Object Tracking and Identification by Quantum Radar

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Abstract

Quantum Radar is a promising technology that could have a strong impact on the civilian and military realms. In this study we introduce a new concept design for implementing a Quantum Radar, based on the time and polarization correlations of the entangled photons for detection and identification and tracking of high-speed targets. The design is focused on extracting high resolution details of the target with precision timing of entangled photons that provides important operational capabilities like distinguishing a target from a decoy. Time correlations of the photon detection events can be extracted via cross-correlation operation between two sets of photon detection time-tags for the entangled photons. The fact that the wavelengths of the entangled photons can be tuned also makes the Quantum Radar concept an enticing candidate for tracking stealth objects. We present the proof-of-principle test results of the Quantum Radar and discuss the technical challenges and limitations of the design.

Concept And Design Concern

Our quantum radar design uses entangled photons. The design does not focus on the sensitivity only and uses coincidence detection and entanglement property; based on statistical signal processing on timing of reflected single photons and violation of Bells inequality, respectively, to distinguish between a real target and a decoy. This requires Radars time measurements resolution extremely high in a way that its limit is our time-stamp hardwares resolution and relativistic effects of the fast-moving target on time-of-flight. In this approach, targets are discriminated by using successive cross correlation of received photon timings with multiple Doppler shifted and relativistic time dilated replicas to evaluate targets range, speed and form.

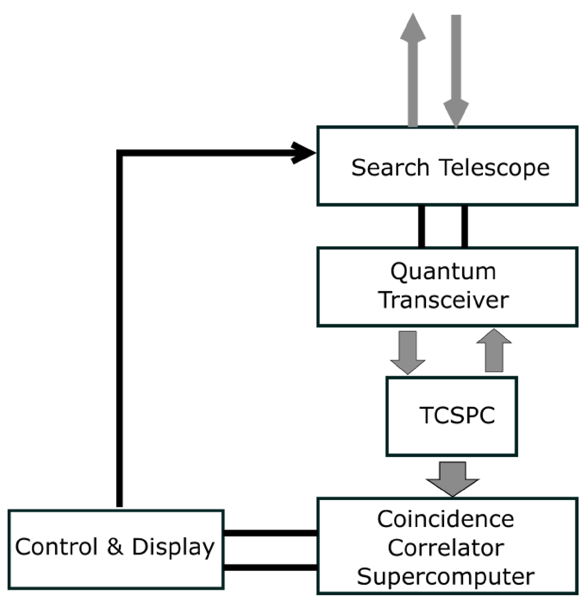

Figure 1: Block diagram of quantum radar design.

