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

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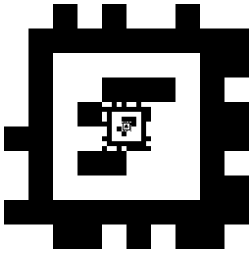
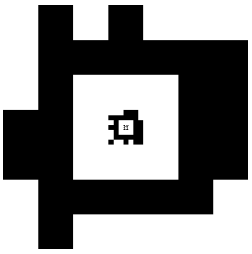
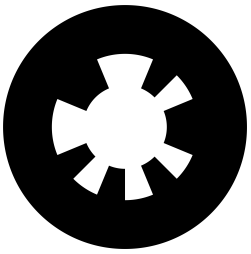
Fiducial Markers



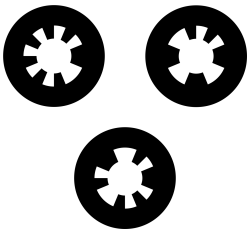
(a) April Tag 48h12 [2]



(b) April Tag 24h10 [1]

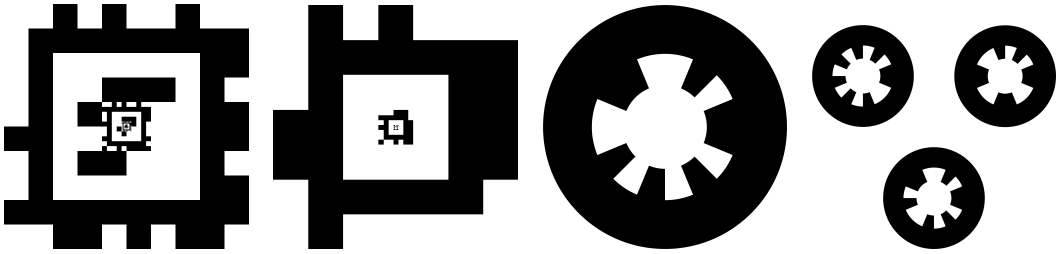


(c) WhyCode (Orig)[3]



(d) WhyCode Multi [1]

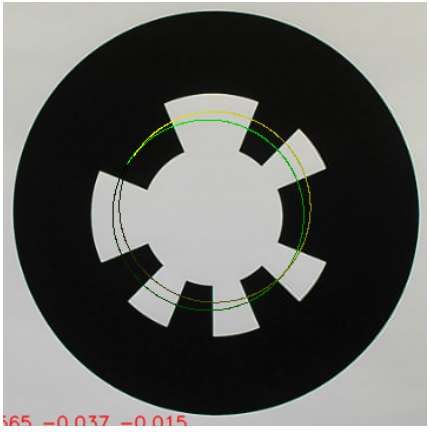
Fiducial Markers



(a) April Tag 48h12 [2] **(b)** April Tag 24h10 [1] **(c)** WhyCode (Orig)[3] **(d)** WhyCode Multi [1]

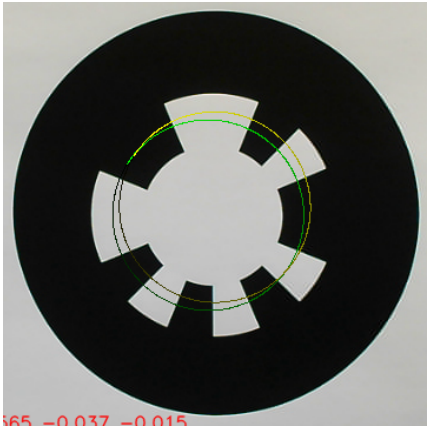
- Marker *position* $\rightarrow$ accurate
- Marker *orientation* $\rightarrow$ ambiguous
- Application: autonomous precision drone landing

WhyCode (Orig)



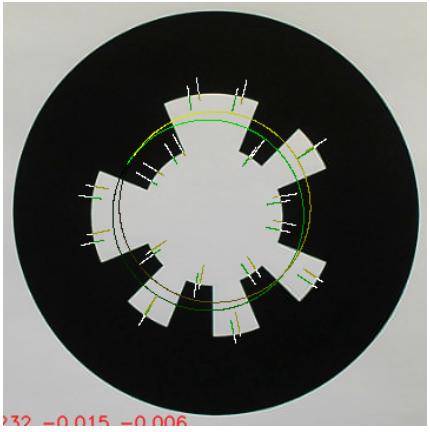
- Position → camera intrinsics, marker size (known a priori)

WhyCode (Orig)



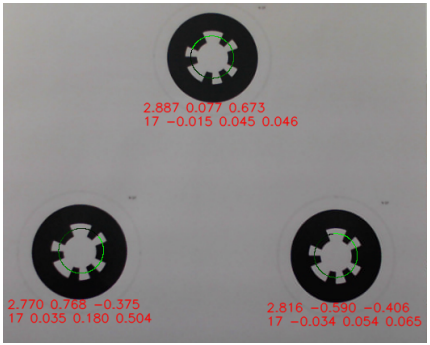
- Position → camera intrinsics, marker size (known a priori)
- Orientation → two candidates (yellow/green ellipses)
  - Which one fits better?
  - Minimize variance of intersection length of sampling circle with each tooth

