

FIRE CONTROL METHOD AND SYSTEM

FIELD AND BACKGROUND OF THE INVENTION

5 The present invention relates to a method and system of fire control and, more particularly, to a fire control method and system for a tank gun, or the like, that is mounted on a platform such as a tank turret.

 Tank fire control includes a series of operations, the purpose of which is to aim the tank's gun so as to hit the target. If the first shot does not hit the target,
10 adjustments must be made in the gun's aim in the quickest and most accurate way. While many efforts have been made in the art to facilitate hitting the target with the first shot, no efficient process and/or apparatus is at present available for permitting a single tank to adjust its fire when the first shot has failed to hit. Fire adjustments are difficult to effect by a single tank for many reasons, including the shocks due to the
15 firing, the difficulty of observing the impact of the projectiles if they do not produce an explosion or, even if they do produce an explosion, because of the presence of dust, the period of time that must pass between the observation of the projectile impact and the firing of the next projectile with an adjusted aim, and so forth. As a result, fire control must be entrusted to a station separate from the tank or at least requires the
20 collaboration of at least one other tank, and even these means do not provide as prompt an adjustment of the aim as would be desirable. This is very disadvantageous from the viewpoint of the operational autonomy and of the firing efficiency of the tanks.

There is thus a widely recognized need for, and it would be highly advantageous to have, a method and system of tank fire control that would enable the crew of a tank to correct the aim of the tank's gun autonomously.

SUMMARY OF THE INVENTION

5 It is a purpose of this invention to provide a fire control system for a tank's gun that is entirely autonomous and does not require the collaboration of a separate fire control station or of another tank.

It is another purpose of the invention to provide such a system that permits rapid and accurate adjustment of the gun's aim on the part of the tank's crew.

10 It is a further purpose of the invention to provide such a system that permits automatic adjustment of the gun's aim on the part of the gun's firing system.

It is a still further purpose of the invention to provide such a system that does not require visual observation of the projectile's impact. Indeed, the present invention can initiate correction of the aim of the gun even before projectile impact.

15 It is a still further purpose of the invention to provide such a system that is not adversely affected by the firing shocks and by the presence of dust.

Therefore, according to the present invention there is provided a method of aiming a gun that is mounted on a platform and that has fired a projectile at a target, the firing of the gun causing the platform to vibrate, including the steps of: (a)
20 tracking the projectile and the target, using a tracking device, at least a portion whereof is operationally connected to the platform; and (b) inferring an aim error vector from the tracking.

Furthermore, according to the present invention there is provided A fire control system for a gun that is mounted on a platform and that fires a projectile at a

target, including: (a) an antenna that is operationally connected to the platform; (b) a transmitter for transmitting projectile-tracking RF pulses and target-tracking RF pulses via the antenna; (c) a receiver for receiving echoes of the RF pulses via the antenna; and (d) a signal processor for receiving signals, representative of the echoes,
5 from the receiver and transforming the signals into measurement vectors for the projectile and the target.

The term "trajectory" is used herein to refer to the position and velocity of an object, specifically, of the projectile or of the target, as a function of time. Typically, the trajectory of the projectile is a ballistic trajectory, and the trajectory of the target is
10 whatever motion, if any, the target executes. In the special case of a stationary target, the target trajectory is simply the fixed position of the target.

The scope of the present invention includes methods and systems of autonomous fire control for any platform-mounted gun. Nevertheless, the focus of the description herein is on autonomous fire control for a tank, in which the platform on
15 which the gun is mounted is the turret of the tank. According to the present invention, at least a portion of a tracking device, for example, the antenna of a radar tracking system, is mounted on the platform. After the gun is fired at the target, and preferably after the vibration (shock) of firing has substantially stopped, the tracking device is used to track both the projectile, in flight, and the target. This tracking allows the
20 determination, in real time, of the trajectory of the projectile and the deviation of that trajectory from the trajectory of the target. An aim error vector, that includes an azimuth error and an elevation error, is inferred from this deviation, and the gun is moved to correct its aim accordingly.

Preferably, the portion of the tracking device, that is mounted on the platform, is mounted rigidly thereon.

