



Evaluation of Orientation Ambiguity and Detection Rate in April Tag and WhyCode

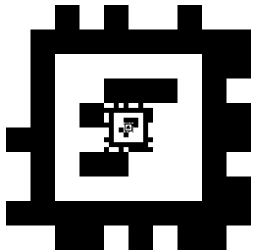
Joshua Springer, Marcel Kyas

29 November 2022

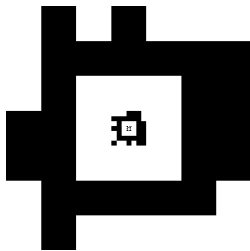
Reykjavik University

Department of Computer Science

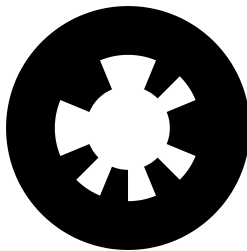
Fiducial Markers



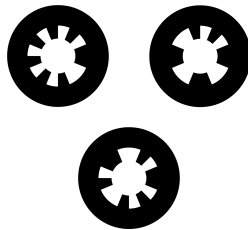
(a) April Tag 48h12 [2]



(b) April Tag 24h10 [1]

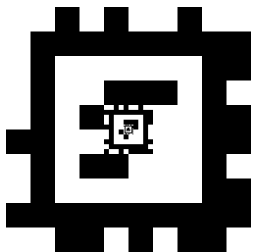


(c) WhyCode (Orig)[3]

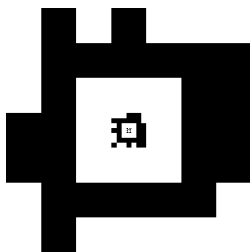


(d) WhyCode Multi [1]

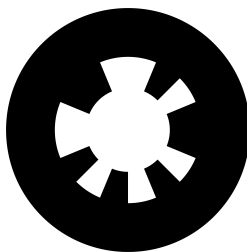
Fiducial Markers



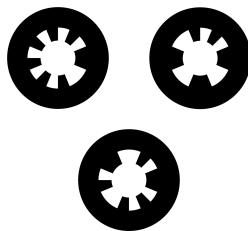
(a) April Tag 48h12 [2]



(b) April Tag 24h10 [1]

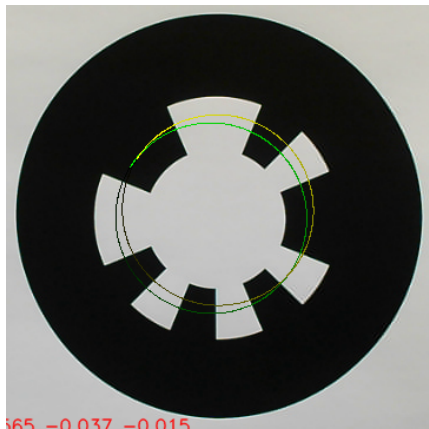


(c) WhyCode (Orig)[3]

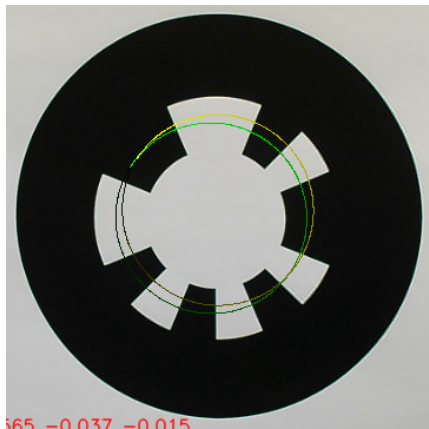


(d) WhyCode Multi [1]

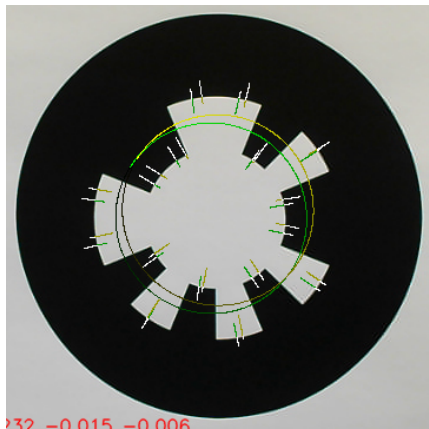
- ▶ Marker *position* → accurate
- ▶ Marker *orientation* → ambiguous
- ▶ Application: autonomous precision drone landing



