US 20200166310A1

(19) United States
(12) Patent Application Publication
SULLIVAN
(10) Pub. No.: US 2020/0166310 A1
(43) Pub. Date: May 28, 2020

(54) APPARATUS AND METHODOLOGY FOR TRACKING PROJECTILES AND IMPROVING THE FIDELITY OF AIMING SOLUTIONS IN WEAPON SYSTEMS

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(21) Appl. No.: 16/573,170

(22) Filed: Sep. 17, 2019

Related U.S. Application Data

(60) Division of application No. 15/228,255, filed on Aug. 4, 2016, now abandoned, which is a continuation-in-part of application No. 14/220,404, filed on Mar. 20, 2014, now abandoned.

(60) Provisional application No. 62/201,255, filed on Aug. 5, 2015, provisional application No. 61/803,826, filed on Mar. 21, 2013.

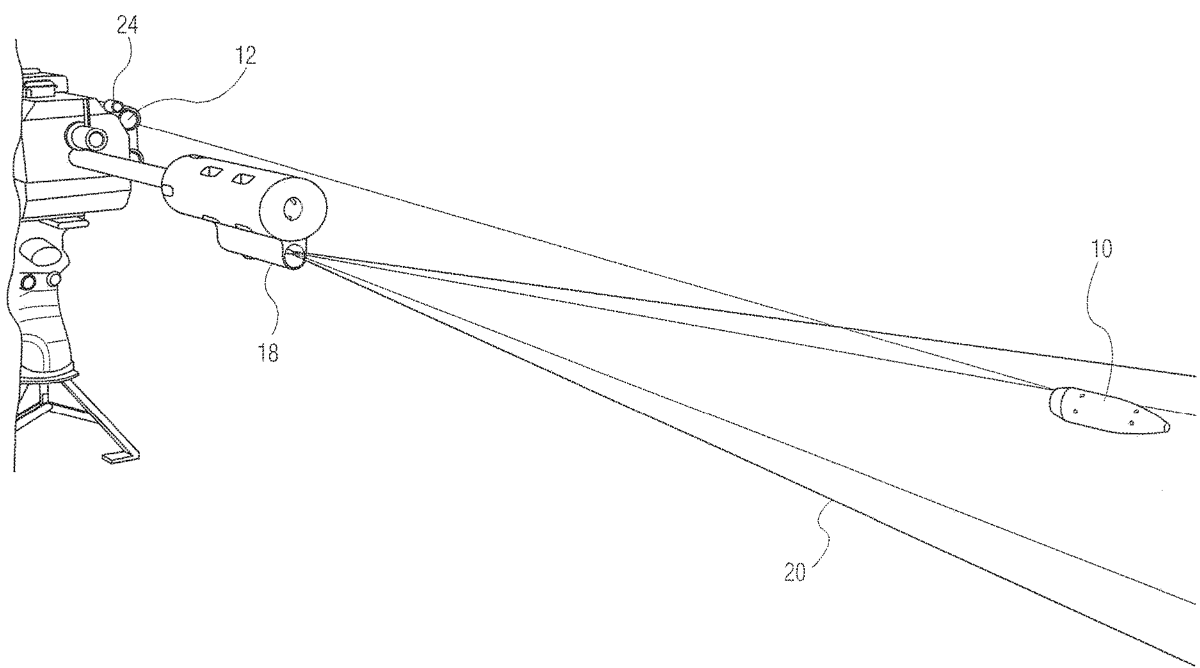
Publication Classification

(51) Int. Cl.
F41G 3/14 (2006.01)
F41G 3/16 (2006.01)
F42B 12/38 (2006.01)

(52) U.S. Cl.
CPC ***F41G 3/142*** (2013.01); ***F42B 12/387*** (2013.01); ***F41G 3/165*** (2013.01)

(57) ABSTRACT

A system for tracking projectiles in flight and correcting the aim of a firearm or cannon. The system allows for the observation and recording of the ballistic path of projectiles which are coated with a fluorescent die or affixed with retro-reflectors. Laser emitted radiation, preferably strobed, forms a cone of light that intersects with ballistic path of the projectile. It is possible to measure the drift and drop of an illuminated projectile at time or distance intervals. Marksman, snipers or spotters may use the system to adjust the placement of subsequent shots. An automated system may use optical detectors to measure the reflected light beam and may be coupled with a regressive algorithm to produce improved fire control solutions. Such automated systems use the measured projectiles to calculate the influence of wind on the projectile and allow for the measurement and registration of other occasion to occasion errors.



