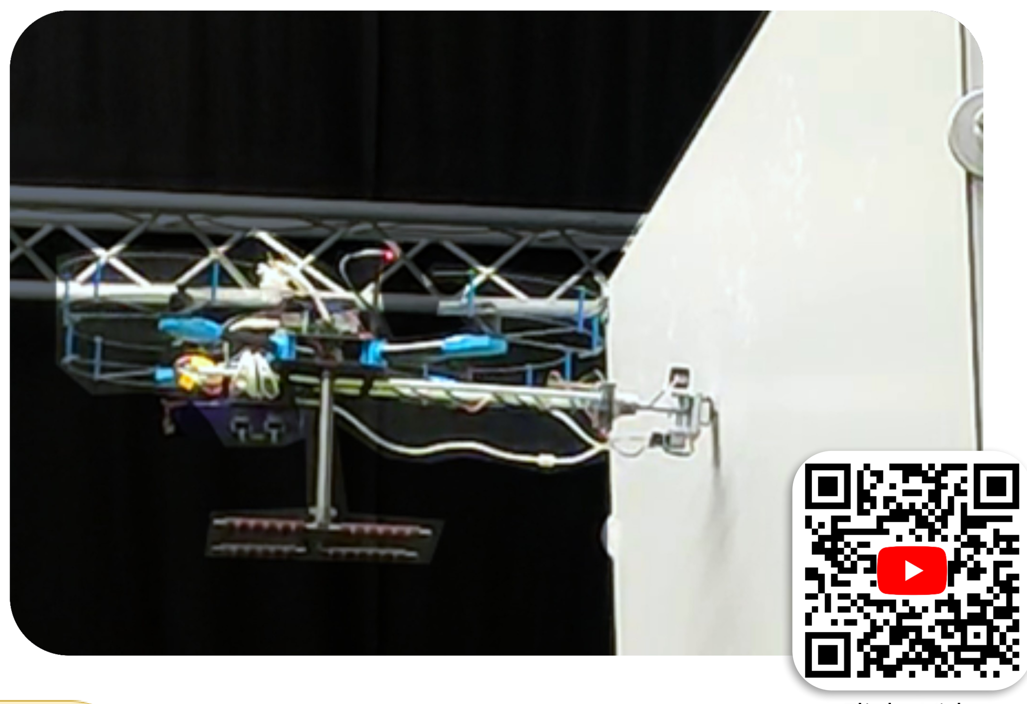
# Tactile Odometry in Aerial Physical Interaction

**Micha Schuster[1*], Anton Bredenbeck[2*], Michael Beitelschmidt[1], Salua Hamaza[2]**

*Equal contribution, [1]Dynamics and Mechanism Design Group, TU Dresden, [2]Biomorphic Intelligence Lab, Aerospace Engineering, TU Delft