- Position \rightarrow camera intrinsics, marker size (known a priori)

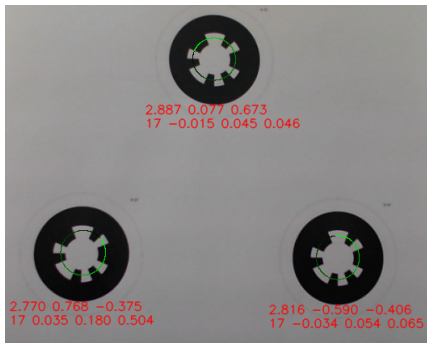


- ▶ Position → camera intrinsics, marker size (known a priori)
- ▶ Orientation → two candidates (yellow/green ellipses)
 - ▶ Which one fits better?
 - ▶ Minimize variance of intersection length of sampling circle with each tooth

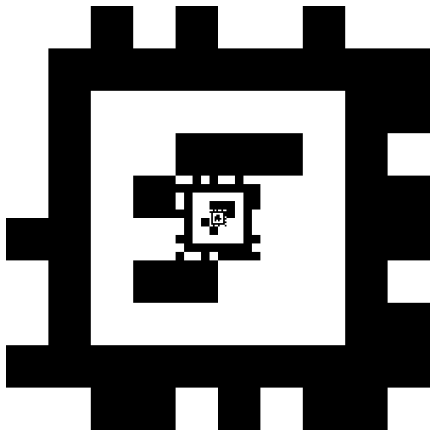


- ▶ Changes the method for choosing the orientation candidate
 - ▶ Original sampling predicts tooth transition locations
 - ▶ Sample again along radii through tooth centers
 - ▶ Try to center radial sampling lines on white-to-black transitions

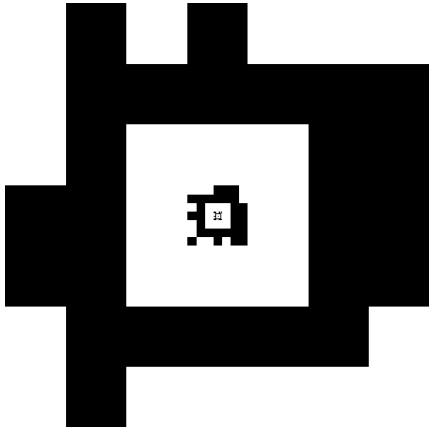
WhyCode “Multi”



- ▶ Assumes coplanar marker arrangements
- ▶ Samples as in WhyCode Orig
- ▶ Uses only marker size, positions and IDs.
- ▶ Regresses a plane to the marker positions
- ▶ Assigns the plane's orientation to all of the markers



- ▶ 36 outer ID bits + 12 inner ID bits
- ▶ 28 black border bits
- ▶ 20 white border bits
- ▶ 4 undefined, center bits (for marker embedding)
- ▶ 42,211 markers in a single hash table in RAM



- ▶ 24 outer ID bits
- ▶ 16 black border bits
- ▶ 8 white border bits
- ▶ 1 undefined center bit (for marker embedding)
- ▶ 18 total markers

- ▶ For autonomous landing application
- ▶ A **position target** P in the a relative “east, north, up” (ENU) coordinate frame
- ▶ The marker’s **orientation quaternion** q
- ▶ The **normalized pixel position** $u_n, v_n \in [-1, 1]$ of the center of each marker
- ▶ The marker’s **orientation components**: yaw, pitch, and roll (where not originally exposed)