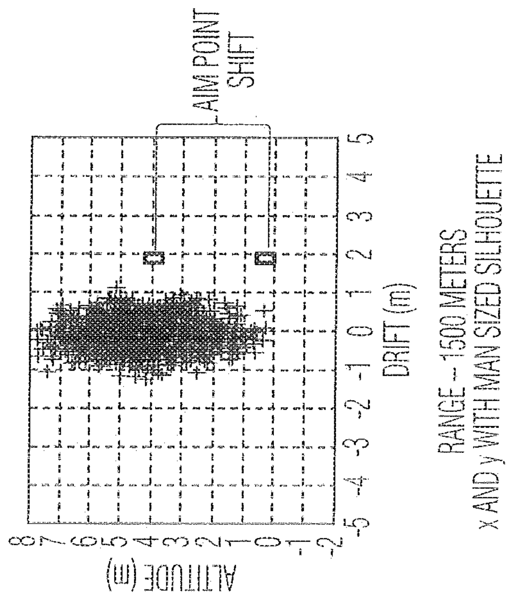


FIG. 1C

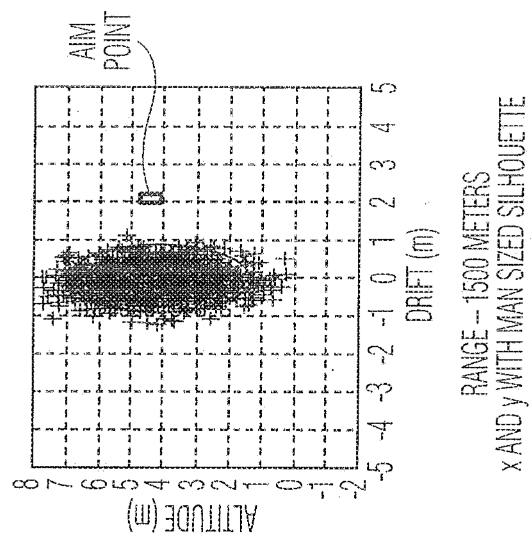


FIG. 1B

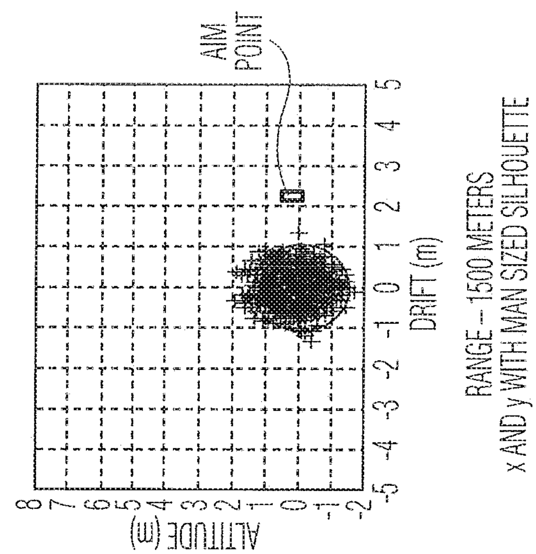


FIG. 1A

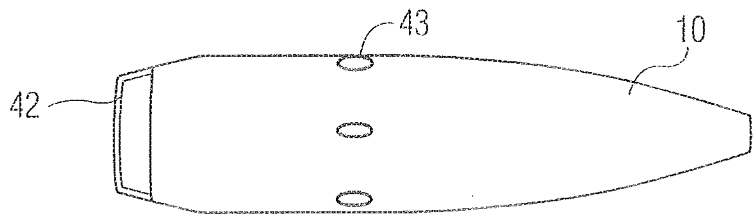


FIG. 2A

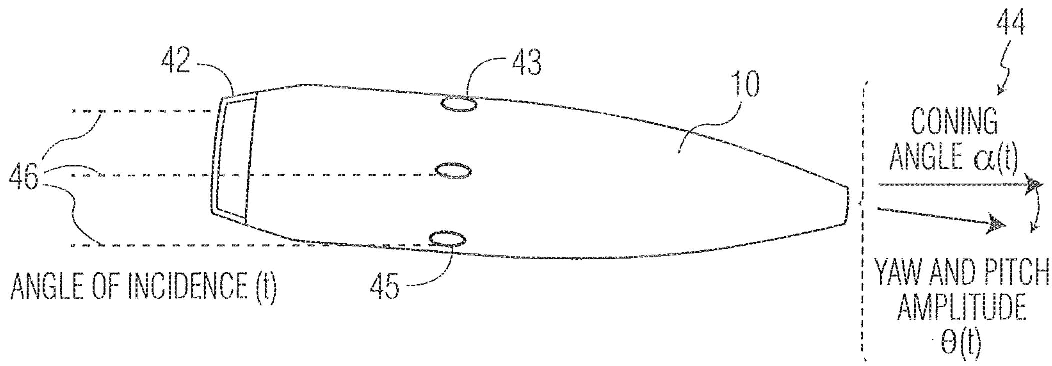


FIG. 2B

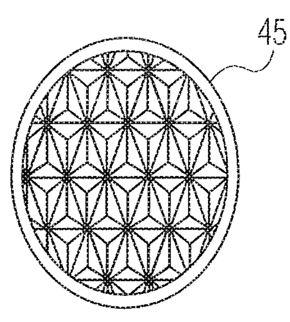


FIG. 2C

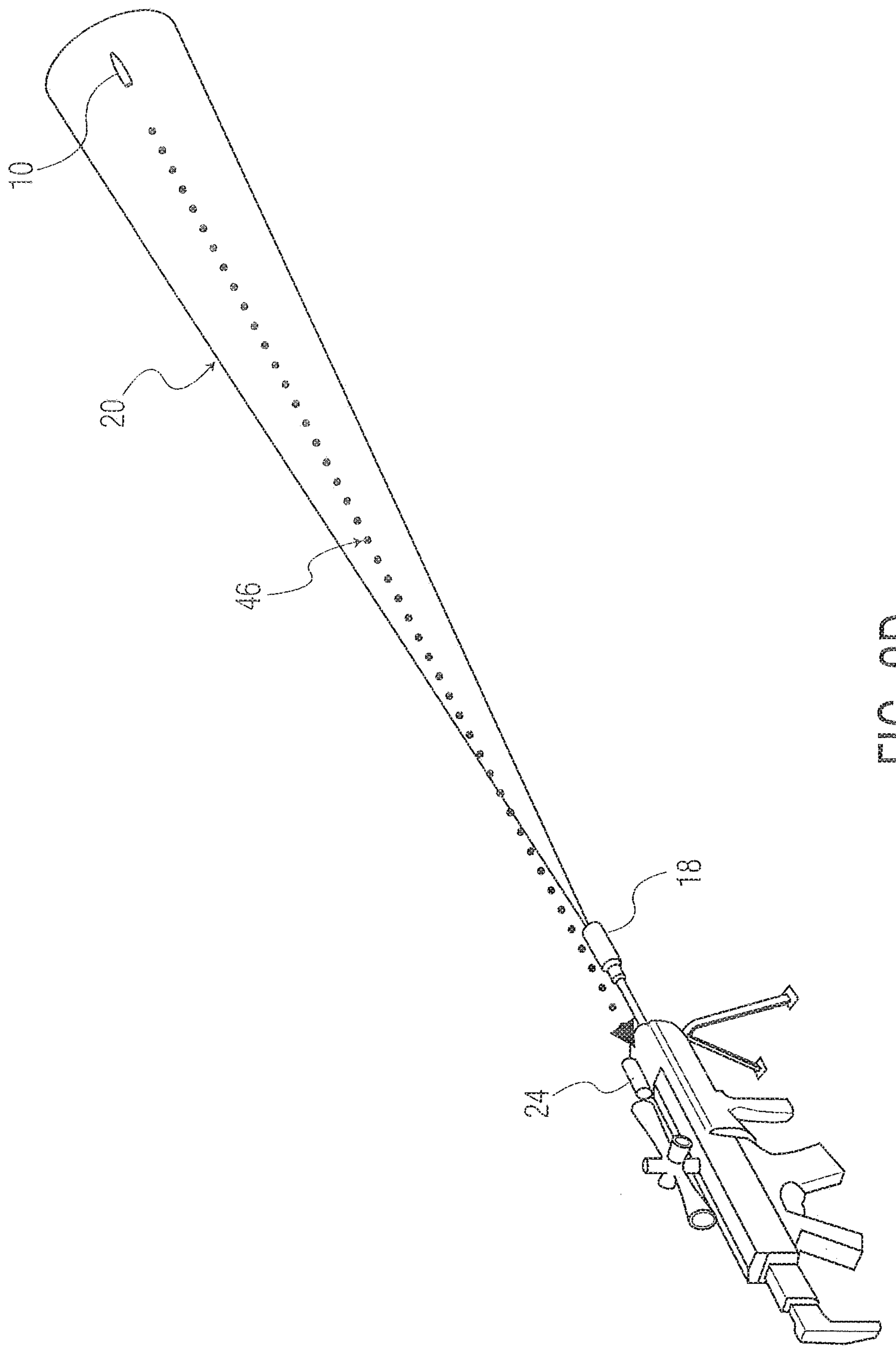


FIG. 2D

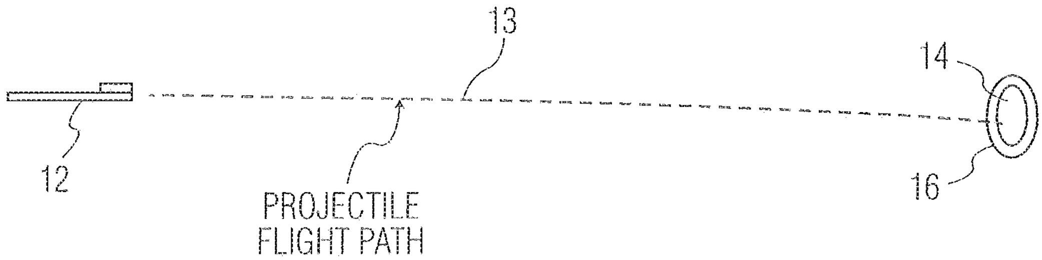


