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Your World, Our World: Resilient Environment and Sustainable Resource Management for All

Possibilities and Limitations in the extrinsic Synchronization of Observations from Networks of Robotic Total Stations

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Overview

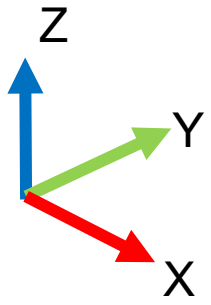
Total station network definition

Current possibilities and limitations with a Trimble S7 network

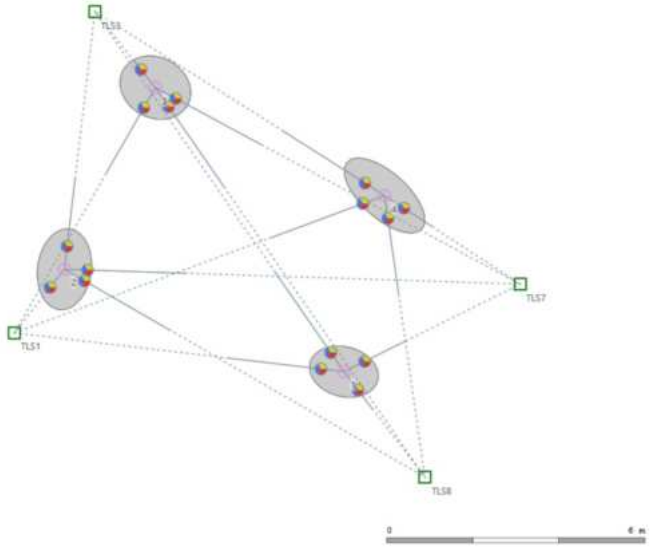
Perspectives & Conclusions

Definition

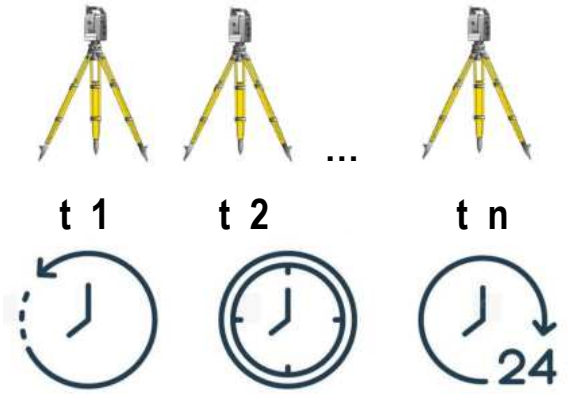
Total station network =
network of several TS (or RTS), that work within the same spatial and temporal reference frame.



Space



Time

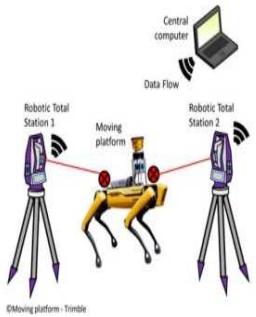


?

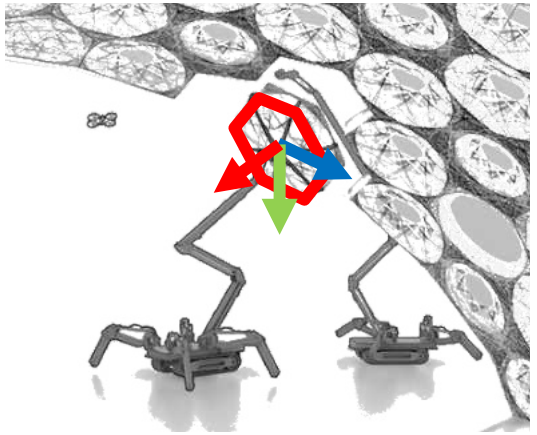
Motivation

- Kinematic Positioning of Robots
- Continuous tracking in case of line-of-sight interruption
- Improved precision and redundancy (through real-time network adjustment)
- High update rate needed for moving objects / robots