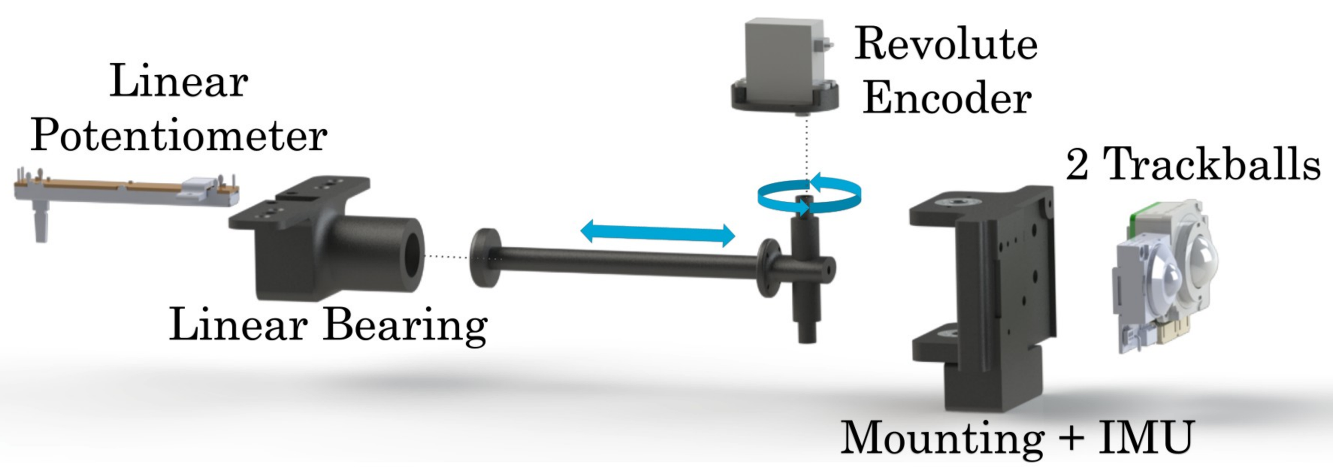
## Motivation

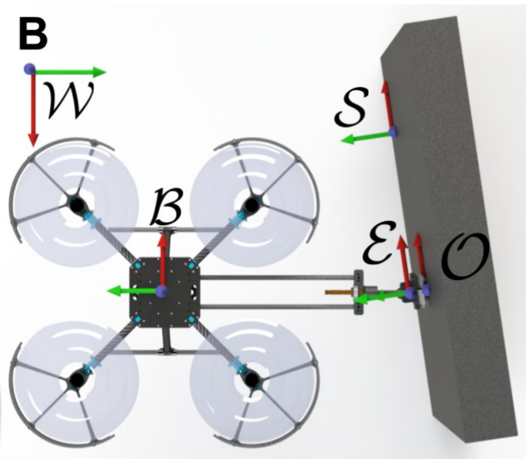
One of the biggest challenges in aerial physical interaction is accurately estimating the position of the vehicle in relation to the target. GNSS and vision are the most commonly used methods for position estimation, but there are scenarios where they are either not available (GNSS indoors or vision at night or in fog) or do not provide the required accuracy.
By integrating a tactile trackball in the end effector (EE) of the UAV, we utilize the contact during physical interaction tasks to provide a precise position estimation that can either replace or complement state of the art position estimation approaches.

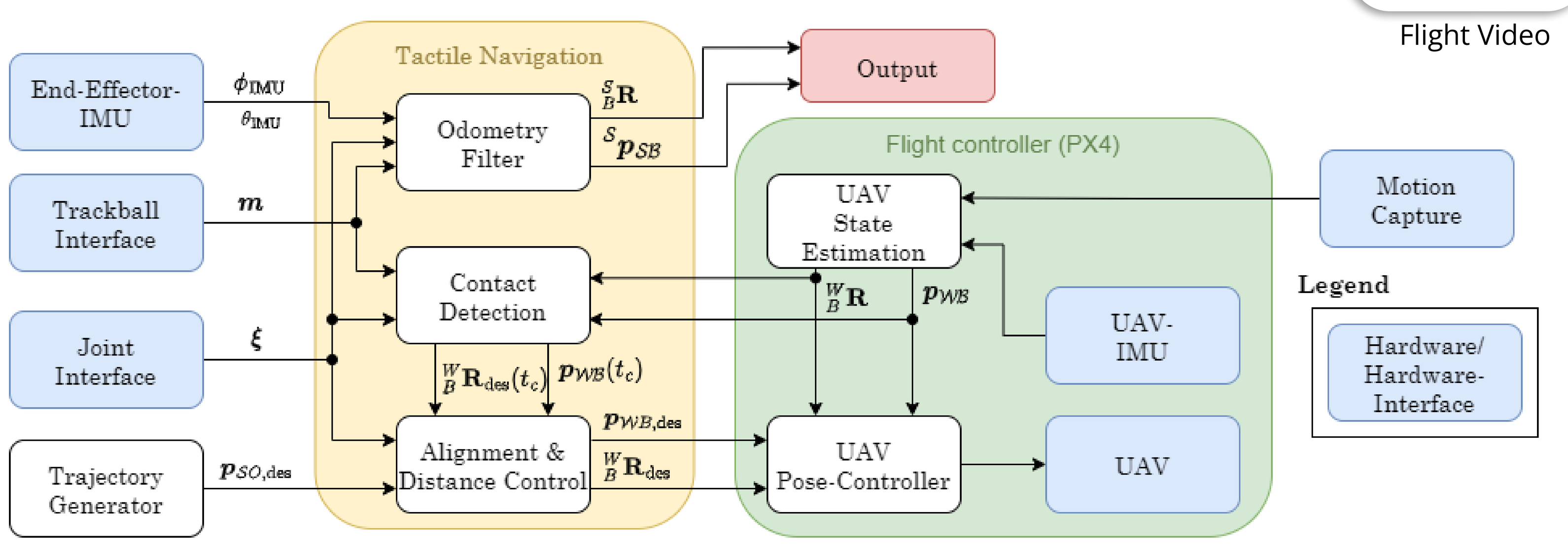


Flight Video

## Design




### Approach

The *tactile odometry* system is designed to work in unknown environments. After a pilot guided flight towards the wall, the UAV autonomously detects contact, aligns itself to the wall, regulates the contact normal force and follows the desired path on the wall's surface while estimating its local position using the trackball based *odometry filter*.