FIG. 3

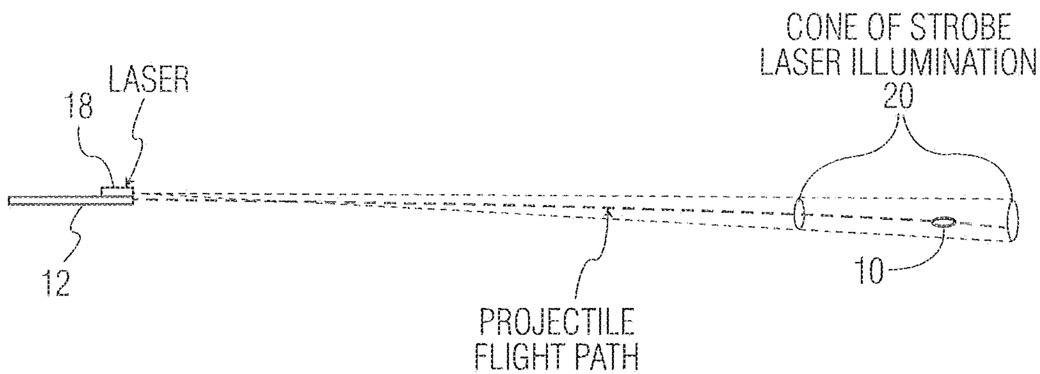


FIG. 4

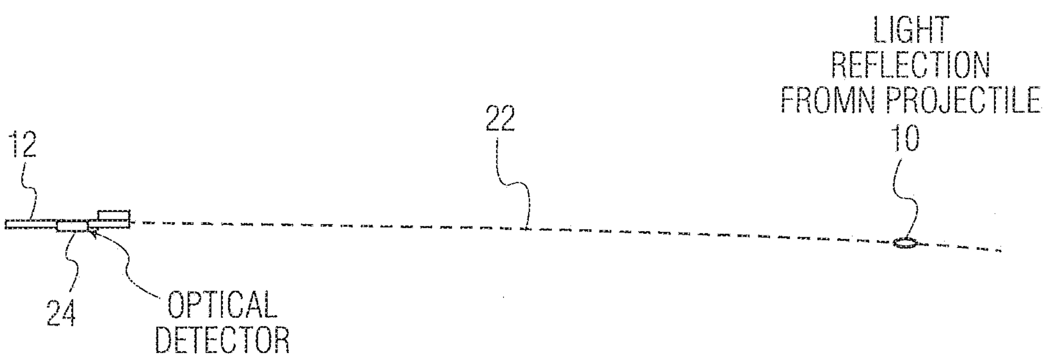


FIG. 5

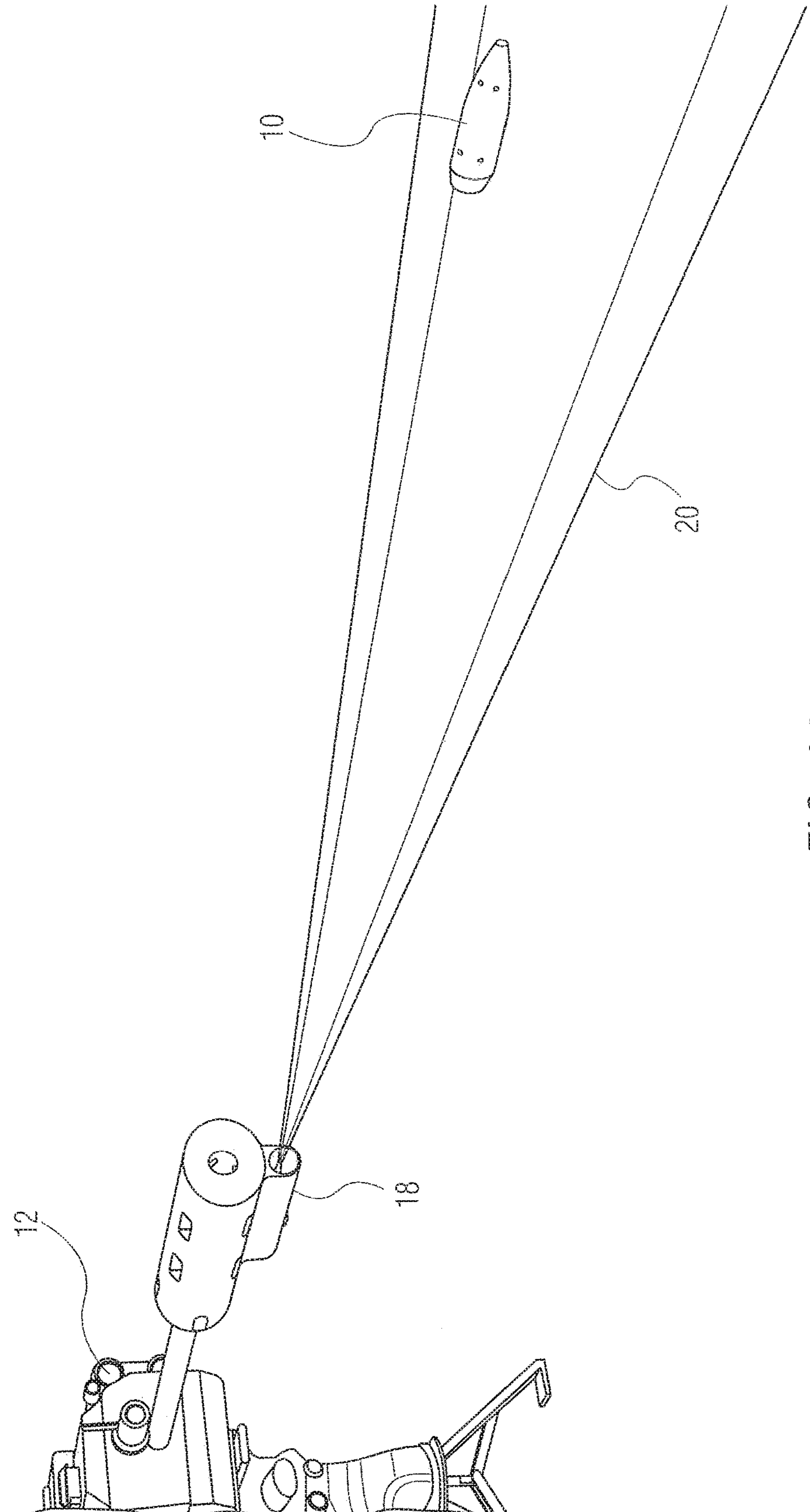


FIG. 6A

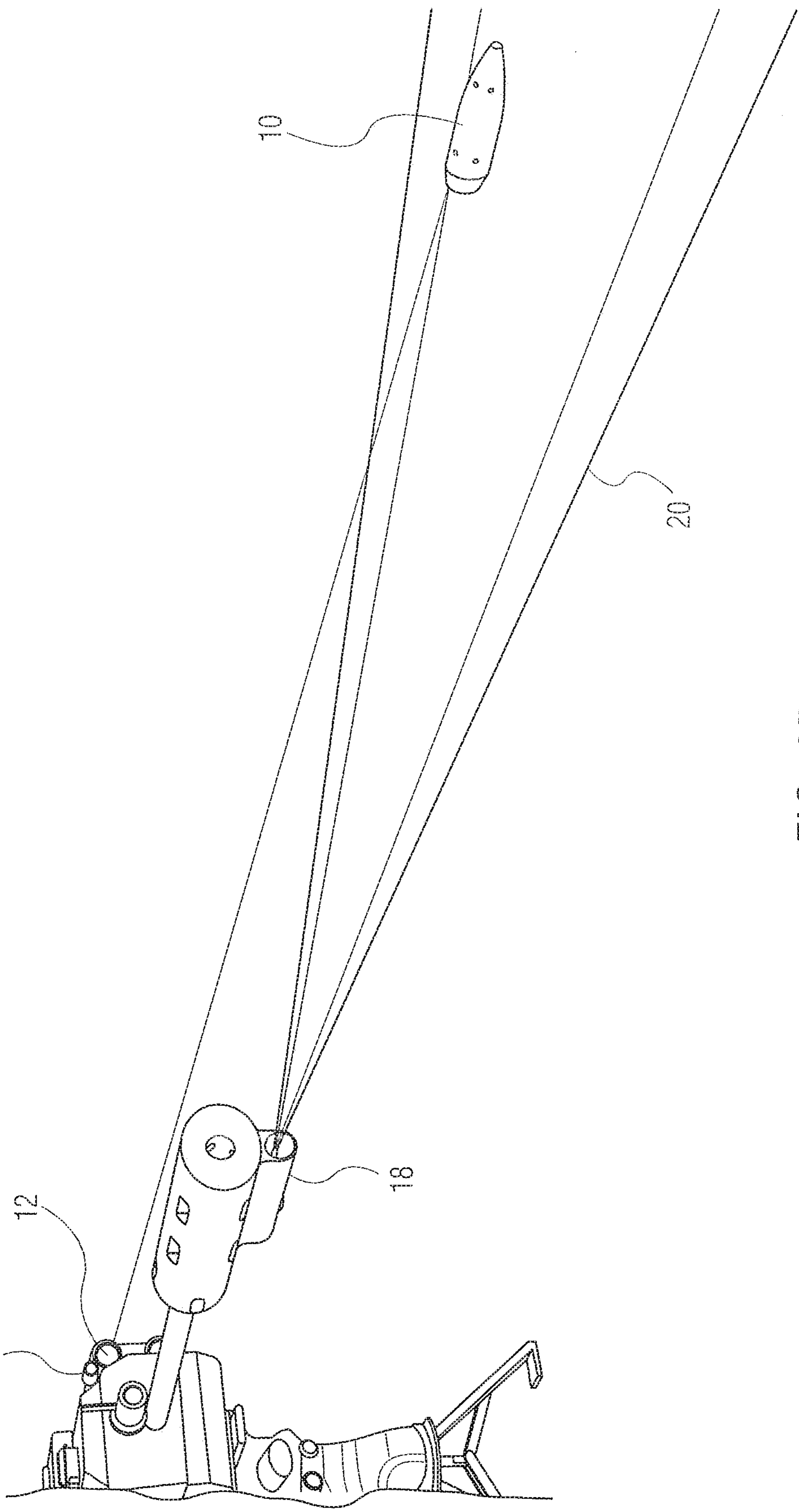


FIG. 6B

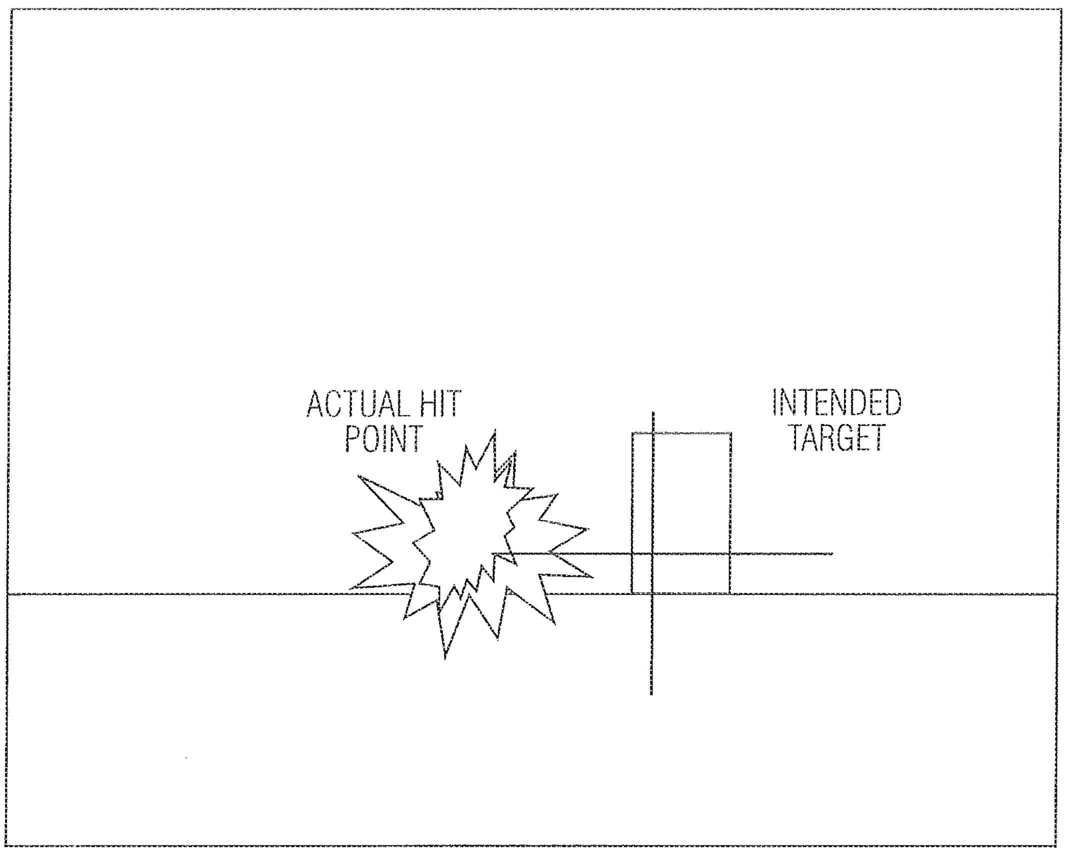


FIG. 7

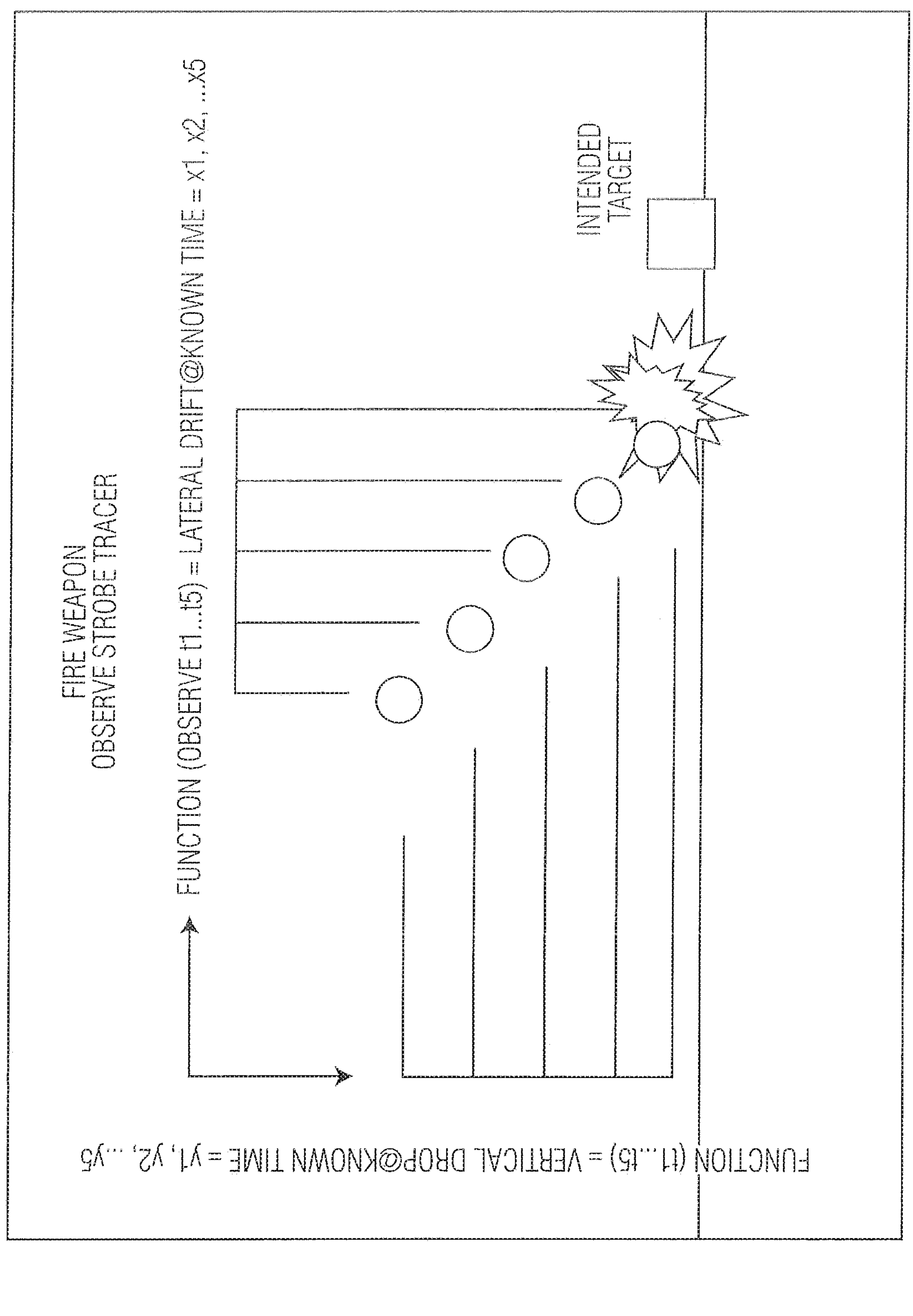

FIRE WEAPON
OBSERVE STROBE TRACER