Linear Discontinuities

$$P = \langle p_e, p_n, p_u \rangle$$

$$\frac{p_{x,i+1}}{p_{x,i}} < \theta_l < 0$$

$$\theta_l = -0.8$$

Angular Discontinuities

$$q = \langle q_w, q_x, q_y, q_z \rangle$$

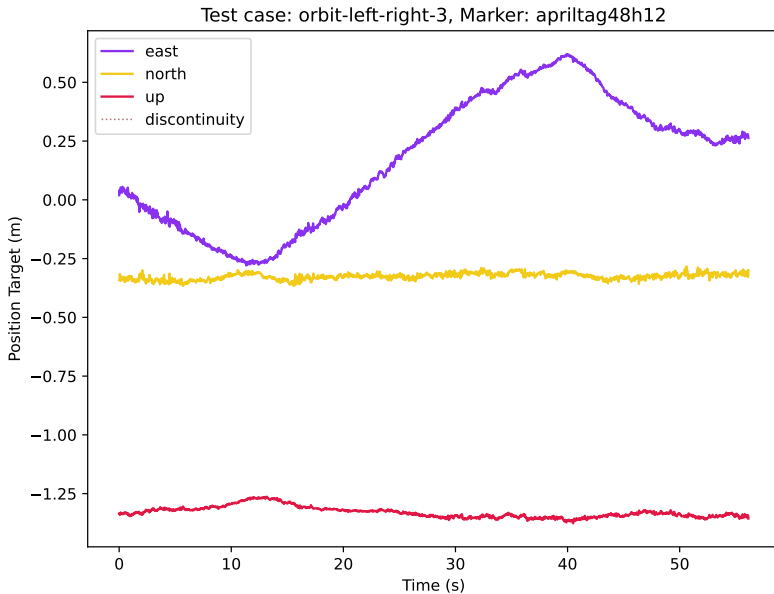
$$s_a = \frac{\text{dist}(q_i, q_{i+1})}{t} > \theta_a > 0$$

$$\theta_a = 1.0 \frac{\text{rad}}{s}$$

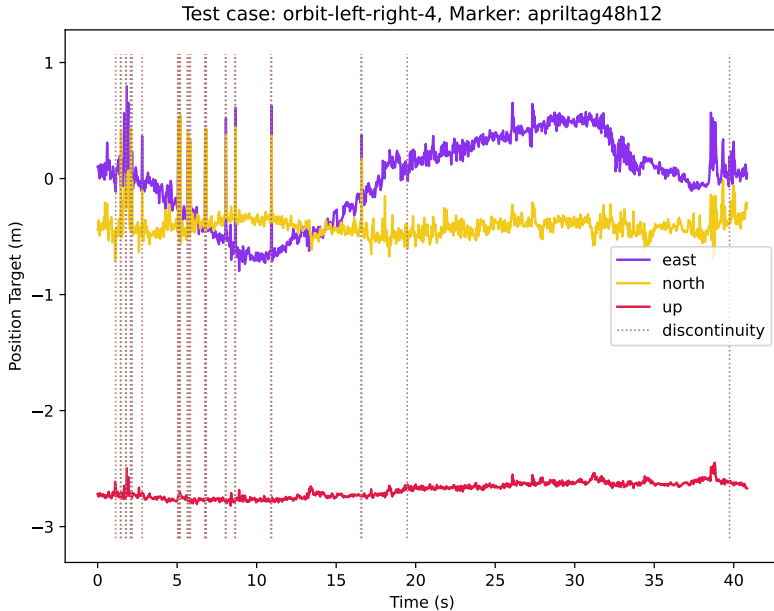
- ▶ Single marker arrangement showing all markers
- ▶ All markers fully contained in every frame
- ▶ Discontinuity occurs when both conditions are true
- ▶ Discontinuity rate: $r_d = \frac{d}{n}$: d is number of discontinuities, n is number of detections

- ▶ One static marker per video
- ▶ Multiple distances
- ▶ Constant camera, framerate, resolution
- ▶ Detection rate: $F = \frac{n}{t}$: n is number of detections, t is the length in seconds of each test case
- ▶ Raspberry Pi 4 with 2 GB of RAM