### Mechanical Design

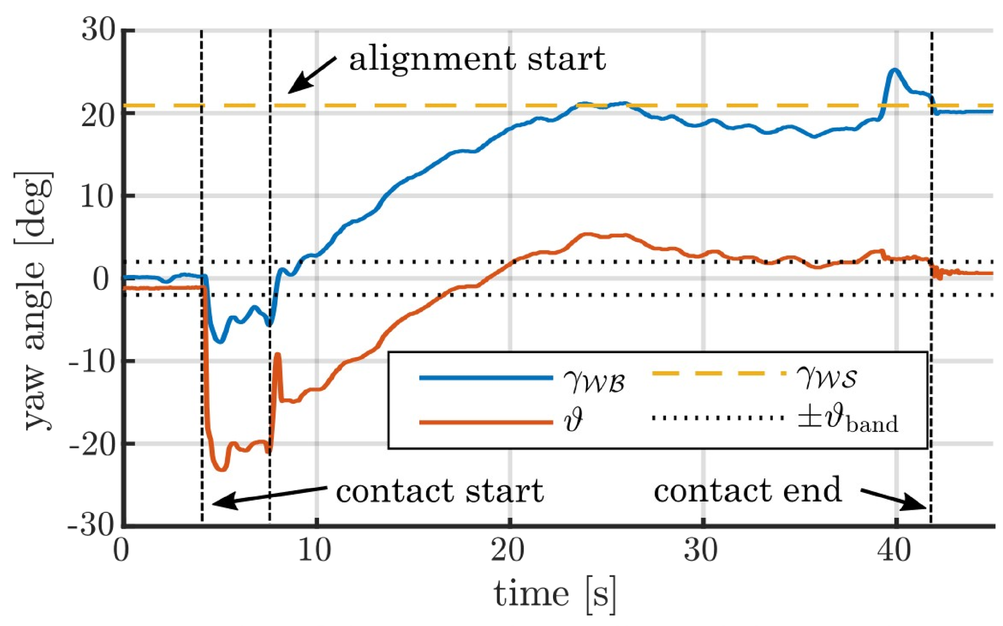
Three key features comprise the overall system:

1) a mechanically *compliant* EE to ensure stable contact and to regulate the normal force magnitude
2) a passive rotary joint in the EE to ensure a proper alignment with the target surface
3) a trackball to provide measurement data for dead reckoning position estimation

### Odometry Filter

The *odometry filter* estimates both, the local EE position ${}_{\mathcal{S}}\boldsymbol{p}_{\mathcal{SO}}$ and the UAV's position ${}_{\mathcal{S}}\boldsymbol{p}_{\mathcal{SB}}$ w.r.t. wall surface based on the trackball data $\boldsymbol{m}$, the current orientation $\mathbf{R}_{\mathcal{SO}}$ obtained by the IMU and the EE angle and length :

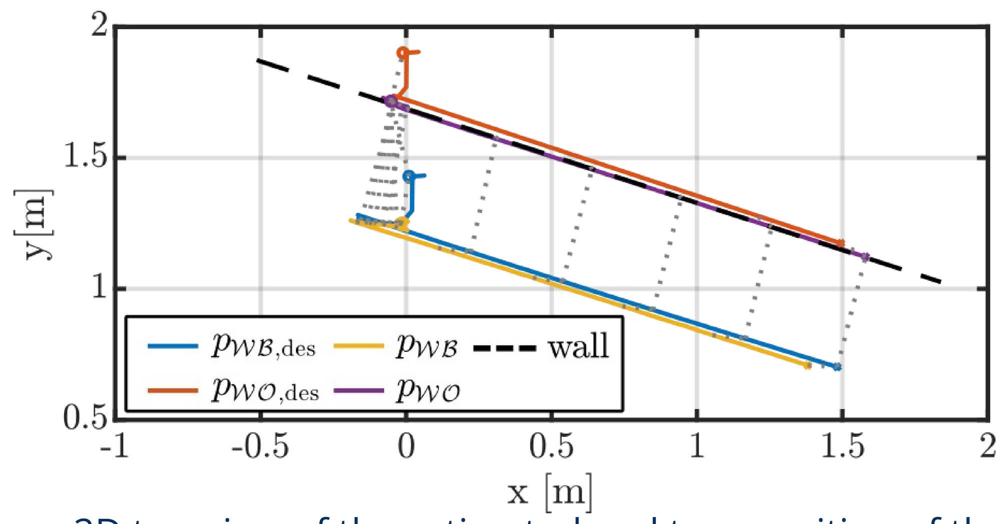
$$ {}_{\mathcal{S}}\boldsymbol{p}_{\mathcal{SO}}(t) = \sum_{t_i=t_c}^{t_i=t} \mathbf{R}_{\mathcal{SO}}(t_i)\cdot k \cdot \boldsymbol{m}(t_i) \qquad {}_{\mathcal{S}}\boldsymbol{p}_{\mathcal{SB}} = {}_{\mathcal{S}}\boldsymbol{p}_{\mathcal{SO}} - \mathbf{R}_{\mathcal{SB}}\cdot\left[{}_{\mathcal{B}}\boldsymbol{p}_{\mathcal{BE}}(d) + \mathbf{R}_{\mathcal{BE}}(\vartheta)\cdot {}_{\mathcal{E}}\boldsymbol{p}_{\mathcal{EO}}\right] $$