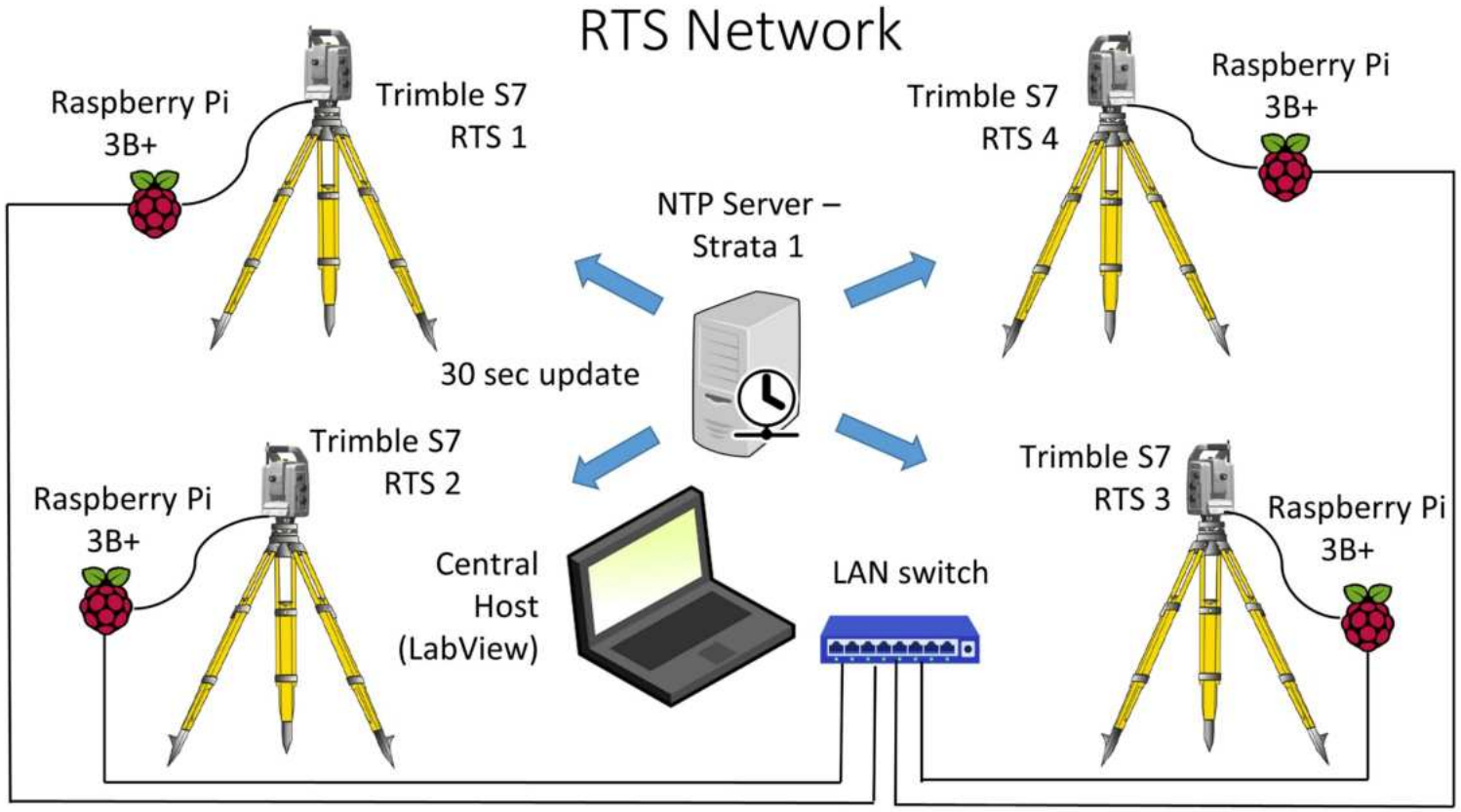
Reference trajectory



Co-working robots



Current Network – Trimble S7



Scope for current network

- Define a common time reference (extrinsic synchronization)
- Obtain measurements simultaneously
- Achieve positioning accuracy

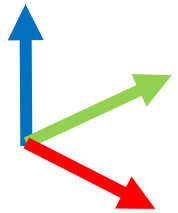
Robotnik

RB-VOGUI
AUTONOMOUS MOBILE ROBOT (AMR)