Preferably, the tracking device is based on radar, the antenna whereof is rigidly mounted on the platform. Most preferably, the antenna is a two-way monopulse antenna. A transmitter transmits, via the antenna, alternately, Doppler RF pulses for tracking the projectile and linear frequency modulated (chirp) pulses for tracking the target. A receiver receives echoes of the pulses via the antenna and provides signals representative of the echoes, typically Σ signals, Δ_{Az} signals and Δ_{El} signals, to a signal processor. The signal processor uses a CFAR method to discriminate echoes from the projectile and the target from clutter echoes, and transforms the signals corresponding to projectile echoes and target echoes to measurement vectors of the projectile's instantaneous position and velocity and of the target's instantaneous position and velocity. These measurement vectors are input to a post-processor, in which a Kalman filter uses the measurement vectors to update corresponding state vectors. The state vector of the projectile defines the projectile's trajectory. The state vector of the target defines the target's trajectory. The post-processor computes the amount by which the projectile's trajectory misses the target's trajectory and infers therefrom the aim error vector.

Preferably, a synchronizer coordinates the transmission of the RF pulses and the reception of the echoes thereof, and also coordinates the alternation between projectile-tracking pulses and target-tracking pulses.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

The sole FIGURE is a schematic depiction of a system of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a fire control method and system which can be used to correct the aim of a platform-mounted gun, that has fired a projectile at a target, while the projectile is in flight. Specifically, the present invention can be used to adjust the aim of a tank gun autonomously.

The principles and operation of fire control according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, the sole Figure is a schematic illustration of a system of the present invention, as applied to fire control for the firing of a gun mounted on a turret of a tank.

Also mounted on turret is a two-way monopulse antenna. Preferably, antenna is mounted rigidly on turret. As used herein, the term "mounted rigidly" means that antenna may be rigidly attached to turret, so that antenna points in a direction determined exclusively by the orientation in space of turret; but also means that antenna may alternatively be mechanically steerable by virtue of being mounted on a mount, such as an altazimuth mount, that in turn is rigidly attached to turret. Preferably, if antenna is rigidly attached to turret, then the

field of view of antenna **20** is at least 15 mrad in azimuth and at least 32 mrad in elevation.

A transmitter **22** generates radio frequency (RF) pulses that are launched by antenna **20** towards the projectile and towards the target. Specifically, transmitter **22** alternates between generating Doppler pulses, that are used to track the projectile, and linear frequency modulated (chirp) pulses, that are used to track the target. Preferably, the RF pulses are in the Ka band. Echoes of the RF pulses are received, via antenna **20**, by a receiver **24**. The received echoes are downconverted in frequency and, in the case of the received chirp echoes, also dechirped. The echoes thus received are passed by receiver **24** to a signal processor **28** as analog signals, specifically, Σ , Δ_{Az} and Δ_{El} signals. Signal processor **28** digitizes the analog signals and processes the digitized signals by standard methods. In particular, the signals preferably are processed using Fast Fourier Transforms (FFTs) of appropriate lengths. The FFT length for processing the projectile-echo signals depends on the Doppler pulse repetition frequency and on the required Doppler resolution, which is on the order of one meter per second. Typically, this length is in the hundreds (256 or 512). The FFT length for processing the target echo signals also typically is in the hundreds. A constant false alarm rate (CFAR) method is used to discriminate projectile echoes and target echoes from clutter echoes.

The output of the processing in signal processor **28** is, for each projectile echo, a measurement vector M_P whose components are projectile range, projectile azimuth, projectile elevation, and three components (range, azimuth, elevation) of the projectile velocity vector; and, for each target echo, a measurement vector M_T whose components are target range, target azimuth, target elevation, and, optionally, three

components (range, azimuth and elevation) of the target velocity vector. Projectile range is determined from the round-trip travel time of the projectile echo. Projectile azimuth and elevation are determined from appropriate processing of the corresponding Σ , Δ_{Az} and Δ_{El} signals. The range component of the projectile velocity vector is determined from the Doppler shift of the projectile echo. The azimuth and elevation components of the projectile velocity vector are determined from the numerical time derivative of the azimuth and elevation components of successive projectile echoes. Target range is determined from the round-trip travel time of the target echo. Target azimuth and elevation are determined from appropriate processing of the corresponding Σ , Δ_{Az} and Δ_{El} signals. Optionally, the three components of the target velocity vector are determined from the numerical time derivative of the range, azimuth and elevation components of successive target echoes.

