Field Trail for Covert Rangefinding

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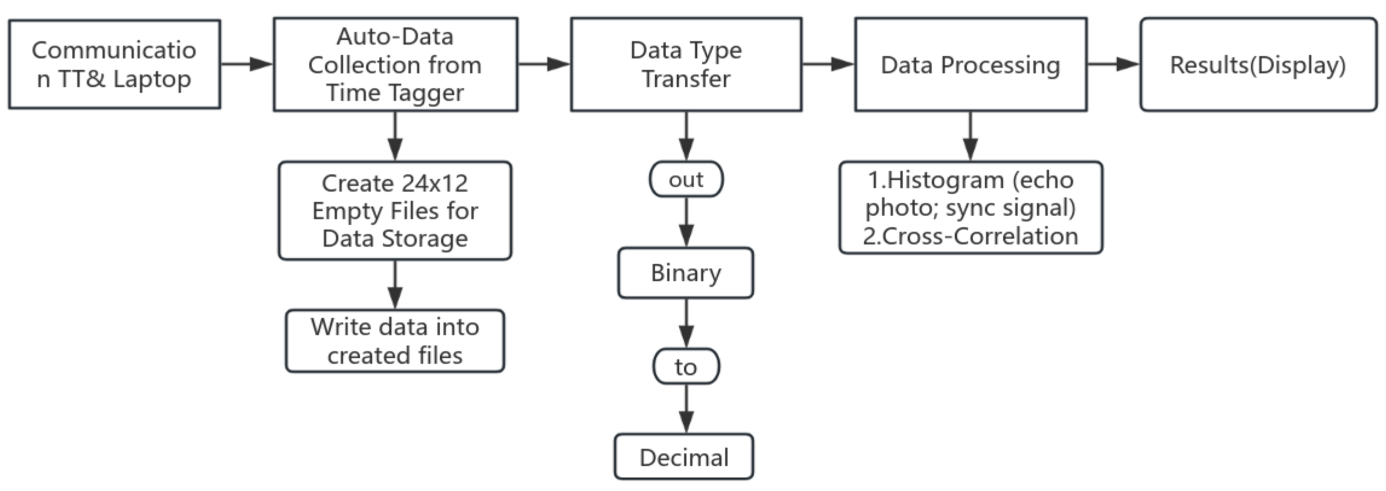
The project is inspired by quantum rangefinding and is using a semi-classical approach (classical for the source and quantum for the detection) to simulate a quantum source. The advantage of quantum illumination in noise reduction comes from the entanglement and correlation of energy and time. In order to enhance detection in noisy environments, we have built energy-time correlation into the developed classical light source so that it maintains the advantage of noise reduction while improving the brightness for remote detection. The experiments focus on long-range detection, and the system's tolerance to solar noise is evaluated in tests up to about 150 metres conducted day and night. The results show that quantum rangefinding has the potential for accurate covert sensing and remote detection under challenging conditions.

Introduction

Quantum rangefinding is an accurate and efficient distance measurement method widely used in navigation, engineering, construction, and military applications[1]. By measuring the time for laser pulses to travel to a target and back, these systems calculate distances using a laser transmitter and a receiver to detect reflections[2].

The research focus of this experiment was to explore the potential of utilising frequency flexibility to propagate signals to multiple wavelengths to enable detection over longer distances, thereby improving response speed and accuracy. Wherever possible, the original code was redeveloped and modified to be as automated as possible to reduce the human effort and errors caused during the experiment. This method has important future applications for remote measurements in complex environments.

Objective and Problems



The experiment begins with data collection at regular intervals, generating a .ptu file. The binary data is then converted to readable decimal form through code for processing and result analysis.

```
T2Record = fread(fid, 1, 'ubit32');     % all 32 bits:
%   +-------------------------------+  +-------------------------------+
%   |x|x|x|x|x|x|x|x|x|x|x|x|x|x|x|x|  |x|x|x|x|x|x|x|x|x|x|x|x|x|x|x|x|
%   +-------------------------------+  +-------------------------------+
dtime = bitand(T2Record,33554431);   % the last 25 bits:
%   +-------------------------------+  +-------------------------------+
%   | | | | | | | |x|x|x|x|x|x|x|x|x|  |x|x|x|x|x|x|x|x|x|x|x|x|x|x|x|x|
%   +-------------------------------+  +-------------------------------+
channel = bitand(bitshift(T2Record,-25),63);   % the next 6 bits:
%   +-------------------------------+  +-------------------------------+
%   | |x|x|x|x|x|x| | | | | | | | | |  | | | | | | | | | | | | | | | | |
%   +-------------------------------+  +-------------------------------+
special = bitand(bitshift(T2Record,-31),1);   % the last bit:
%   +-------------------------------+  +-------------------------------+
%   |x| | | | | | | | | | | | | | | |  | | | | | | | | | | | | | | | | |
%   +-------------------------------+  +-------------------------------+
```

The image above illustrates how Time Tagger stores data in a 32-bit binary structure:
Bits 0-24 : Store dtime (25 bits) for time information.
Bits 25-30: Store channel (6 bits) for channel information.
Bit 31 : Stores special (1 bit) as a flag.
This allocation allows efficient data parsing using bitwise operations like bitand and bitshift.