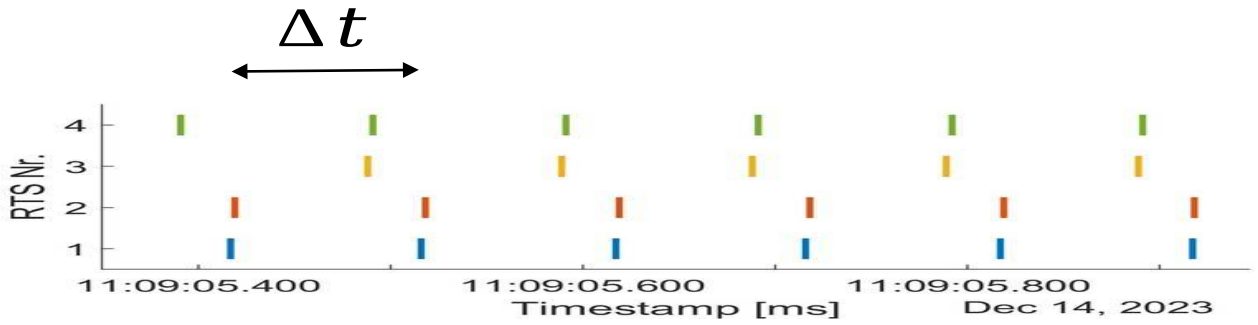
Definition	lowest robot speed	speed of rotation arm	highest robot speed
Velocity [m/s]	0.15	0.66	2.5
Required simultaneity for 1 mm max error [ms]	< 6.7	< 1.5	< 0.4
Travelled distance in 1 ms [mm]	0.15	0.66	2.5

Test workflow

- RTS Stationing redisuals 0.2 … 0.5 m
- Circle fit RMS 70 µm from LT measure



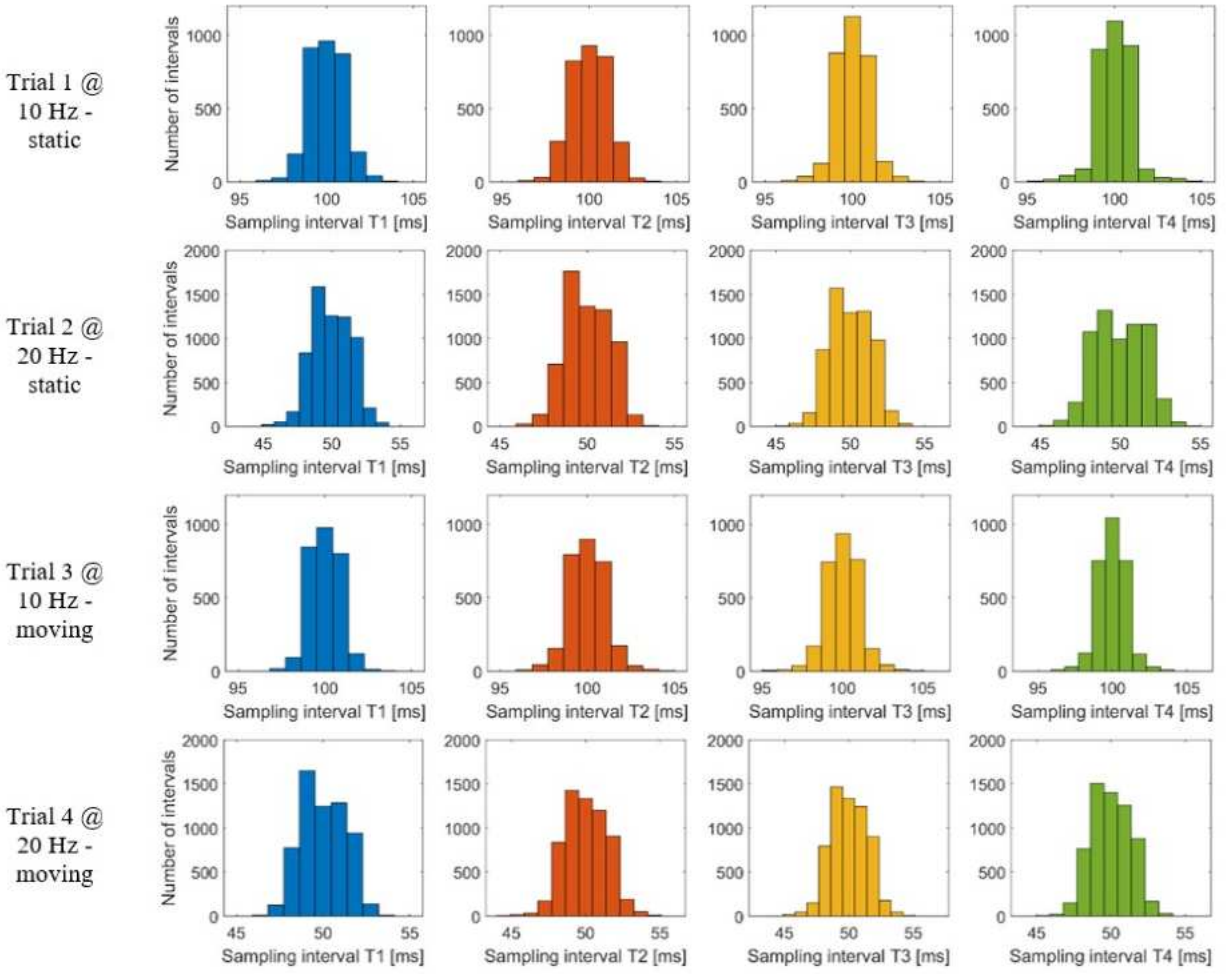
Time consistency - individual time stamps of each RTS