FUNCTION (OBSERVE t1...t5) = LATERAL DRIFT@KNOWN TIME = x1, x2, ...x5
INTENDED TARGET
FUNCTION (t1...t5) = VERTICAL DROP@KNOWN TIME = y1, y2, ...y5

FIG. 8

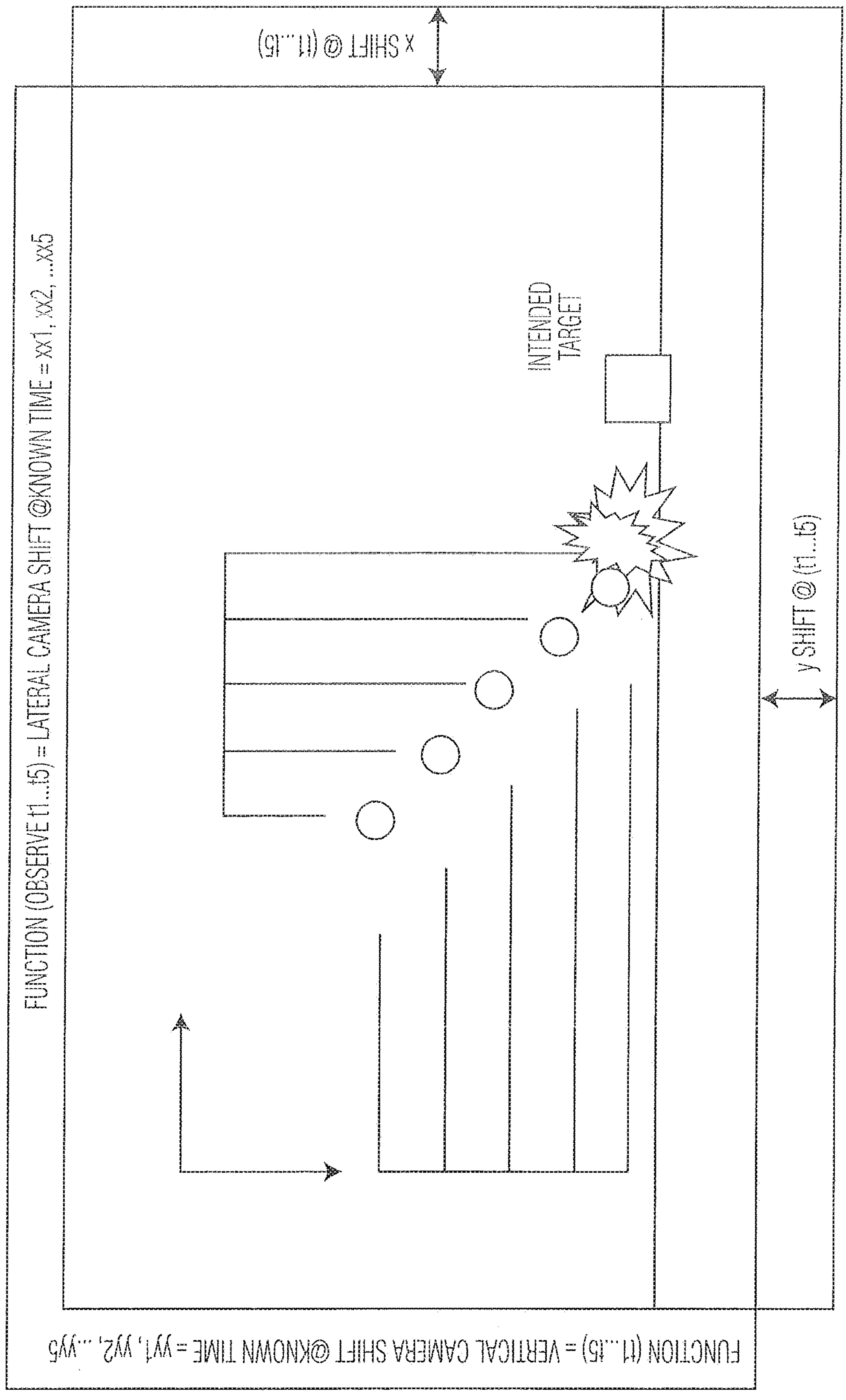

FUNCTION (OBSERVE t1...t5) = LATERAL CAMERA SHIFT @KNOWN TIME = xx1, xx2, ...xx5
x SHIFT @ (t1...t5)
INTENDED TARGET
y SHIFT @ (t1...t5)
FUNCTION (t1...t5) = VERTICAL CAMERA SHIFT @KNOWN TIME = yy1, yy2, ...yy5