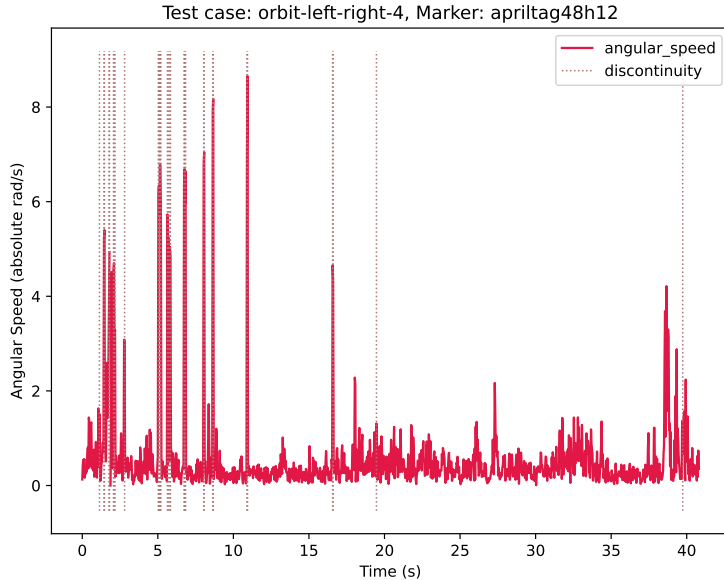
Example Test Case



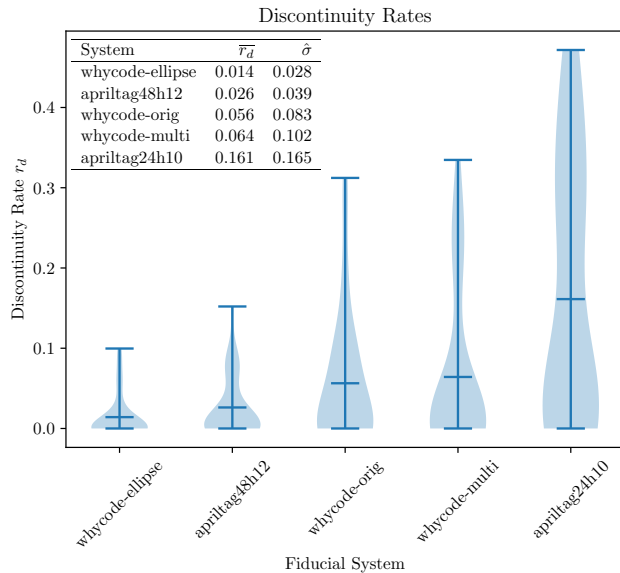
Example Test Case with Discontinuities



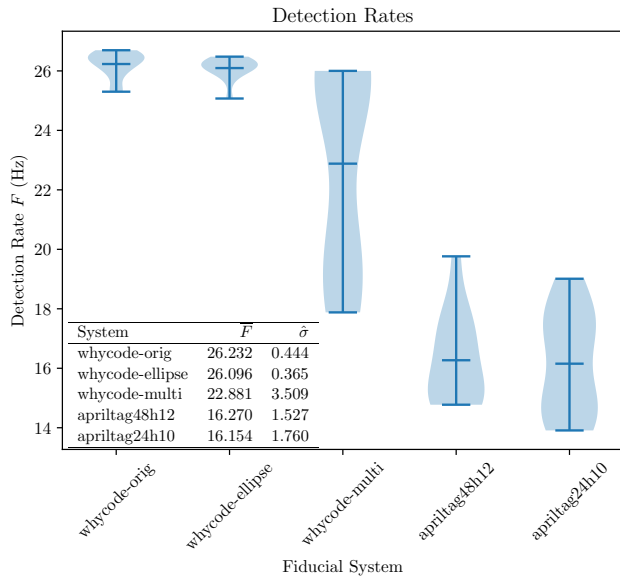
Example Test Case - Angular Speed



Results: Discontinuity Rates



Results: Detection Rates



- ▶ Fiducial markers: orientation is hard to determine
 - ▶ Orientation ambiguity manifests as sign flips
 - ▶ Present in all fiducial systems, but at different rates
- ▶ Detection rate
 - ▶ Limited by hardware capabilities
 - ▶ Limited by software architecture
 - ▶ Some faster than others

- ▶ Joshua Springer and Marcel Kyas.
Evaluation of Orientation Ambiguity and Detection Rate in April Tag and WhyCode.
In 2022 IEEE International Conference on Robotic Computing, December 2022.
- ▶ M. Krogus, A. Haggemiller, and E. Olson.
Flexible layouts for fiducial tags.
In 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pages 1898–1903, 2019.
- ▶ Peter Lightbody, Tomáš Krajník, and Marc Hanheide.
A Versatile High-performance Visual Fiducial Marker Detection System with Scalable Identity Encoding.
In Proceedings of the Symposium on Applied Computing, SAC '17, pages 276–282, New York, NY, USA, 2017. ACM.