$$10\,Hz -> \Delta t = 100\,ms$$

$$20\,Hz -> \Delta t = 50\,ms$$

Time consistency - individual time stamps of each RTS

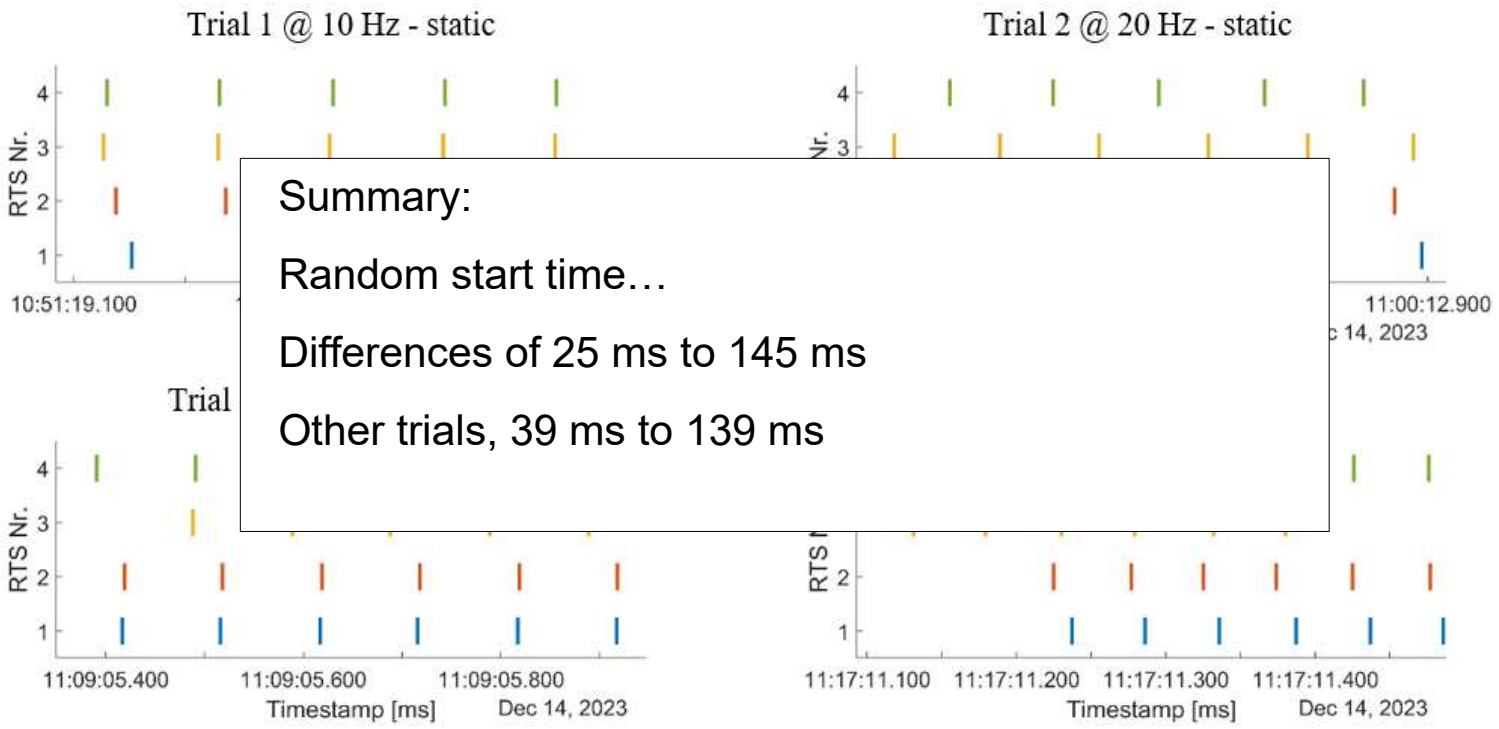


Summary:

For 10 Hz 80 % to 90 % values within 100 ms ± 1 ms

For 20 Hz 53% to 69% values within 50 ms ± 1 ms

Time consistency - RTS network time in tracking mode



Summary:

Random start time…

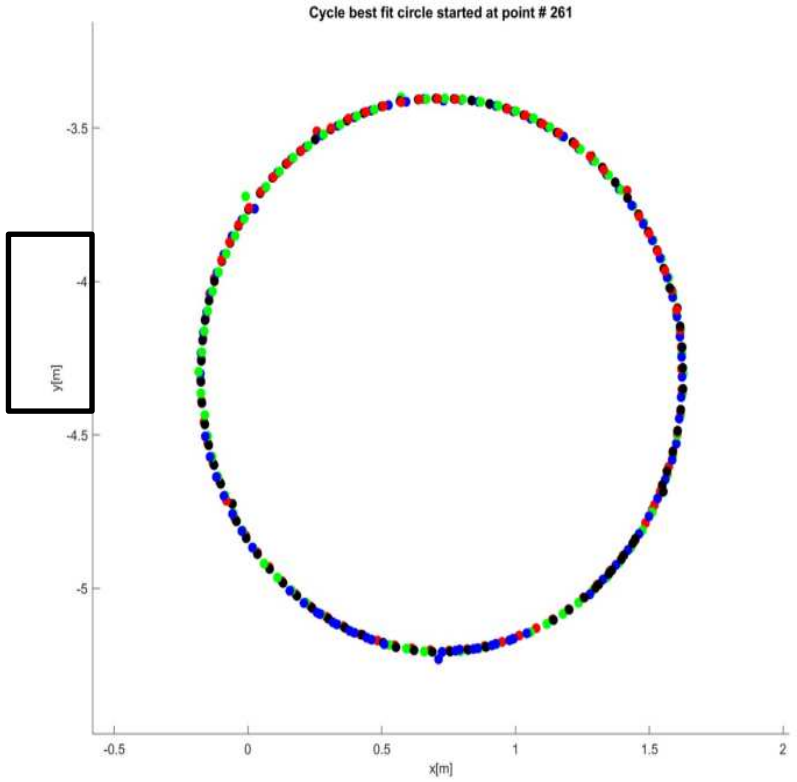
Differences of 25 ms to 145 ms

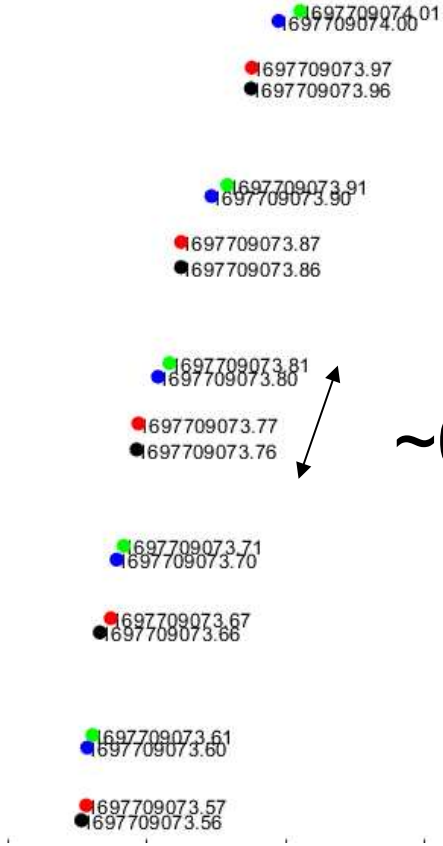
Other trials, 39 ms to 139 ms

Trigger = global variable in LabView used to simultaneously start streaming.

Expected -> start streaming at the same time or systematic delay….