FIG. 9

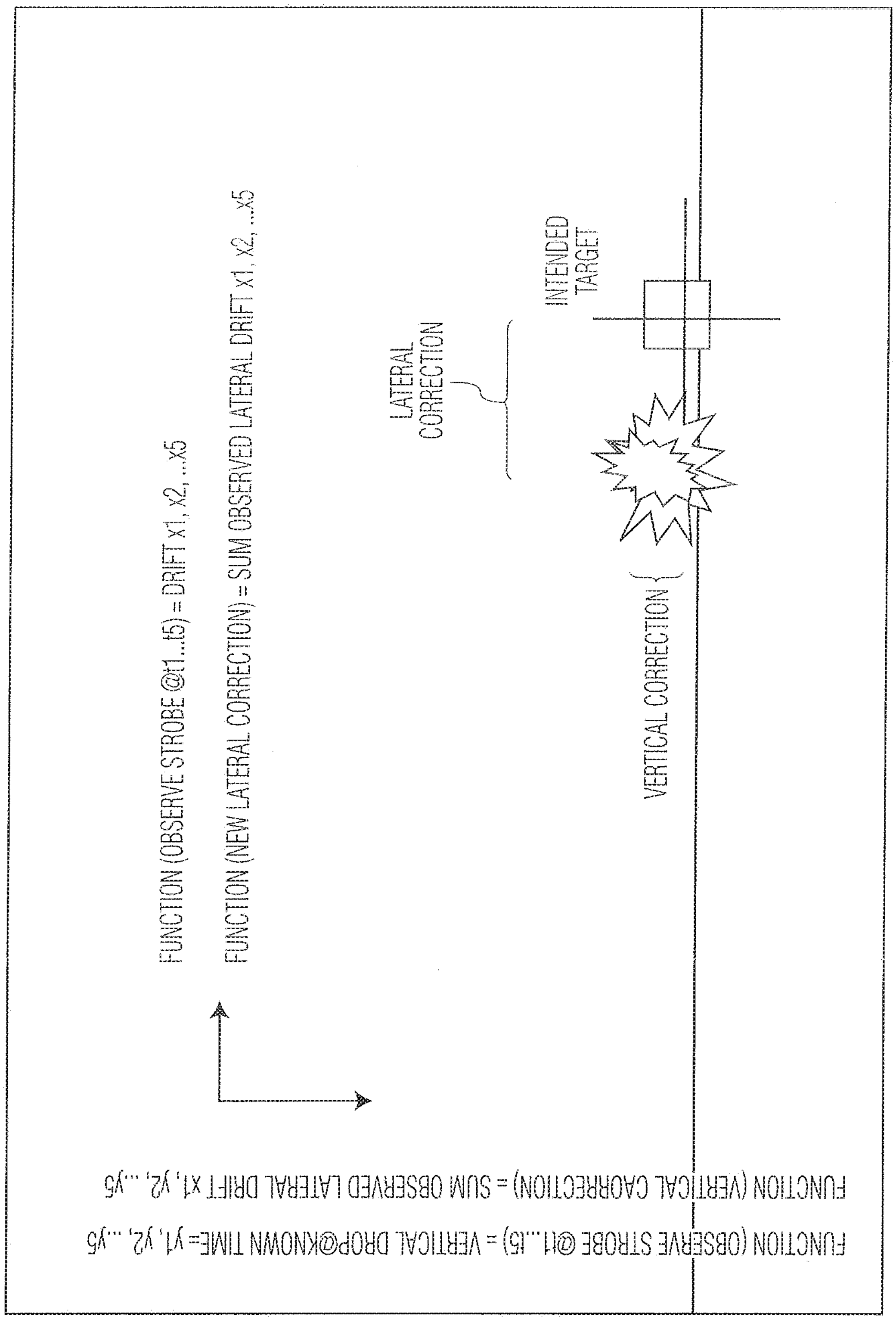

FUNCTION (OBSERVE STROBE @t1...t5) = DRIFT x1, x2, ...x5
FUNCTION (NEW LATERAL CORRECTION) = SUM OBSERVED LATERAL DRIFT x1, x2, ...x5
LATERAL CORRECTION
INTENDED TARGET
VERTICAL CORRECTION
FUNCTION (VERTICAL CAORRECTION) = SUM OBSERVED LATERAL DRIFT x1, y2, ...y5
FUNCTION (OBSERVE STROBE @t1...t5) = VERTICAL DROP@KNOWN TIME= y1, y2, ...y5