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Quantum Radar Concept

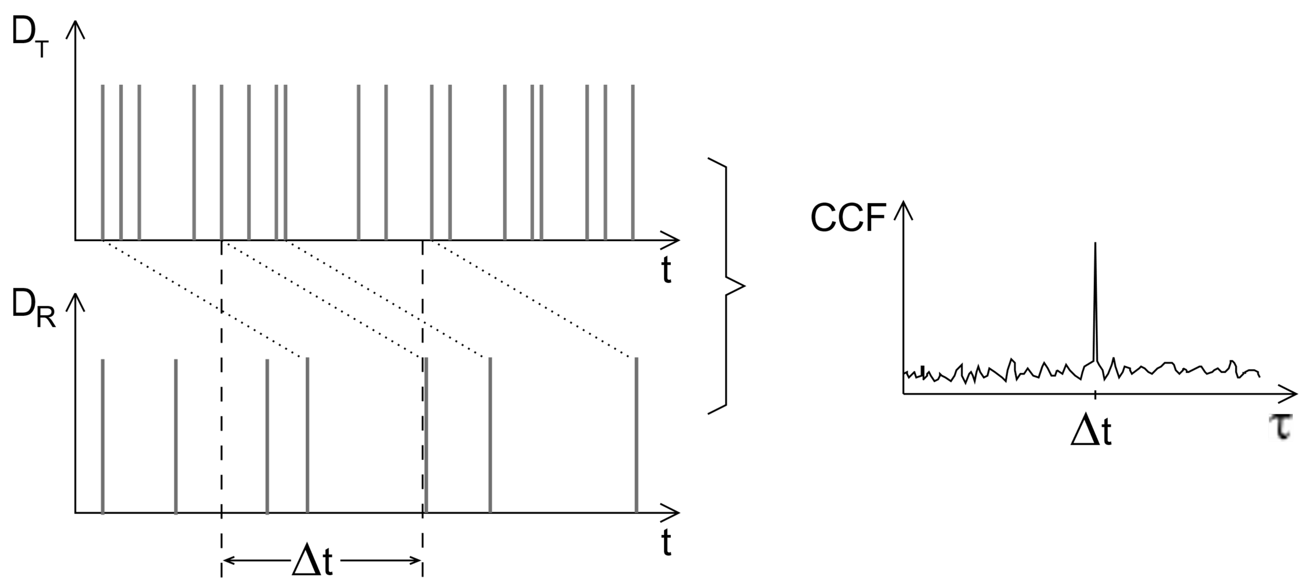

Figure 2: Extracting the target range by cross correlation of timing signals.

As shown in Figure 2 the Radar repeatedly sends single photons to space by a telescope and evaluates the received photons in the following way:
◦ One of the photon pairs, say signals, are kept as reference and their compressive timing table are recorded,;
◦ Transmitter sends N idler photons and makes a combination of delta functions as a time signal (Fig.2)
◦ When the idler photons are back-scattered from the object, they are captured by the telescope and the receiver digitizes the output signal of the detectors;
◦ Receiver calculates the cross-correlation function for all possible time delays, doppler shifts and all possible relativistic time dilations;
◦ The receiver finds the peak of the cross-correlation function revealing the precise round-trip transit time of the single photon.

Jam and Decoy Resistance of Quantum Radar

As an example of Air Launched Decoys, The MALD-J version has electronic jammers. Yet the Quantum Radar can even detect even these decoys.

Figure 3: Raytheon's Miniature Air Launched Decoy (MALD)

Experiment and Results

In this setup, we use an entangled photon source for illumination of the test object. While one arm of the pairs are measured by single photon counter and their time-stamp information is kept as reference, the others are sent into free-space for a possible object detection. Only a small portion of the reflected photons from the object are received by the telescope and they are also detected. The received photons timing is captured by the event timer of the time-stamp unit.
Figure 3 shows the schematic of the experimental setup.

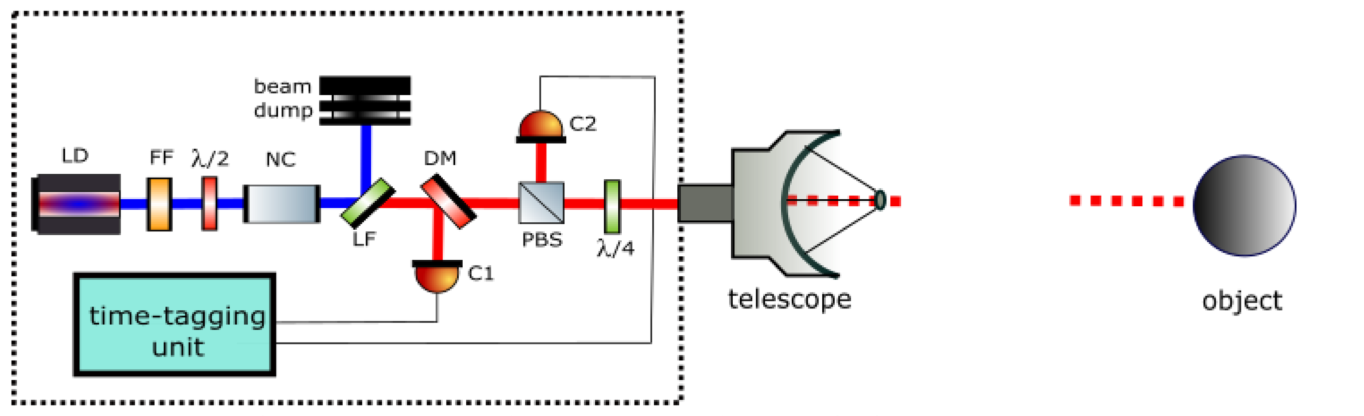

Figure 4: Schematic of the experimental setup to test the proof-of-principle quantum radar concept

The coincidence rates are measured by finding the correct time delay between entangled photons by cross-correlation operation.