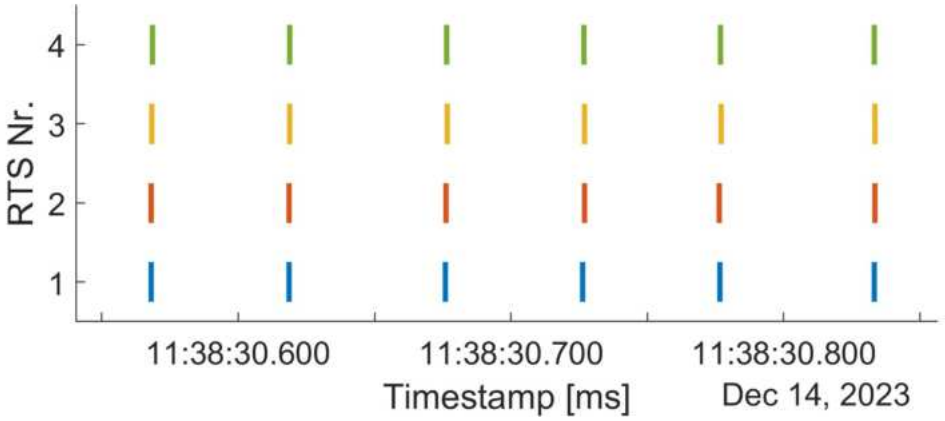
Time consistency - RTS network time in tracking mode





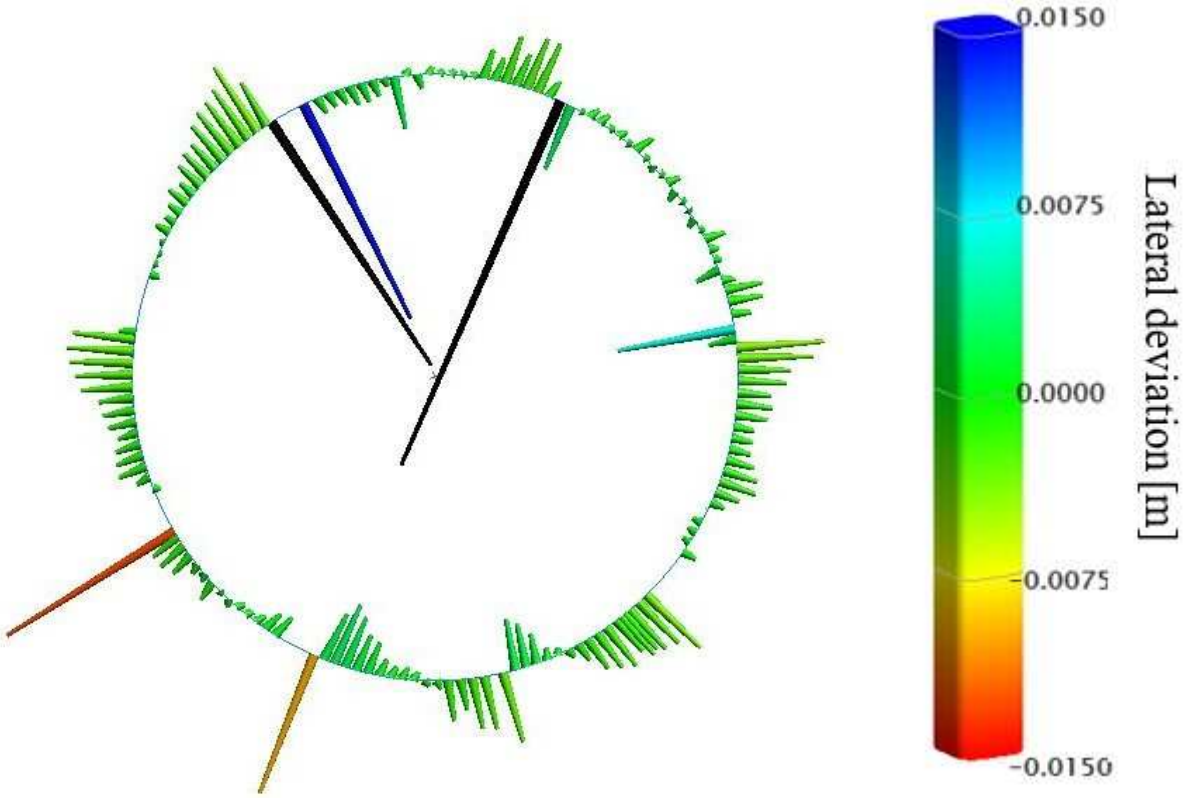
~0.0335 m

Time consistency - RTS network time angle inquiry

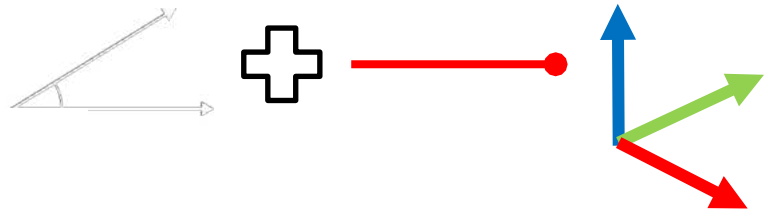


Mode	Trial	Max delay (ms)	Mean delay (ms)	Standard deviation (ms)
Static reflector	a	0.423	0.330	0.133
	b	0.145		
	c	0.395		
	d	0.559		
	e	0.164		
	f	0.406		
	g	0.216		
Moving reflector	h	0.241	0.292	0.059
	i	0.365		
	j	0.290		
	k	0.398		
	l	0.238		
	m	0.319		
	n	0.193		