FIG. 10

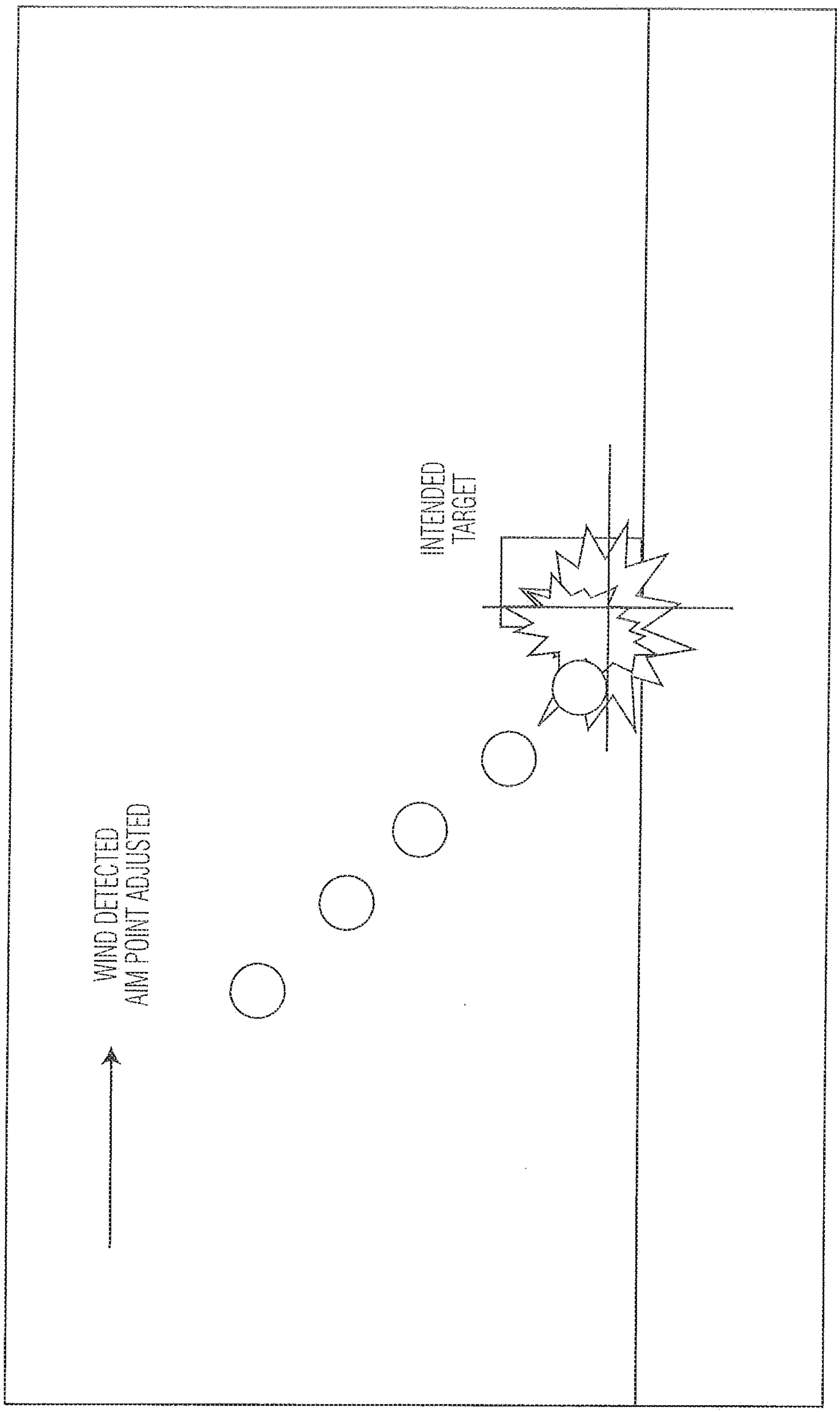


FIG. 11

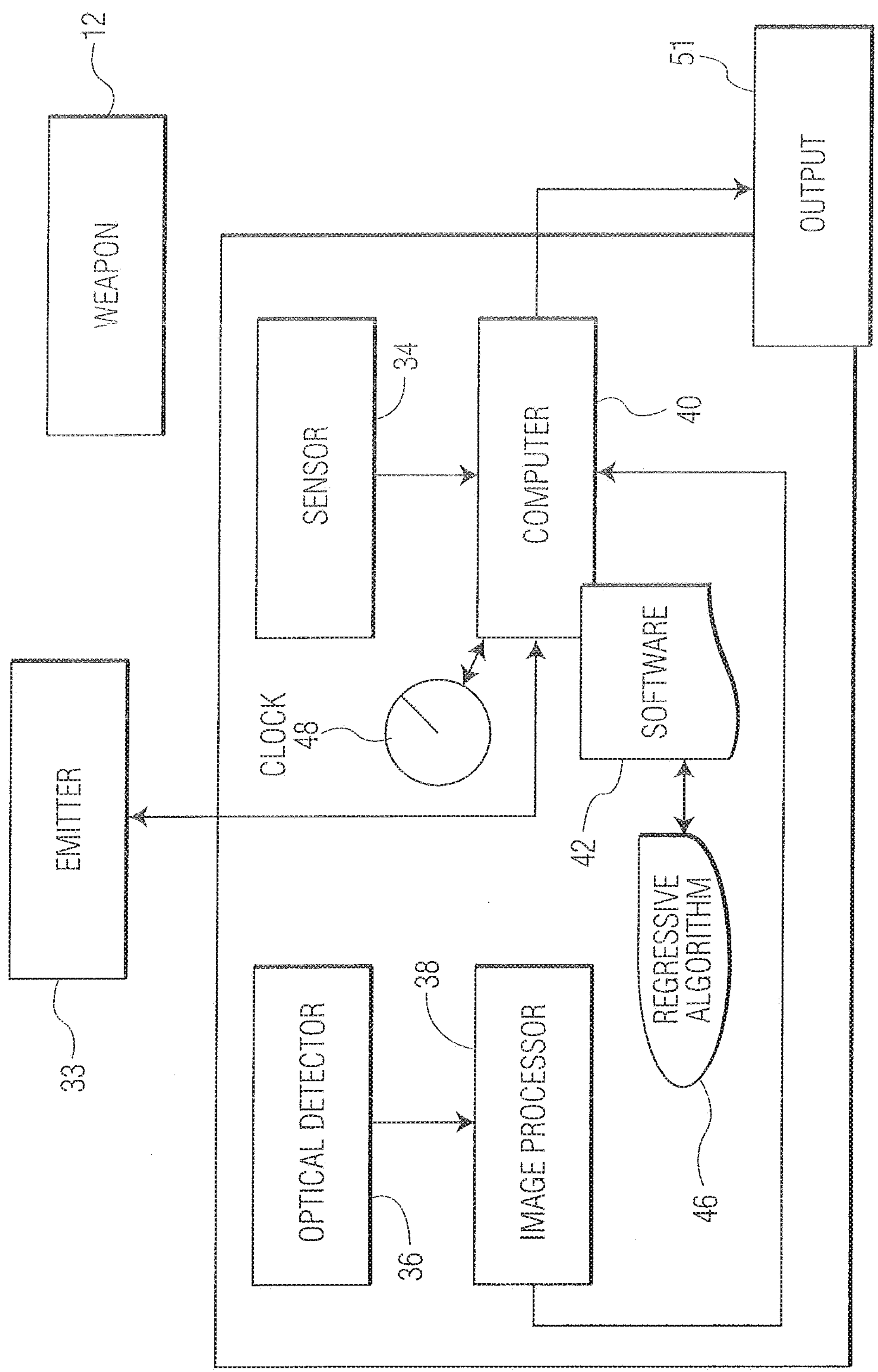

12
WEAPON
51
OUTPUT
34
SENSOR
COMPUTER
40
SOFTWARE
42
CLOCK
48
EMITTER
33
OPTICAL DETECTOR
36
38
IMAGE PROCESSOR
REGRESSIVE
ALGORITHM
46

FIG. 12

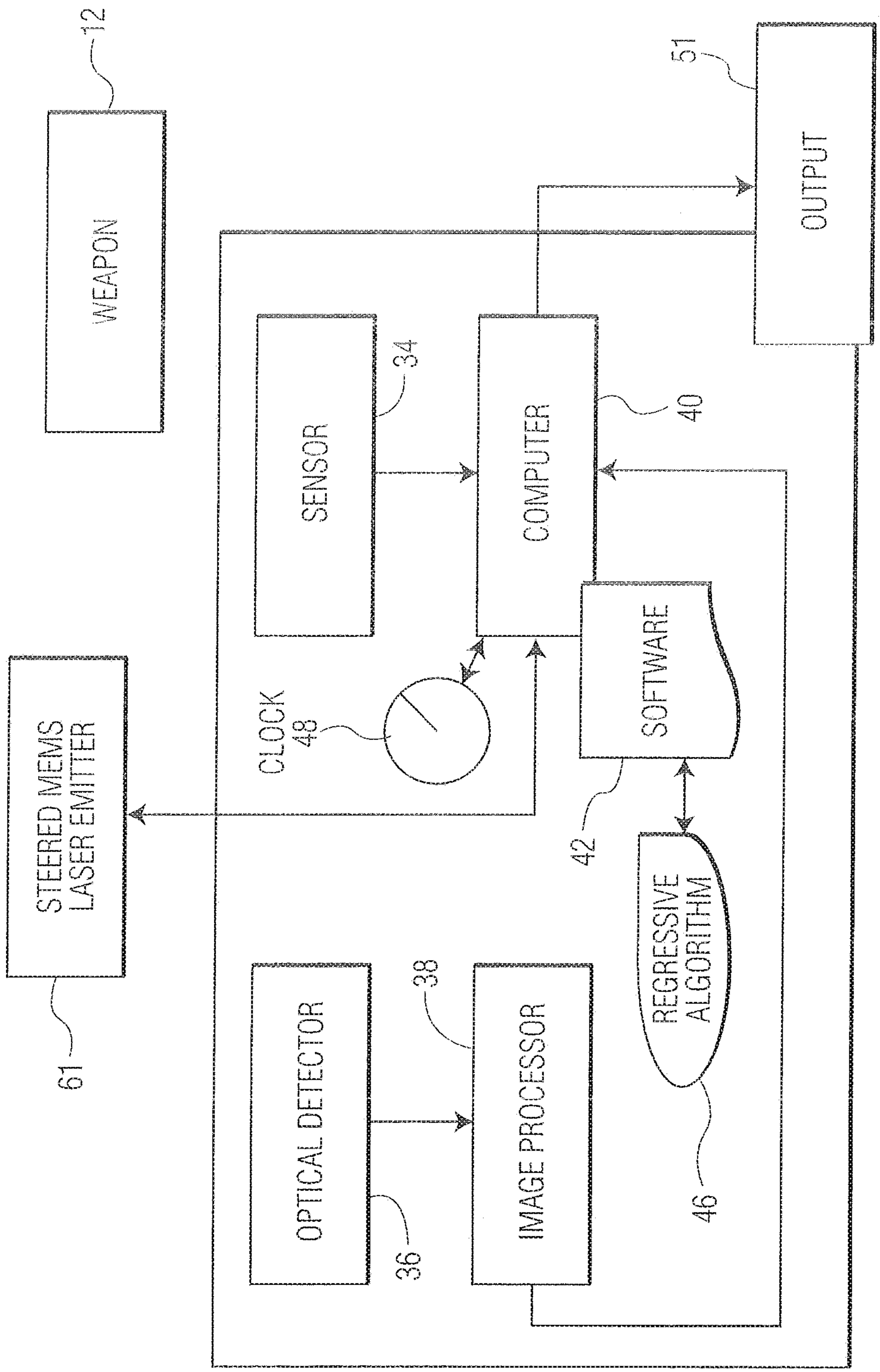

WEAPON
12
OUTPUT
51
SENSOR
34
COMPUTER
40
CLOCK
48
SOFTWARE
42
STEERED MEMS
LASER EMITTER
61
REGRESSIVE
ALGORITHM
46
OPTICAL DETECTOR
36
IMAGE PROCESSOR
38