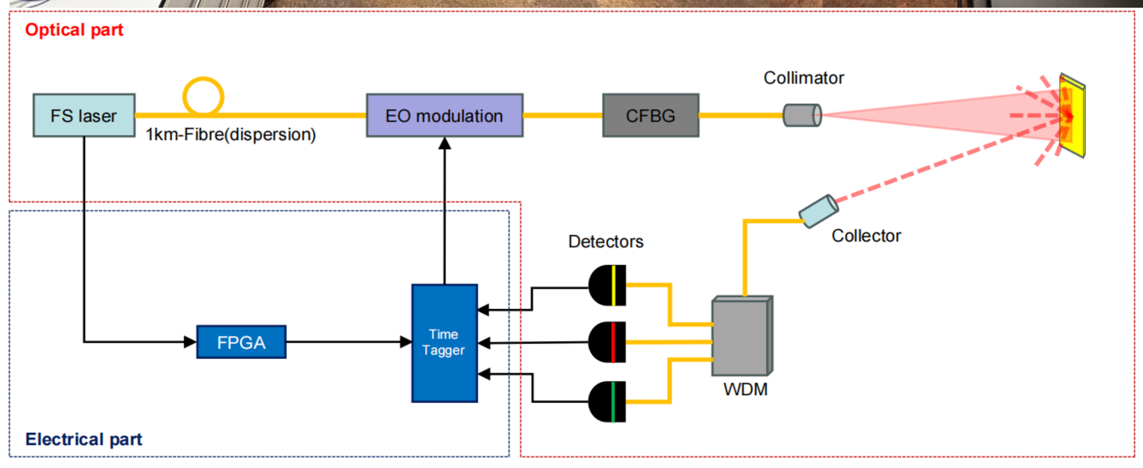
Problems:

Since the data collection equipment (Time Tagger) does not provide automatic data collection, manual data collection is required every 5 minutes for 24 hours. This process is highly labor-intensive and cannot consistently maintain low error levels. Therefore, automated data collection is crucial for ensuring the accuracy of experimental data.

Solutions:

To automate the rangefinding system, the device manipulation code provided by the supplier was modified to create empty .out files. The collected .ptu data was then converted to .out format using Python (or Matlab), chosen for its compatibility and flexibility. This process was automated in a loop with a delay of about 5 minutes between iterations, adjustable as needed. Although data processing algorithms were not fully developed due to time constraints, future work will focus on refining them to improve system accuracy and efficiency.

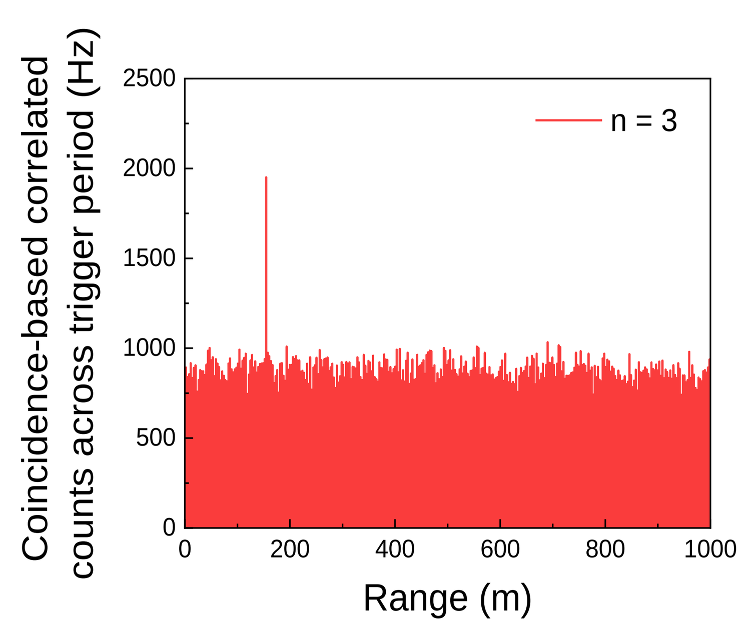
Experimental Setup



The experimental setup uses a femtosecond laser as the light source, which stretches pulses to nanoseconds via a telecommunication fibre. These pulses are modulated into three wavelength channels by an electro-optical modulator controlled by an FPGA board. The pulses are compressed by a chirped fibre Bragg grating to irradiate a Lambertian target at a distance of 154m at Target1 (with the possibility of subsequent measurements at Target2, which is further away). The echo photons are collected by a telescope and single-mode fibre, then separated by a WDM before being recorded by three single-photon detectors[3].

Results

$$R = \frac{c * \Delta t}{2}$$



The location of the peak is the measured distance to the external wall of Wills Building.

It is determined using a coincidence-based cross-correlation method, which calculates the cross-correlation between the normalized reference signal and the detected echo photons from the three energy channels.

Conclusion and Future Plan

The experiment demonstrated effective noise reduction under strong solar background and high transmission loss of approximately 100 dB using a quantum-inspired energy-time correlation method. While accurate ranging was not the main focus, the results highlight its robustness in challenging conditions. To enable near real-time processing, the algorithm could be implemented in C++ to calculate ranges during data collection intervals. Real-time processing would require handling data within the collection duration, typically between 0.1 and 1 second.

Reference

[1] Frick, S. (2019). Quantum rangefinding. Doctoral Thesis, Doctor of Philosophy (PhD).
[2] Buller, G. S., Harkins, R. D., McCarthy, A., Hiskett, P. A., MacKinnon, G. R., Smith, G. R., & Rarity, J. G. (2005). Multiple wavelength time-of-flight sensor based on time-correlated single-photon counting. Review of Scientific Instruments, 76(8).
[3] W.Nie, et al. (2023). Quantum-inspired frequency-agile rangefinding. Optica British and Irish Conference on Optics and Photonics(BICOP 2023).

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