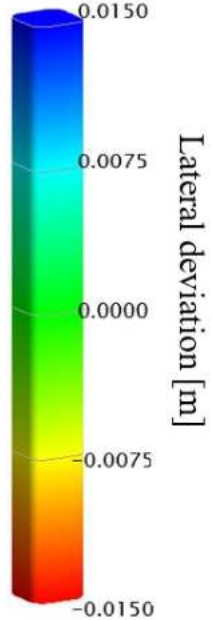
Geometric quality - RTS individual observations



Geometric quality - RTS individual observations

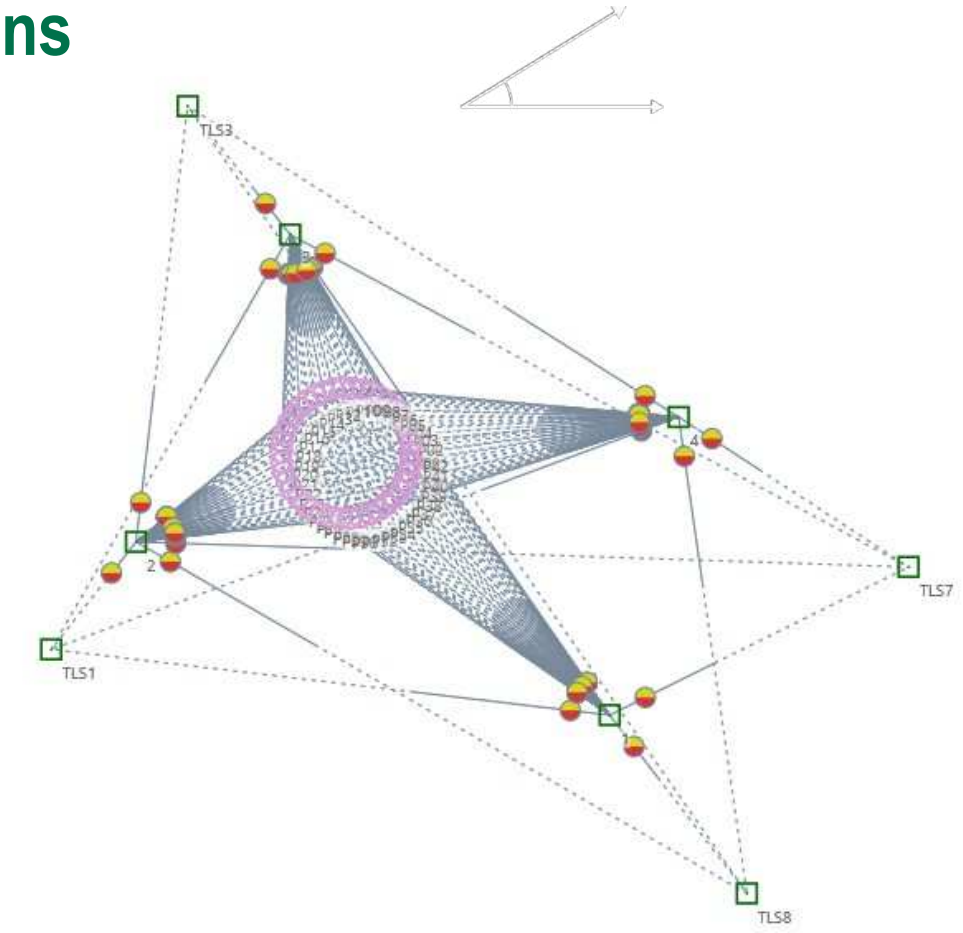


	T1	T2	T3	T4
Trial 3 @ 10 Hz	Max= 14.8 mm, RMS= 3.1 mm Max_f = 3.8 mm, RMS_f= 1.7 mm	Max= 18.6 mm, RMS= 3.2 mm Max_f = 3.9 mm, RMS_f = 1.9 mm	Max= 21.4 mm, RMS= 4.5 mm Max_f = 5.7 mm, RMS_f = 2.4 mm	Max= 6.9 mm, RMS= 2.2 mm Max_f = 3.8 mm, RMS_f = 1.7 mm
Trial 4 @ 20 Hz	Max = 13.9 mm, RMS = 2.7 mm Max_f = 4.3 mm, RMS_f = 1.6 mm	Max = 23.6 mm, RMS = 3.5 mm Max_f = 4.3 mm, RMS_f = 1.8 mm	Max = 22.6 mm, RMS = 4.6 mm Max_f = 6.4 mm, RMS_f = 2.6 mm	Max = 18.6 mm, RMS = 2.9 mm Max_f = 4.3 mm, RMS_f = 1.9 mm