FIG. 13

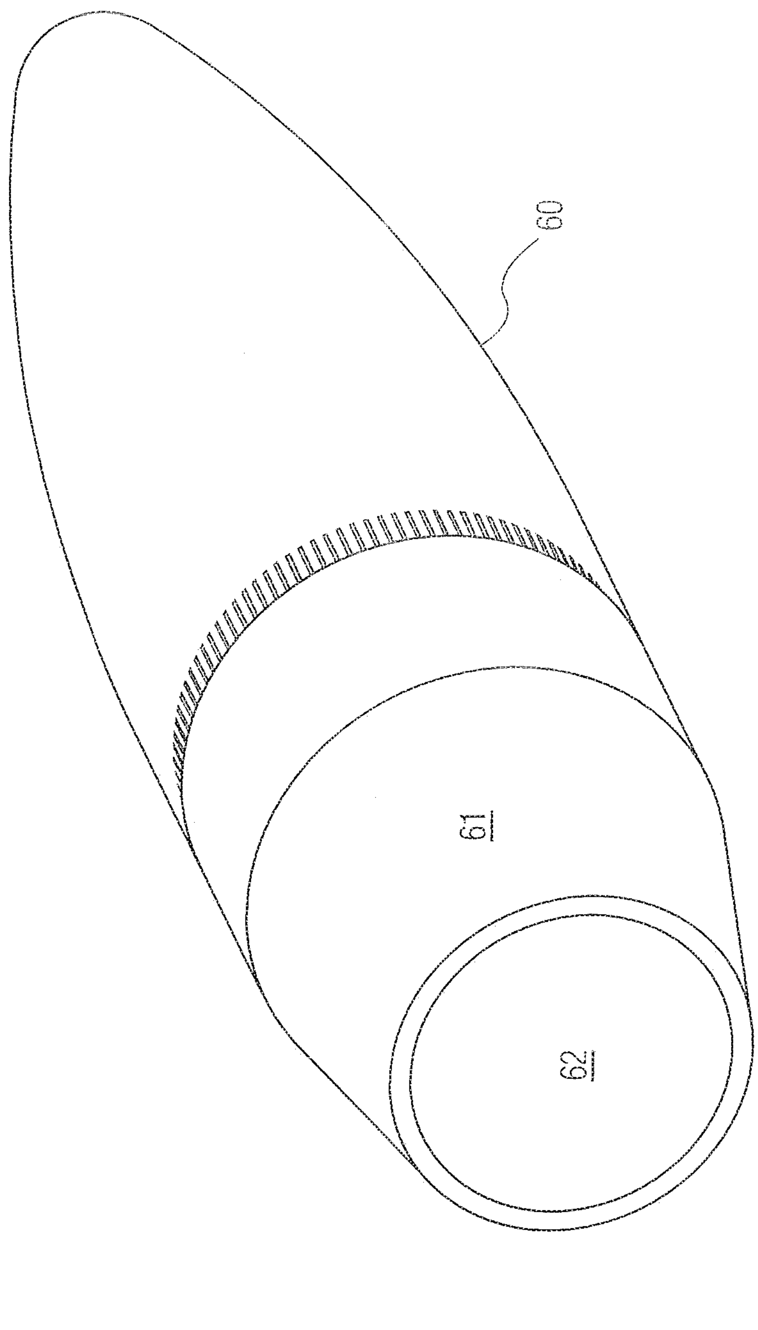


FIG. 14A

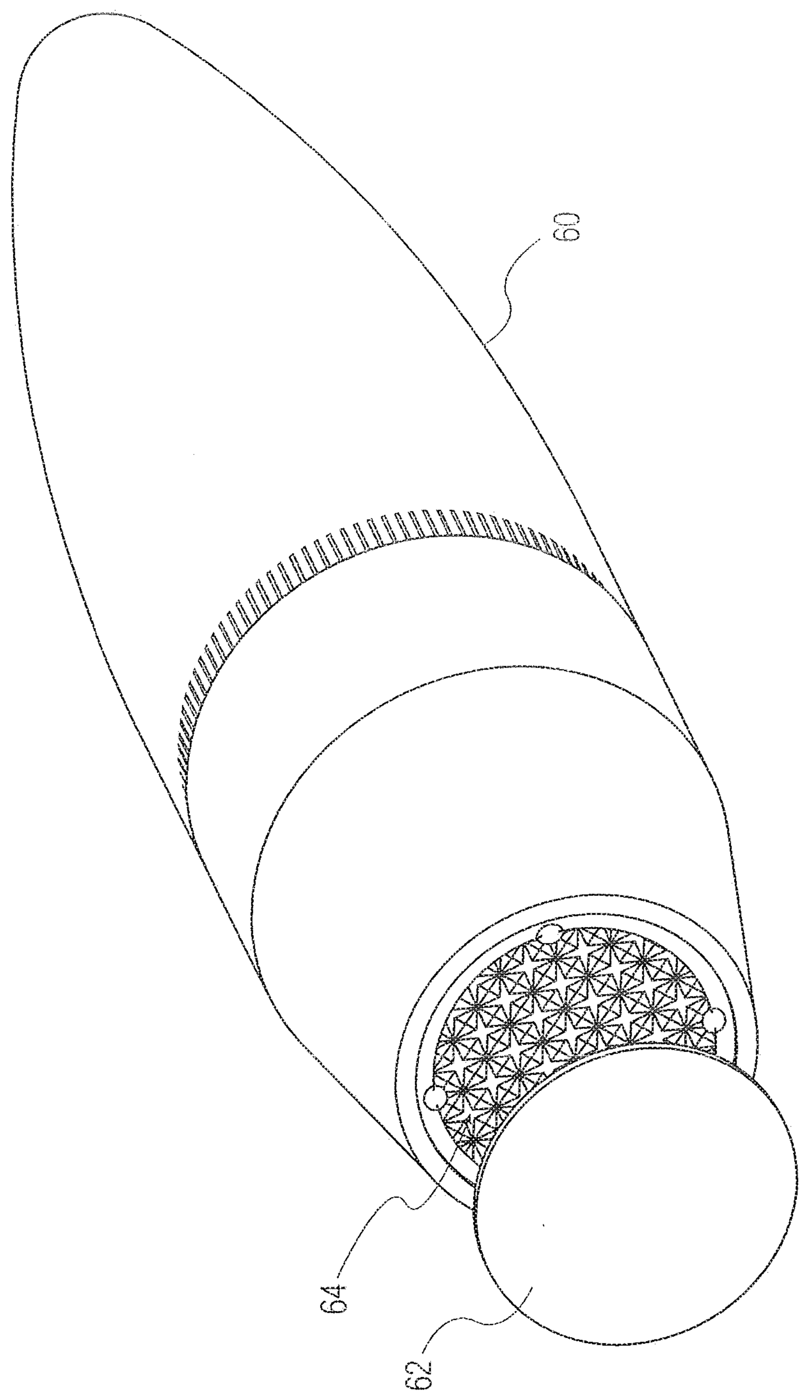


FIG. 14B

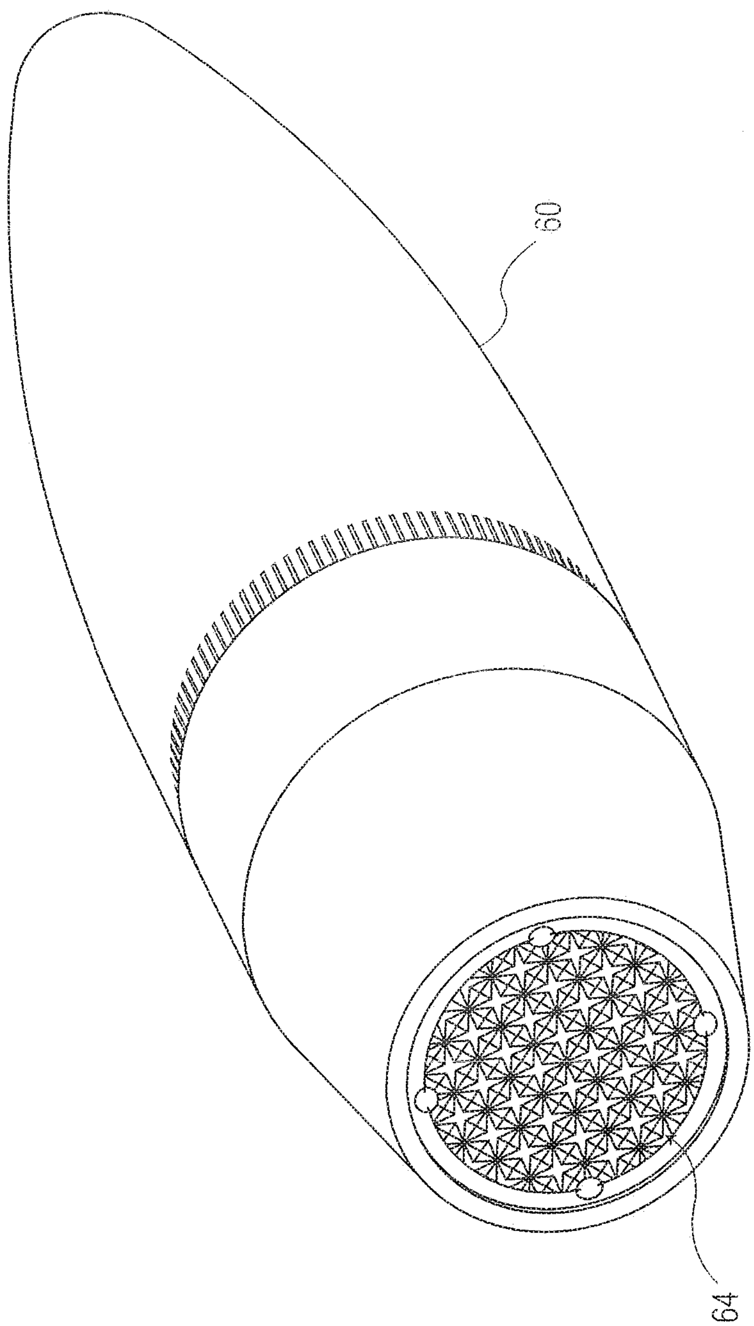


FIG. 14C

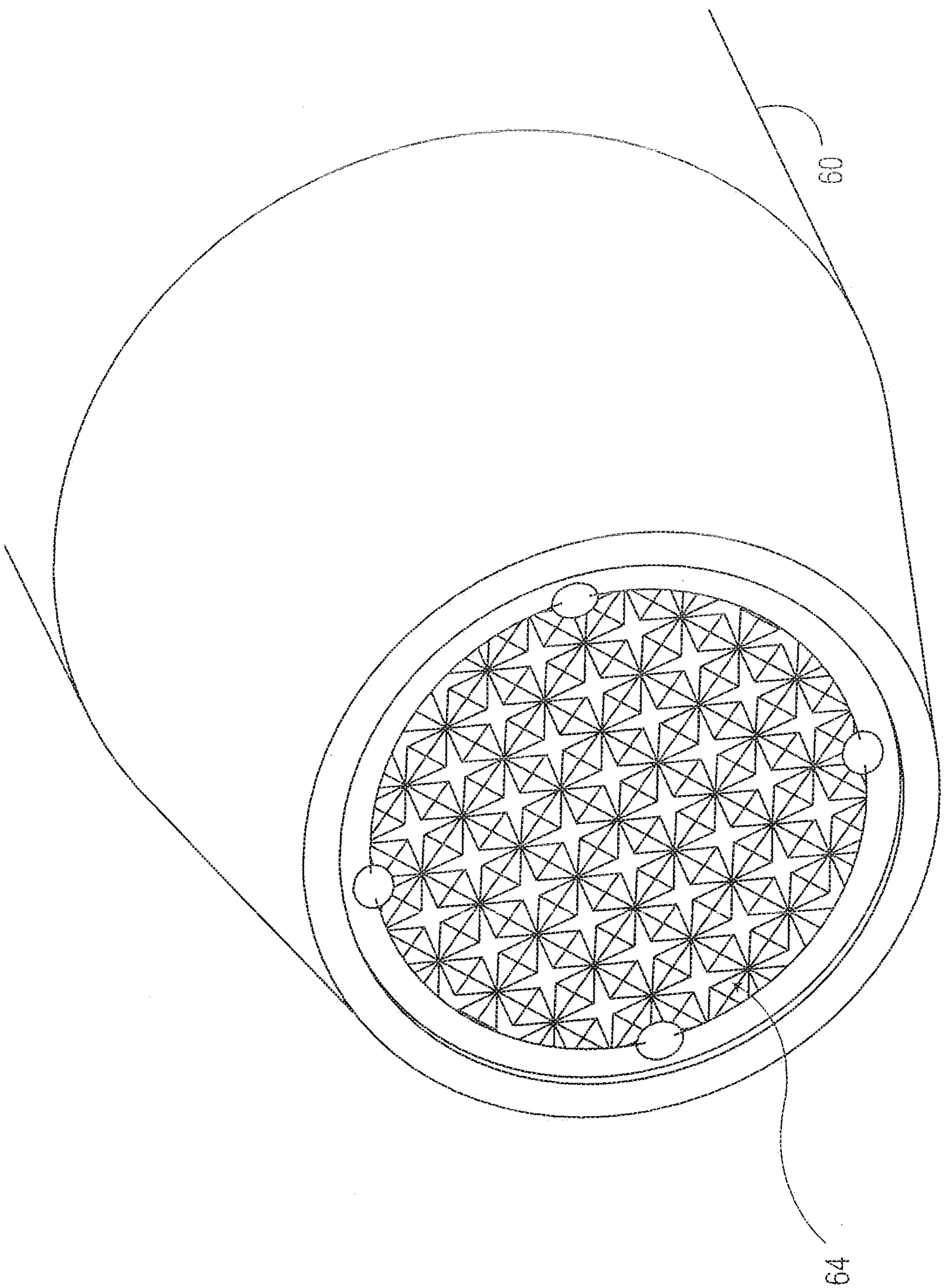


FIG. 14D

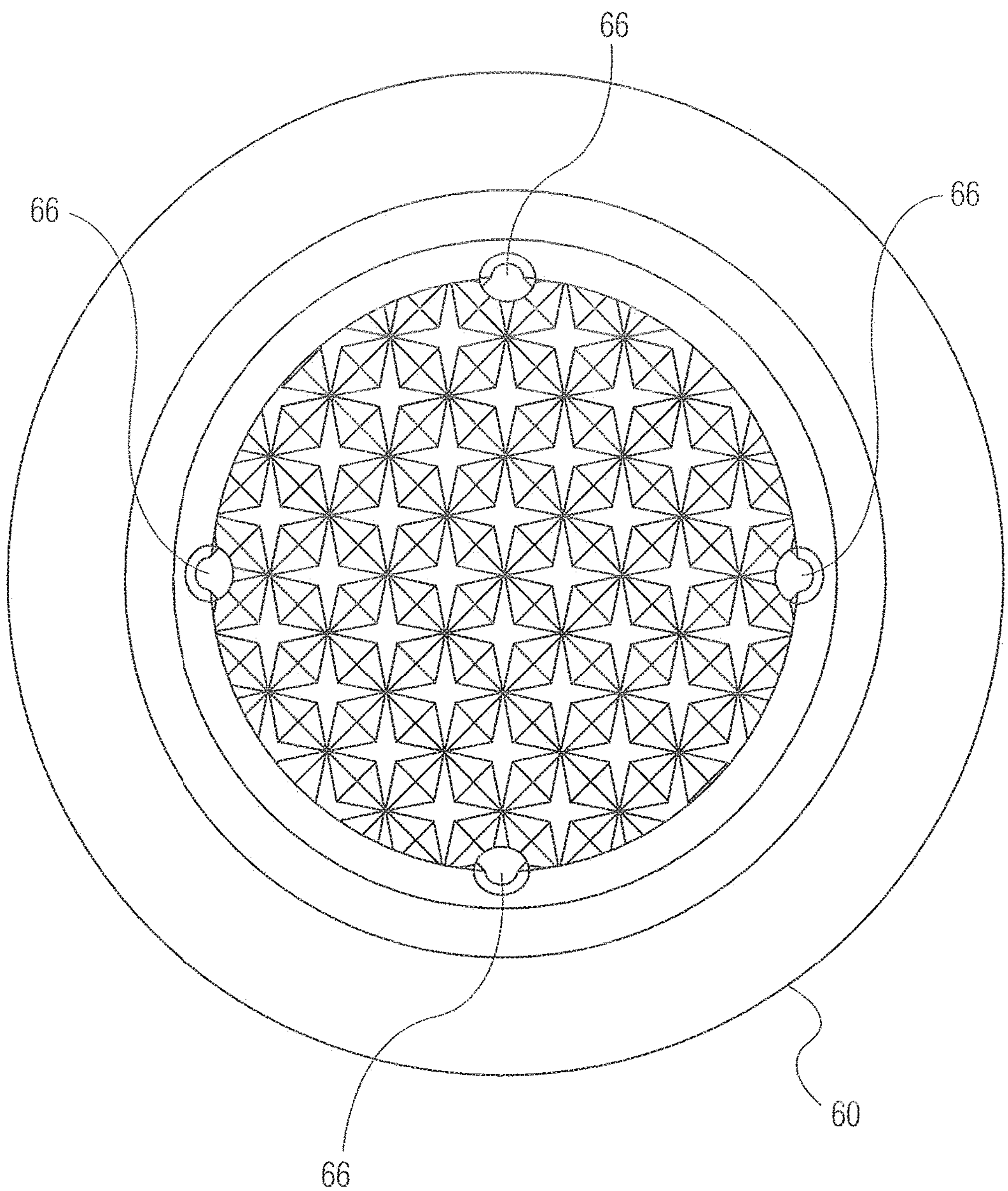


FIG. 14E

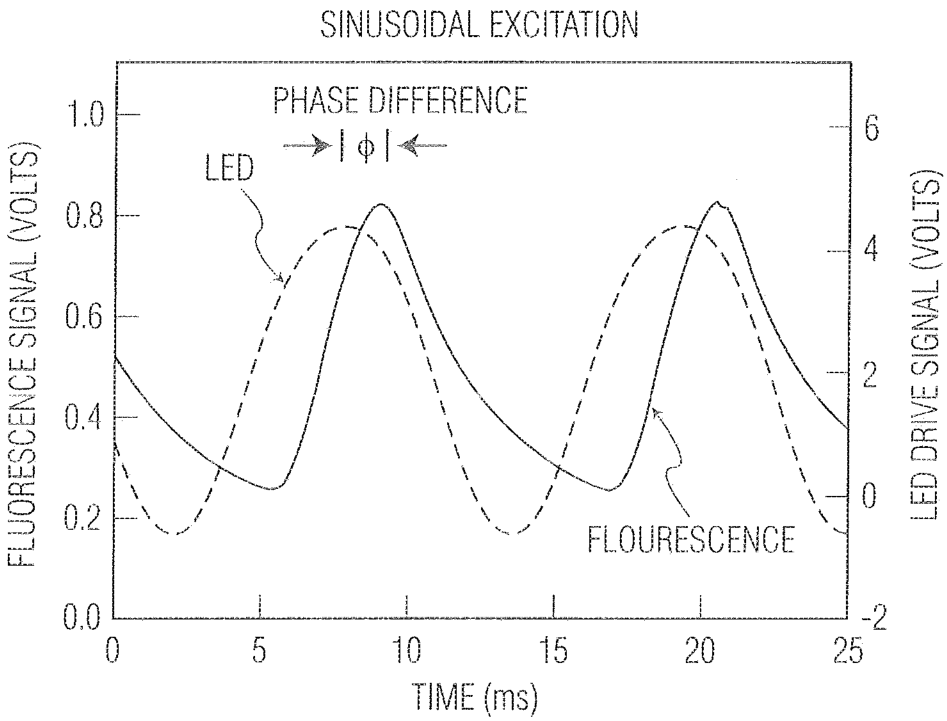

