Beam tracking system using pan-tilt module and MEMS-based fast steering mirror in quantum key distribution

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Abstract

Compact beam tracking system & Tracking performance

- System Configuration
  - **- Coarse tracking : Pan-tilt module + CMOS camera**
  - **- Fine tracking : MEMS-based FSM + Quadrant cell detector**
  - ➢ **Overall size : 15 × 15 × 30 cm** (can be further reduced)
- Performance (tracking speed @ 20 mrad/s)
  - Coarse tracking error : **≤ ±0.62 °**
  - Fine tracking error : **< ±0.072 °**
  - Beam tracking induced coupling loss : **< 2.3 dB**

Introduction

- Quantum key distribution (QKD) : inherent against eavesdropping
- Free-space QKD : wide range according to applications
- Satellite-to-ground QKD (Global-scale QKD)
  - Transmission distance : ~ > 1000 km
  - High performance tracking required ➔ Bulky tracking system
- Short-to-intermediate range QKD
  - QKD for small moving platforms
  - Transmission distance : ~a few kilometers

➔ Requires compact tracking system loadable on small platforms

System configuration

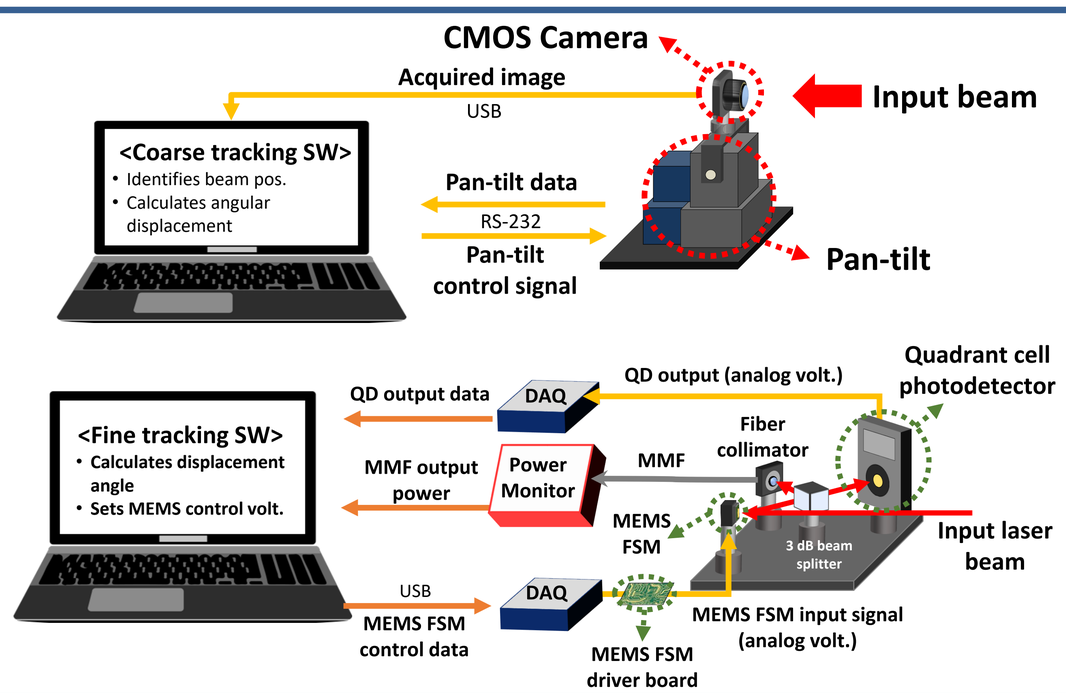
Coarse tracking

➔ Wide-range coarse alignment
- **CMOS camera** : acquires image, sends the image to the SW
- **Coarse tracking SW** : identifies beam pos., calculates angular displacement
- **Pan-tilt** : rotates to the beam position

Fine tracking

➔ Narrow-range precise alignment & beam stabilization
- **Quadrant-cell photodetector (QD)** : detects beam displacement
- **DAQ** : Receives & transmits volt. data
- **Fine tracking SW** : calculates displacement angle & sets MEMS control volt.
- **MEMS FSM & driver** : stabilizes beam displacement
- **Multimode fiber & power monitor** : measures coupling efficiency improvement

➔ **Overall system size : 15 cm × 15 cm × 30 cm**



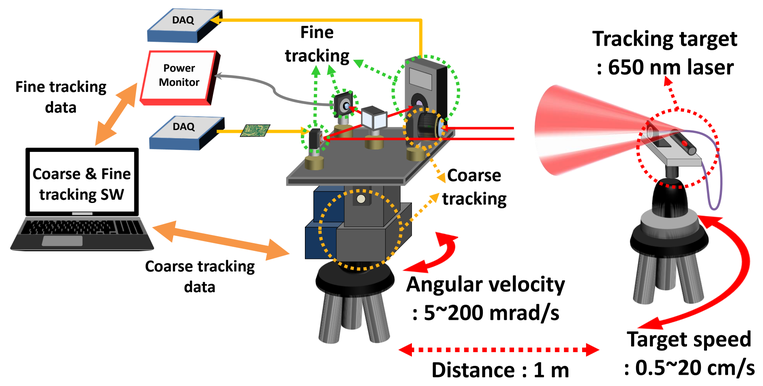
Measurement environment

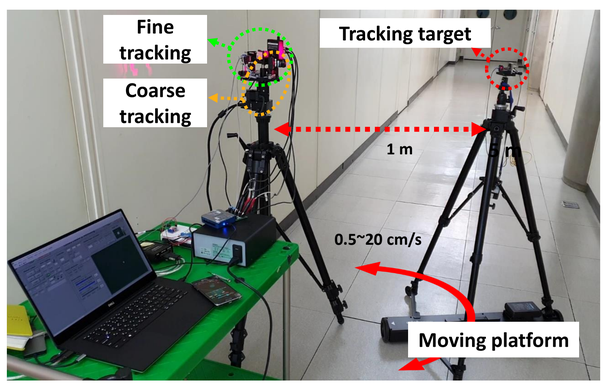
Tracking target

- 650 nm diverging laser
- Moving platform : 1 m distance, 0.5~20 cm/s speed
  - ➔ **Angular speed : 5~200 mrad/s**