WhyCode “Ellipse”



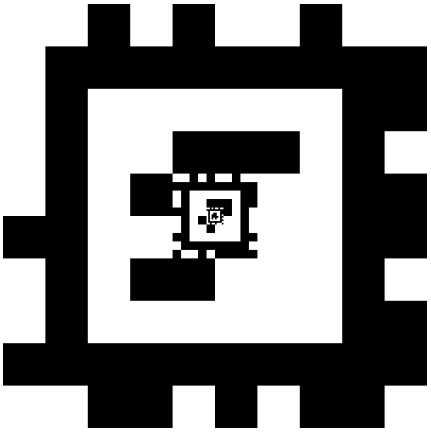
- Changes the method for choosing the orientation candidate
  - Original sampling predicts tooth transition locations
  - Sample again along radii through tooth centers
  - Try to center radial sampling lines on white-to-black transitions

WhyCode “Multi”



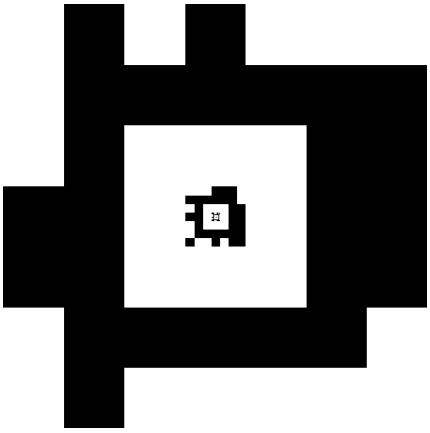
- Assumes coplanar marker arrangements
- Samples as in WhyCode Orig
- Uses only marker size, positions and IDs.
- Regresses a plane to the marker positions
- Assigns the plane’s orientation to all of the markers

April Tag 48h12



- 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

April Tag 24h10



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

ROS Message Attributes

- 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)

Quantifying Orientation Ambiguity

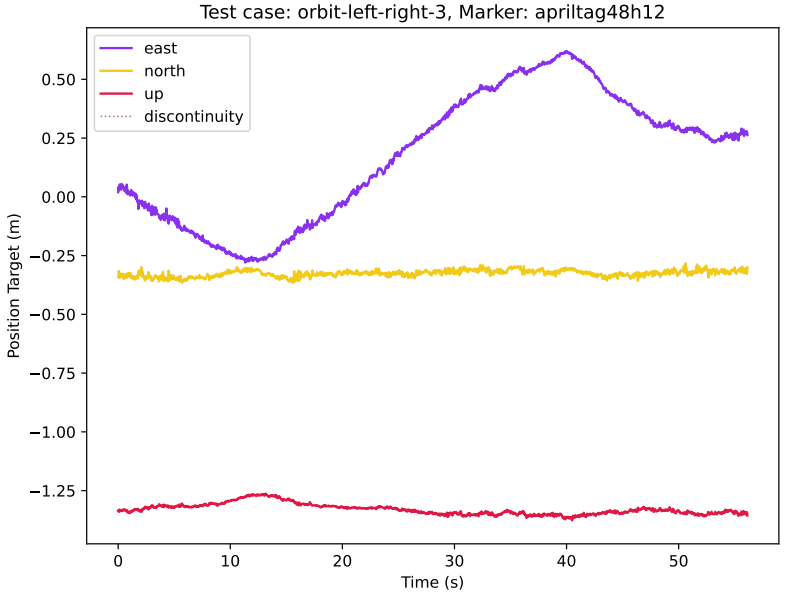
Linear Discontinuities	Angular Discontinuities
$P = \langle p_e, p_n, p_u \rangle$	$q = \langle q_w, q_x, q_y, q_z \rangle$
$\frac{p_{x,i+1}}{p_{x,i}} < \theta_l < 0$	$s_a = \frac{\mathrm{dist}(q_i, q_{i+1})}{t} > \theta_a > 0$
$\theta_l = -0.8$	$\theta_a = 1.0 \frac{\mathrm{rad}}{s}$