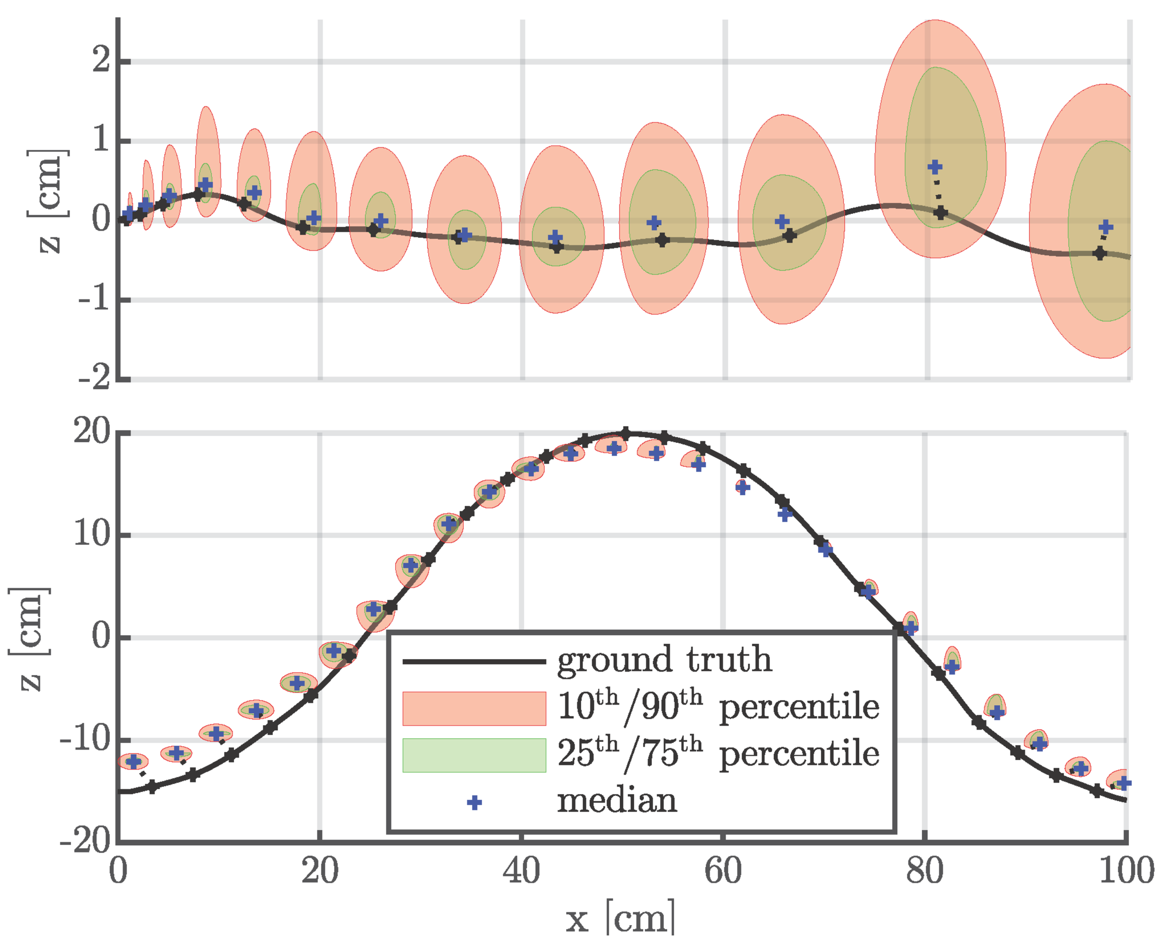

Yaw angle of the UAV, the wall , and the revolute EE joint during the alignment procedure.