A synchronizer **26** coordinates the activities of transmitter **22** and receiver **24**. Specifically, for each projectile-tracking pulse or target-tracking pulse launched by transmitter **22**, synchronizer **26** activates receiver **24** only in a corresponding time gate during which a corresponding echo from the projectile or from the target is expected to arrive at antenna **20**. In addition, synchronizer **26** causes transmitter **22** to alternate between transmitting projectile-tracking pulses (Doppler) and target-tracking pulses (chirp). Preferably, the projectile and the target are tracked almost concurrently, with the time interval between the transmission of a projectile-tracking pulse and a target-tracking pulse being on the order of a few milliseconds. Preferably, successive sightings of the projectile and of the target are effected at a rate of about 100 Hz (100 times per second). The total number of sightings depends on the type of projectile and on the type of target, but preferably is at least about 100.

Tracking of the projectile and of the target is not initiated until the shock of the firing of gun 14 has substantially dissipated. Typically, this time interval between the firing of gun 14 and the initiation of tracking is several tenths of a second.

Signal processor 26 passes the measurement vectors M_P and M_T to a post-processor 30. Post-processor 30 uses these measurement vectors as input to a predictor-corrector algorithm for updating state vectors that represent estimates of the true positions and velocities of the projectile and of the target. The preferred predictor-corrector algorithm is a Kalman filter. The components of the state vectors correspond to the components of the measurement vectors: the components of the projectile state vector are the projectile range, the projectile azimuth, the projectile elevation, and time derivatives thereof (*i.e.*, the projectile velocity vector); and the components of the target state vector are the target range, the target azimuth, the target elevation, and, optionally, time derivatives thereof (*i.e.*, the target velocity vector). The state vectors are initialized when gun 14 is fired. The initial position of the projectile is at gun 14. The initial velocity of the projectile is the muzzle velocity of the projectile. The illustrated analog components (antenna 20, transmitter 22, receiver 24) also serve as components of a target acquisition radar system (not shown) that is used to acquire the target and aim gun 14 at the target before gun 14 is fired; and the initial state vector of the target is obtained from this target acquisition system.

As noted above, the state vectors of the projectile and of the target define the trajectories of the projectile and of the target. Based on these trajectories, post-processor 30 computes an azimuth error and an elevation error for gun 14. The azimuth error is simply the difference between the azimuth of the projectile trajectory, projected out to the range of the target, and the azimuth of the target. The elevation

error is the difference between the actual elevation of the gun and the elevation that would be required for the two trajectories to intersect if there were no azimuth error. This elevation error is computed by post-processor **30** using well-known ballistic equations. The azimuth error and the elevation error are the components of an aim error vector for gun **14**. Note that, even before the projectile impacts, the ballistic equations may be used to predict the remaining trajectory of the projectile. Meanwhile, the future behavior (until projectile impact) of the target may be predicted on the basis of the observed behavior of the target. Therefore, the aim error vector may be computed while the projectile is still in flight.

Post-processor **30** passes the aim error vector along to the crew of tank **10**. The crew of tank **10** corrects the aim of gun **14** in accordance with the aim error vector. Alternatively, if tank **10** is equipped with an automatic system for aiming gun **14**, post-processor **30** sends the aim error vector to the automatic aiming system, which automatically corrects the aim of gun **14**.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

WHAT IS CLAIMED IS:

1. A method of aiming a gun that is mounted on a platform and that has fired a projectile at a target, the firing of the gun causing the platform to vibrate, comprising the steps of:
 - (a) tracking the projectile and the target, using a tracking device, at least a portion whereof is operationally connected to the platform; and
 - (b) inferring an aim error vector from said tracking.
2. The method of claim 1, wherein said portion of said tracking device is rigidly mounted on the platform.
3. The method of claim 1, wherein said tracking is begun after the vibration of the platform has substantially stopped.
4. The method of claim 1, wherein said aim error vector includes an azimuth error and an elevation error.
5. The method of claim 1, further comprising the step of:
 - (c) moving the gun to compensate for said aim error vector.
6. The method of claim 1, wherein said tracking device includes radar.

7. The method of claim 6, wherein said portion of said tracking device that is operationally connected to the platform includes an antenna.

8. The method of claim 6, wherein said tracking is effected by steps including:

- (i) transmitting a plurality of projectile-tracking RF pulses towards the projectile;
- (ii) for each said projectile-tracking RF pulse, receiving an echo of said projectile-tracking RF pulse from the projectile;
- (iii) transmitting a plurality of target-tracking RF pulses towards the target; and
- (iv) for each said target-tracking RF pulse, receiving an echo of said target-tracking RF pulse from the target.

