QDaedalus
Augmentation of Total Stations by CCD Sensor for Automated Contactless High-Precision Metrology

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A Very Short Overview of 3D Commercial Metrological Systems
Augmentation of Total Stations by CCD Sensor for Automated Contactless High-Precision Metrology

CMM: Coordinates Measurement Machine

σ < 1 μm/m range < 1-2 m

Measurement Arm

σ ~ 10 μm/m range < 5 m

Laser Tracker with Absolute EDM

σ ~ 7.5+3 μm/m range < 100 m

Laser Tracker with Interferometer

σ ~ 7.5+3 μm/m range ~ 150 m
The Measurement System

QDaedalus

Close-Range Photogrammetry

$\sigma \sim 15 \mu m/m \quad \text{range} < 50 \text{ m}$

Laser Scanner

$\sigma \sim 1 \text{ mm} \quad \text{range} \sim 100 \text{ m}$
QDaedalus

- High Precise : < 10 \mu m/m
- Touchless
- Fully Automated
- High Rate Measurements : 30 Hz
- Low-cost
- Open & Flexible Software

QDaedalus: System Components

- Main Components
  - Total Station
  - CCD Sensor
  - Focusing Mechanics
  - Software (Qt c++)

- Additional Components
  - Front Lens (for long range obs. > 13 m)
  - Interface box (CCD Triggering synchronization of multiple system)
  - External GPS Receiver (for Absolute CCD Timing)
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1 pixel = 4 arcsec
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CCD-Space ↔ Theodolite-Space

Calibration
Calibration

Affine Transformation (6 parameters)

\[
\begin{align*}
    r_{\text{object}} &= \frac{1}{\sin \theta_p} \left[ a_{11} \cdot (x_{\text{object}} - x_p) + a_{12} \cdot (y_{\text{object}} - y_p) \right] \\
    z_{\text{object}} &= a_{21} \cdot (x_{\text{object}} - x_p) + a_{22} \cdot (y_{\text{object}} - y_p) \\
    \delta_x &= \frac{1}{\sin \theta_p} \\
    \delta_z &= \frac{1}{\sin \theta_p} \\
\end{align*}
\]

calculated \( \delta_x \) and \( \delta_z \) corrections
Calibration

Identification & Extraction of Objects

Optical Target Recognition
OTR: Least-Squares Template Matching

Precision < 0.1 pixel = 0.4 arcsec = 2.5 μm/m

OTR: Centroid Operator

Precision < 0.1 pixel = 0.4 arcsec = 2.5 μm/m
OTR: Robust Circle Matching Operator

precision $< 0.1$ pixel $= 0.4$ arcsec $= 2.5$ $\mu$m/m

OTR: Robust Ellipse Matching Operator

precision $< 0.1$ pixel $= 0.4$ arcsec $= 2.5$ $\mu$m/m
OTR: Robust Ellipse Matching Operator

precision < 0.1 pixel = 0.4 arcsec = 2.5 μm/m

Practical Experiment of QDaEalus at CERN

Automatic Microtriangulation of Linear Collider Components
Future = electron-positron Linear Collider

Future = electron-positron Linear Collider

→ more than 20,000 modules in total to be measured!
Automatic Microtriangulation

1. Import approximate positions of station and targets
2. Camera, focus, circle matching parameters… definition
3. Start measurements, fully automatic process
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4. Adjust micro-triangulation network

QDaedalus System

Illuminated Ceramic Spheres

Scale Bar

Linear Collider Component

1.5° CCR

reference axis

MCT-C1

MCT-C2

MCZ-C2

ceramic spheres

QDaedalus System
Automatic Microtriangulation

0 m 1 m 2 m

confidence ellipses (1σ) external reliability (σ=5.1)
Automatic Microtriangulation

Empirical standard deviation and differences with respect to the Coordinates Measurement Machine (CMM $\sigma = \pm 1\mu m$) of the points measured with the system QDaedalus.

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Oscillation of a Bridge after Passage of a Truck

Kinematic Measurements with QDaedalus

Measurements carried out by HEIG-VD
Kinematic Measurements

- Daedalus, Vertical Displacements, apodization rate = 15 [Hz]

- Windowed FFT, size of window = 5 [sec]

Summary and Conclusions

The system QDaedalus

- can be mounted without mechanical changes at the Total Station
- enables Optical Target Recognition (OTR) using circle operator and pattern matching
- enables accurate time tagging of the observations
- enables real-time dynamic monitoring of displacements, vibrations, and scintillations
- enables tracking of moving objects with a frame rate of up to 30 Hz including time stamps
- is a versatile tool for numerous indoor and outdoor applications
- further object operators and other improvements are under development
Thanks for attention

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Automatic Microtriangulation

Removing the eyepiece and mounting a CCD camera evokes optical blur

Meas. Range = 1.5 to 13 m
Mounting a divergent lens in front of the objective

Meas. Range = 2 m to $\infty$
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External box for GPS receiver, power input, and Interface cable connections

Signal

Amplitude [mm]

-2 -1 0 1 2 3 4

-20 20 40 60 80 100

time [sec]

FFT of the signal

Amplitude [mm]

0 0.2 0.4 0.6 0.8

0 1 2 3 4 5 6 7

Frequency [Hz]

11 cm

9 cm

11 cm
Evolution of the refraction coefficient during 16 hours across Elbe River

\[ \kappa = \text{const.} = +0.13 \]

Variations of \( \Delta H \) during 16 hours across Elbe River due to Refraction