Clock Metrology: A Novel Approach to TIME in Geodesy

Overview over the Research Unit FOR 5456/1

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The Terrestrial Reference Frame

- The terrestrial reference frame (TRF) is the physical realization of a terrestrial reference system (TRS)
- The quantification of global change and applications of positioning and navigation are based on the TRF
- Only the combination of the 4 techniques of space geodesy provides all parameters
- Ties are provided by the local geodetic surveys
- Systematic errors are limiting the achieved accuracy to about a factor of 5 above the desired GGOS value of 1 mm (position) and 0.1 mm/year (velocity)

We illustrate this fact by an example on the next slide!
Clock Comparison by two Techniques

- During the CONT17 campaign we compare the masers of **Matera** and **Wettzell**
- Clock absorbs delays
- Systematic errors **contaminate** the clock offsets
- This means **coordinates** are also contaminated

**Closed-loop delay compensation is a promising approach**

- R-Session Wettzell: Common clock, fixed baseline
- Non-normal noise distribution + drift of delay
- Requirement: Variable “electronic” delays have to be captured
Closed - Loop Delay Compensation

mode-locked laser have excellent low noise properties…

… and provides high time coherence

This allows us to utilize exact phase comparisons for the delay compensation

Phase stability is vital for closure measurements
The Geodetic Observatory Wettzell - a Testbed

In this research unit…

• We demonstrate the concept of clock ties (delay compensation)
• We introduce optical clocks to space geodesy
• We combine all space geodetic techniques on the observation level (proof of concept)
• We demonstrate physical height differences from optical time transfer (ACES)
• We provide the theoretical background for a relativistic geodesy
Local demonstration that we can provide “clock ties” to the measurement techniques of space geodesy.
The Research Unit (Global Component)

A better handle on “Time” in GNSS
P6 (GFZ/TUM)

Closure on common target (VLBI phase observation)
P7 (DGFI)

A tighter grip on atmosphere
P8 (DGFI/IUP)

Consistent inter-technique combination
P9 (DGFI, GFZ)

accurate clock
stable clock
clock ties
delay compensation
closure technique

Constraints from clock ties
P10 (TUB/GFZ)
Condensed Summary: All Projects

PTB
MWL
GNSS-1
H
Elstab
SLR
Potsdam

GNSS-2

MWL
H
SLR

ELT
Wettzell

Common Target

Global network

P5
P6
P2
P7
P8
P9
P10
P3
P4
P1
P5
P8
P8
P8
P8

The full experiment (P2, P3, P5)

Time interval comparison GOW – PTB
→ difference of time intervals $T_1$, $T_2$ measured locally by equal clocks → $\Delta U$

Expected uncertainties (one comparison, $T = 2$ days):
   ELT: $\sqrt{2 \times 3} \text{ ps}$ (common-view via ACES)
   ELSTAB: $\sim 1 \text{ ps}$
   Strontium clock @ PTB: $< 1 \text{ ps}$
   Strontium clock @ GOW: $2 \text{ ps}$
   **Total**: $\sim 5 \text{ ps}$

Goal (1st phase of FOR, 4 yrs.):
(A) repeated determination of $\Delta U$ with uncertainty $0.3 \text{ m}$
   (averaging → $0.2 \text{ m}$ (limited by SOC2 clock);
   → time dependence detectable);
   modeling of systematics

(B) Integration of physical heights data into a future TRF