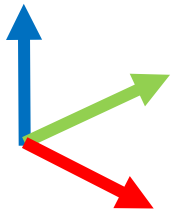


Geometric quality - RTS angle observations

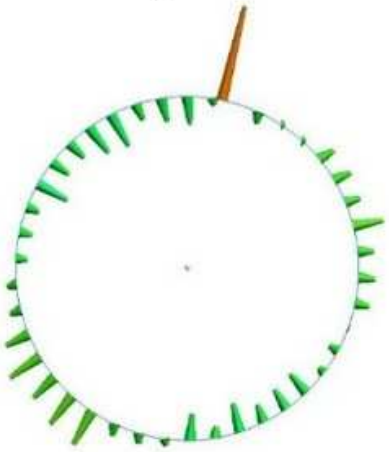
- RTS set in prism lock mode
- Determine coordinates as in a geodetic network
- At least two RTS need to have line-of-sight to the prism



Geometric quality - RTS angle observations

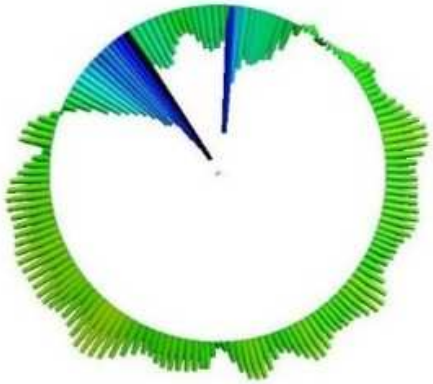


Trial 5 @ 5 Hz – moving fast constant speed

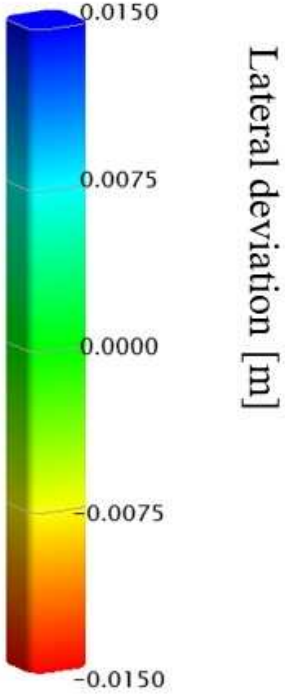


Max = 10.1 mm, RMS = 2.7 mm
Max_f = 4.0 mm, RMS_f = 2.2 mm

Trial 7 @ 5 Hz – moving slow variable speed



Max = 16.4 mm, RMS= 4.8 mm
Max_f= 6.7 mm, RMS_f= 3.8 mm



Possibilities and limitations

Object linear speed [m/s]	Time [ms]	Traveled distance [m]	Temporal requirement 1 ms	Spatial requirement 1 mm
0.15	25	0.004	No	No
	145	0.022	No	No
	1	0.00015	Yes	Yes
	0.3	0.00005	Yes	Yes
0.66	25	0.017	No	No
	145	0.096	No	No
	1	0.00066	Yes	Yes
	0.3	0.00020	Yes	Yes
2.50	25	0.063	No	No
	145	0.363	No	No
	1	0.00250	Yes	No
	0.3	0.00075	Yes	Yes

Conclusions

- Trimble SDK for Linux used
- Time consistency good (10 Hz recommended)
- Exstrinsic synchronization realized with NTP timestamps
- Simultaneity given for angle measurements (0.3 ms average) even with maximal robot speed
- Geometric quality fine in case of eliminated outliers
  - Individual tracking: 1.6 – 2.4 mm
  - Joint angle inquiry: 2.2 – 3.8 mm

- Simultaneity in tracking mode (including distance measuerement) challenging
- Angle inquiries at 10 Hz result in fictive measurements (true 5 Hz) – under intensive testing

Thank you!

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