- 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

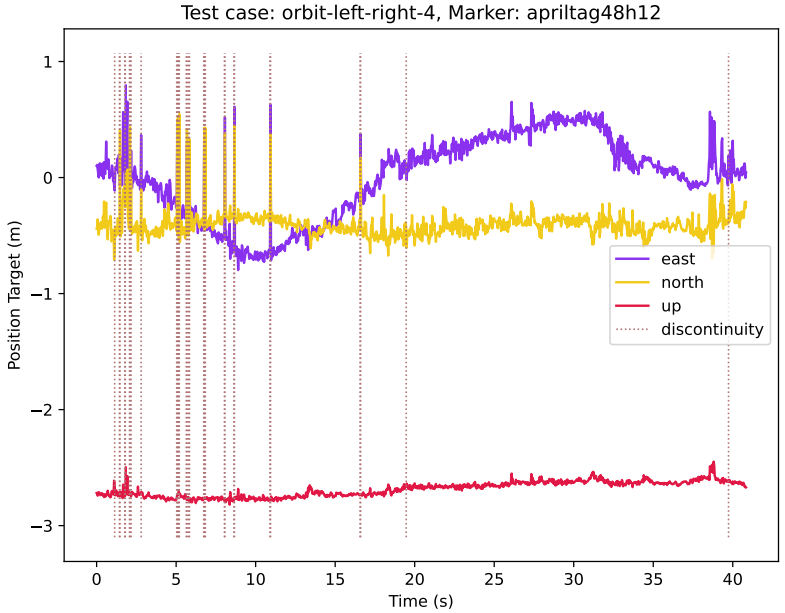
Quantifying Detection Rate

- 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

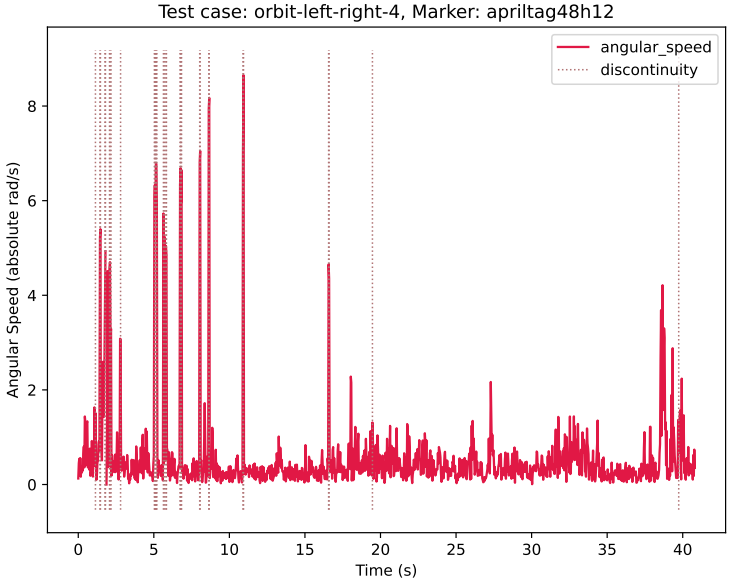
Example Test Case



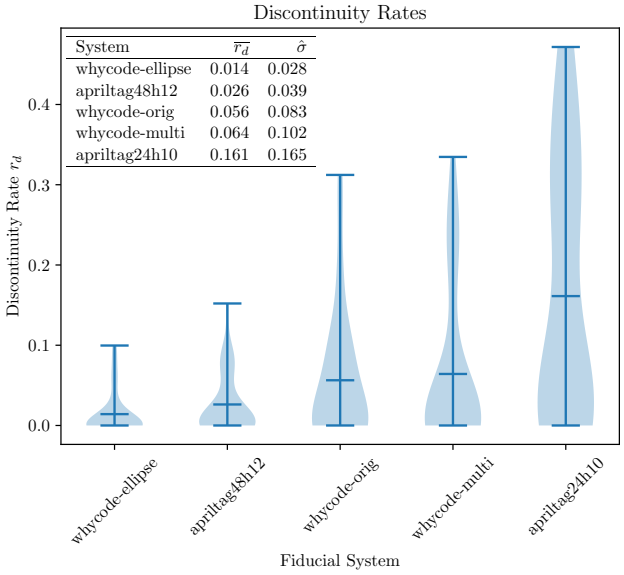
Example Test Case with Discontinuities



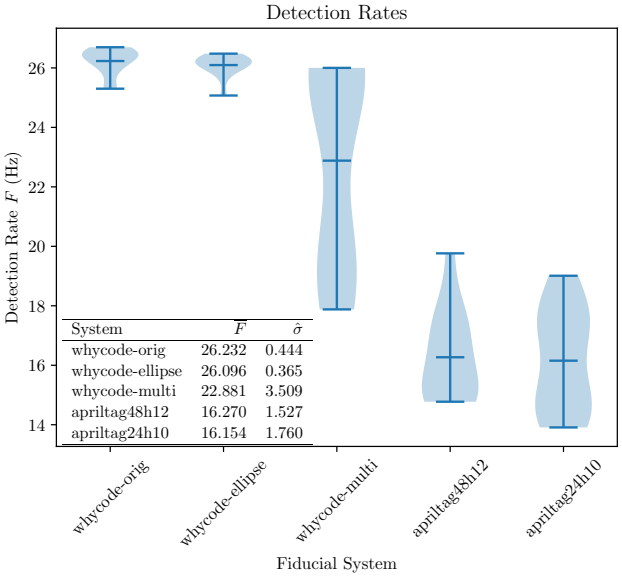
Example Test Case - Angular Speed



Results: Discontinuity Rates



Results: Detection Rates



System	$\overline{F}$	$\hat{\sigma}$
whycode-orig	26.232	0.444
whycode-ellipse	26.096	0.365
whycode-multi	22.881	3.509
apriltag48h12	16.270	1.527
apriltag24h10	16.154	1.760

Main Messages

- 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

References

- 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. Krogius, A. Haggenmiller, 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.