## Results

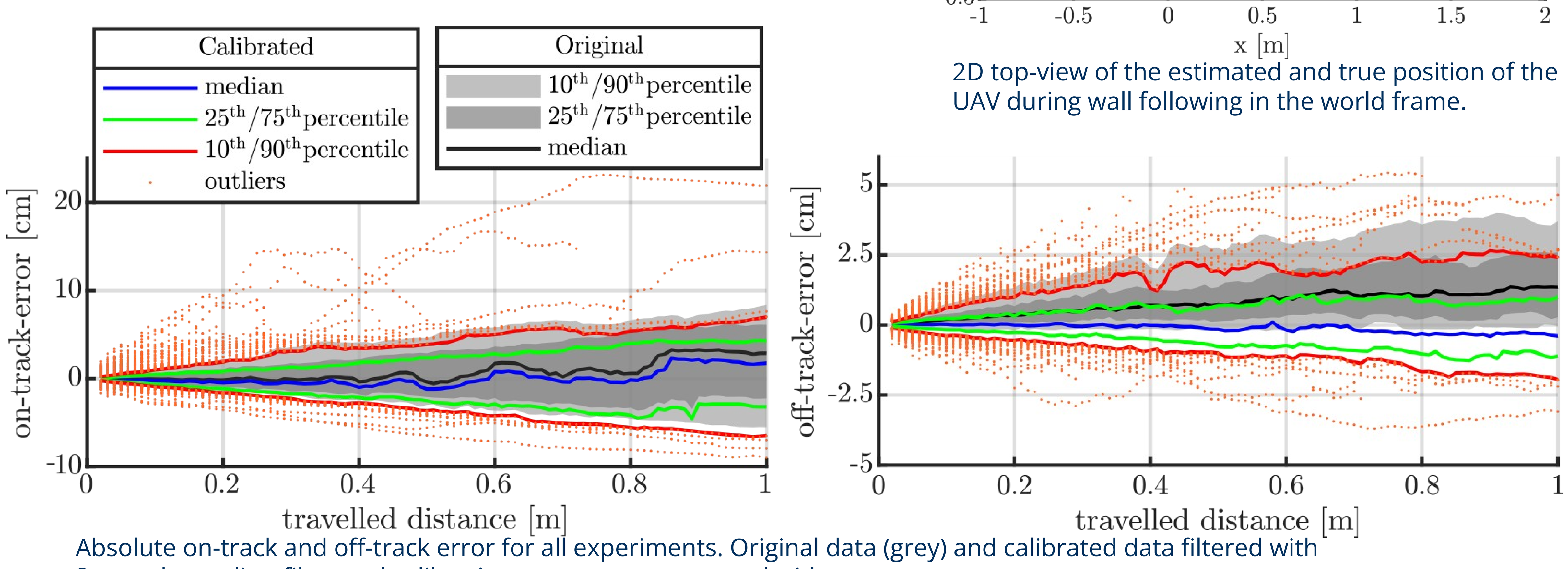
After calibration to minimize systematic errors, the system achieves an overall uncertainty of the EE position of: (on-track) and (off-track) in a total of 32 flights for varying conditions and trajectories.




2D top-view of the estimated and true position of the UAV during wall following in the world frame.




Ground truth and estimated position in the wall frame, averaged over all line and sinusoidal-flights respectively.




Absolute on-track and off-track error for all experiments. Original data (grey) and calibrated data filtered with 3-sample-median-filter and calibration parameters corrected with , .

## Conclusion

This paper presents a novel methodology for estimating a UAV's pose by exploiting information acquired during continuous contact. Akin to traditional wheeled robots that use encoders to estimate their position, we propose to use a trackball embedded in a compliant EE to estimate the aerial robot's position w.r.t. a static environment. Future work will look into utilizing a second trackball to increase robustness and accuracy, further more we aim for closing the loop to transition from contact-based odometry estimation to contact-based flight control.

Paper Pre-Print

Project Website

FAKULTÄT MASCHINENWESEN

TECHNIK ÜBERWINDET GRENZEN