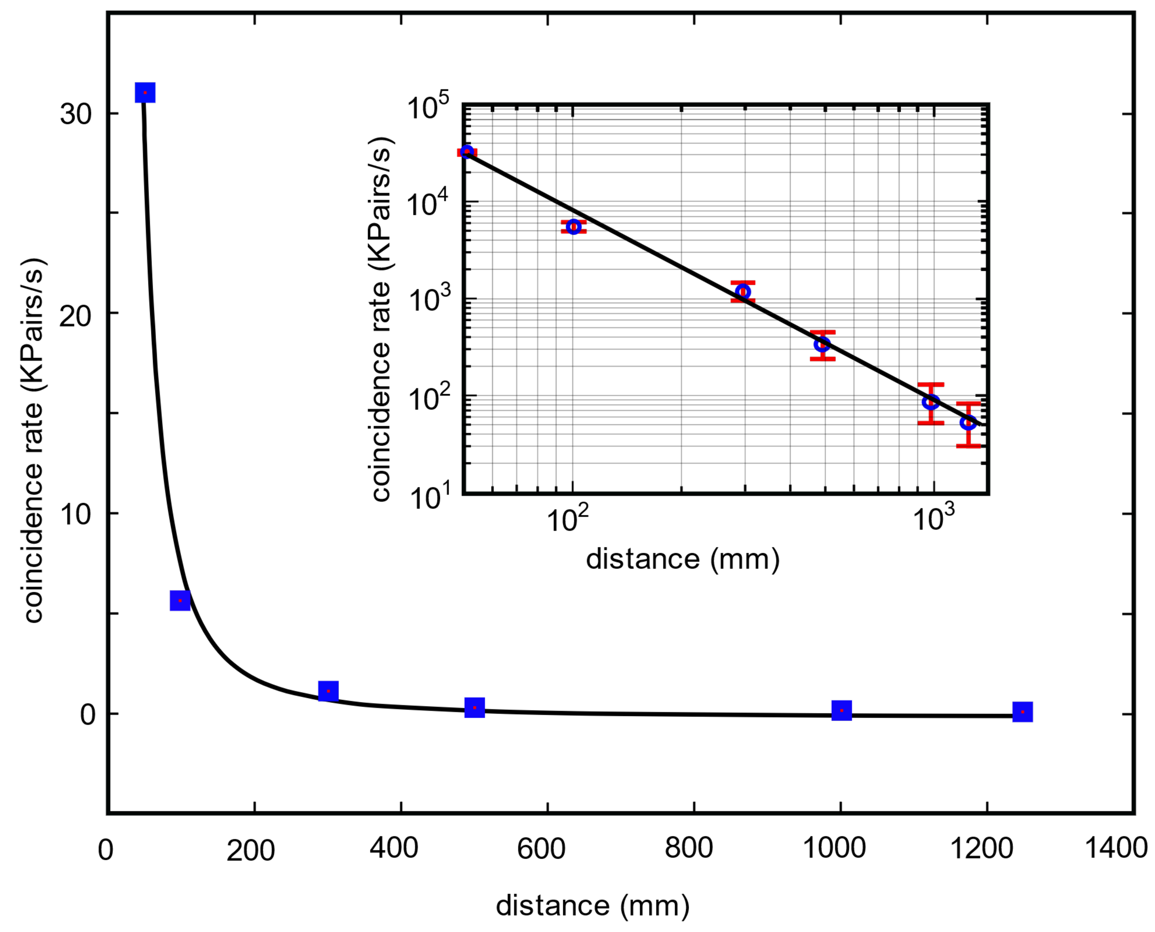

Figure 5: Cross-correlogram delay values are converted to distance. The solid black line shows the theoretical fit to the experimental data. The inset shows the logarithmic scale for the ease of reading.

Fig.-5 The coincidence rates are measured by finding the correct time delay between entangled photons by cross-correlation operation. The fit follows the equation of the form $f(x) = b + a/x^2$.
The experimental data and its extrapolation indicates that with the existing APD technologies the maximum achievable range for a Quantum Radar would be below 1 km if the target to be detected is coated with black anodized aluminum. However, different materials with better scattering and lower absorption may allow higher range target detection. The diameter of the telescope extends the working range quadratically.

Conclusion

In this design and experiment we have explained the electronic warfare superiority of a specially designed Quantum Radar for distinction between targets and decoys. We showed that by using this approach, we can use the statistical nature of photon scattering from a target in a relatively large field-of-view to extract precise information of the target geometry required for distinctive correlations. Although it has superior performance on being undetectable and identifying decoys, the current electro-optic technology limits the Quantum Radar design range to few hundreds of meters with centimeter scale telescope aperture. With more advances in APD technology and large telescope aperture the presented design will be a promising technology.

References

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