9. The method of claim 8, wherein said projectile-tracking RF pulses are Doppler pulses.

10. The method of claim 8, wherein said target-tracking RF pulses are linear frequency modulated pulses.

11. The method of claim 8, wherein said transmitting of said projectile-tracking RF pulses alternates in time with said transmitting of said target-tracking RF pulses.

12. The method of claim 8, wherein said receiving of said echoes of said projectile-tracking RF pulses from the projectile includes the step of discriminating between:

- (A) said echoes of said projectile-tracking RF pulses from the projectile
and
- (B) clutter echoes of said projectile-tracking RF pulses.

13. The method of claim 12, wherein said discriminating is effected using a CFAR method.

14. The method of claim 8, wherein said receiving of said echoes of said target-tracking RF pulses from the target includes the step of discriminating between:

- (A) said echoes of said target-tracking RF pulses from the target and
- (B) clutter echoes of said target-tracking RF pulses.

15. The method of claim 14, wherein said discriminating is effected using a CFAR method.

16. The method of claim 8, wherein said tracking further includes the step of:

- (v) processing said received echoes of said projectile-tracking RF pulses from the projectile to provide, for each said received echo of said projectile-tracking RF pulse from the projectile, a projectile measurement vector.

17. The method of claim 16, wherein said projectile measurement vector includes:

- (A) a measured range to the projectile;
- (B) a measured projectile azimuth;
- (C) a measured projectile elevation; and
- (D) a measured projectile velocity vector.

18. The method of claim 16, wherein said tracking further includes the step of:

- (vi) updating an estimate of a projectile state vector, based on said projectile measurement vector.

19. The method of claim 18, wherein said projectile state vector includes:

- (A) a range to the projectile;
- (B) a projectile azimuth;
- (C) a projectile elevation; and
- (D) a projectile velocity vector.

20. The method of claim 19, wherein said updating is effected using a Kalman filter.

21. The method of claim 8, wherein said tracking further includes the step of:

- (v) processing said received echoes of said target-tracking RF pulses from the target to provide, for each said received echo of said target-tracking RF pulse from the target, a target measurement vector.

22. The method of claim 21, wherein said target measurement vector includes:

- (A) a measured range to the target;
- (B) a measured target azimuth; and
- (C) a measured target elevation.

23. The method of claim 22, wherein said target measurement vector further includes:

- (D) a measured target velocity vector.

24. The method of claim 21, wherein said tracking further includes the step of:

- (vi) updating an estimate of a target state vector, based on said target measurement vector.

25. The method of claim 24, wherein said target state vector includes:

- (A) a range to the target;
- (B) a target azimuth; and
- (C) a target elevation.

26. The method of claim 25, wherein said target state vector further includes:

- (D) a target velocity vector.

27. The method of claim 24, wherein said updating is effected using a Kalman filter.

28. A fire control system for a gun that is mounted on a platform and that fires a projectile at a target, comprising:

- (a) an antenna that is operationally connected to the platform;
- (b) a transmitter for transmitting projectile-tracking RF pulses and target-tracking RF pulses via said antenna;
- (c) a receiver for receiving echoes of said RF pulses via said antenna; and
- (d) a signal processor for receiving signals, representative of said echoes, from said receiver and transforming said signals into measurement vectors for the projectile and the target.

29. The fire control system of claim 28, wherein said antenna is rigidly mounted on the platform.

30. The fire control system of claim 28, wherein said antenna is a two-way monopulse antenna.

31. The fire control system of claim 28, wherein said projectile-tracking RF pulses are Doppler pulses.

32. The fire control system of claim 28, wherein said target-tracking RF pulses are linear frequency modulated pulses.

33. The fire control system of claim 28, wherein said signals include Σ signals, Δ_{AZ} signals and Δ_{EI} signals.

34. The fire control system of claim 28, further comprising:

(e) a synchronizer for synchronizing said transmitting of said RF pulses and said receiving of said echoes of said RF pulses.

35. The fire control system of claim 28, further comprising:

(e) a post-processor for updating state vectors of the projectile and the target, based on said measurement vectors.

36. The fire control system of claim 35, wherein said updating is effected using a Kalman filter.

37. The fire control system of claim 35, wherein said post-processor is further operative to transform said state vectors into an aim error vector.