Measured parameters

- **Angle displacement(angle error)** (CMOS camera & QD)
- **Coupled optical power** (multi-mode fiber)





Experimental results

Coarse tracking performance

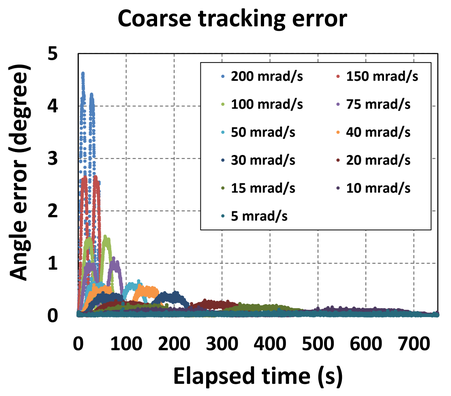
- Angle error increased along with target speed
  - ➔ **20 mrad/s : Instantaneous error : ≤ ±0.62 °, average error : 0.2 °**

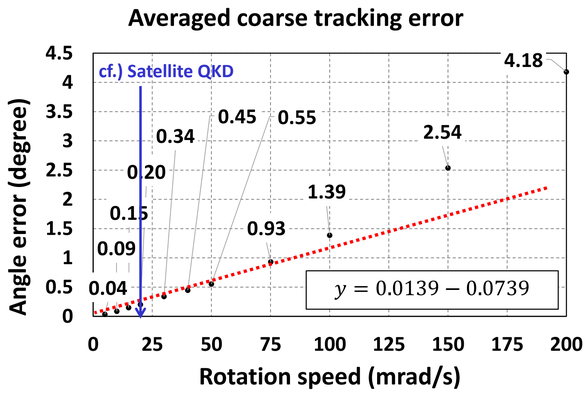
Fine tracking performance

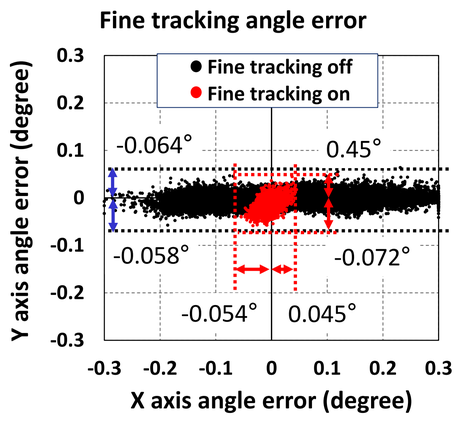
- Target speed : 2 cm/s (coarse tracking 20 mrad/s)
- Angular error
  - Fine tracking OFF : X error > ±0.3 °, Y error < ±0.64 °
  - **- Fine tracking ON : X error : < ±0.054 °, Y error : < ±0.072 °**
  - *(Pugh, C. J. et al., 2017 : tracking error 0.0023° @22 mrad/s, ~ 0.01° @7.9 mrad/s)
- Beam tracking induced MMF coupling loss
  - : Normalized beam power compared to measured max. power
  - Fine tracking OFF : ~ 36.3 dB
  - **- Fine tracking ON : ~ 2.3 dB ➔ Loss improvement : > 30 dB**

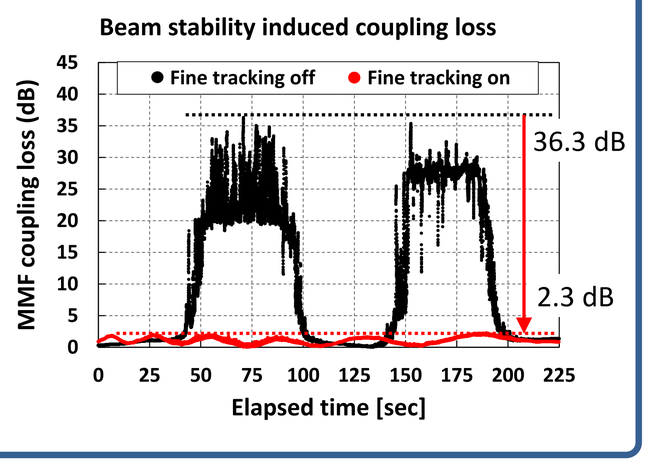
Limiting factors

- Coarse tracking : SW operation speed (~ 75 ms / loop), Pan-tilt delay
  - ➔ Instantaneous coarse tracking error : ~ ±0.62 ° (@ 20 mrad/s)
- Fine tracking : DAQ + MEMS FSM delay (~5 ms + ~5 ms =10 ms)
  - ➔ **Limitation in compensating coarse tracking error**









Conclusion & Future works

- 15 cm × 15 cm × 30 cm beam tracking system
- (Fine) Tracking error: < ±0.072 °
- MMF coupling efficiency improvement: > 30 dB
- Requires improvements in operating speed of SW & electronics and tracking error

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