SINUSOIDAL EXCITATION
PHASE DIFFERENCE
φ
LED
FLOURESCENCE
FLUORESCENCE SIGNAL (VOLTS)
LED DRIVE SIGNAL (VOLTS)
TIME (ms)
1.0
0.8
0.6
0.4
0.2
0.0
6
4
2
0
-2
0
5
10
15
20
25

FIG. 15

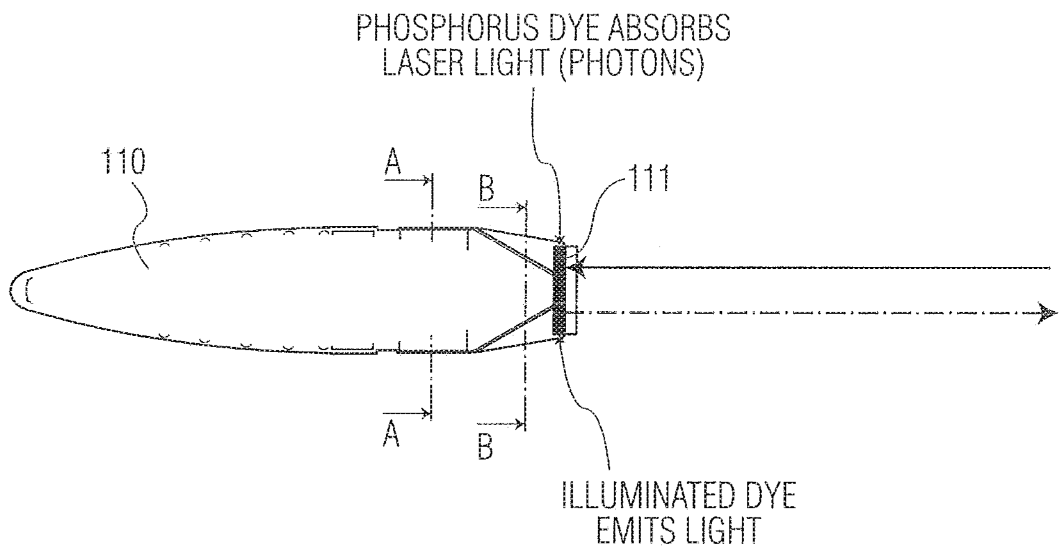

PHOSPHORUS DYE ABSORBS
LASER LIGHT (PHOTONS)
110
A
B
111
A
B
ILLUMINATED DYE
EMITS LIGHT

FIG. 16

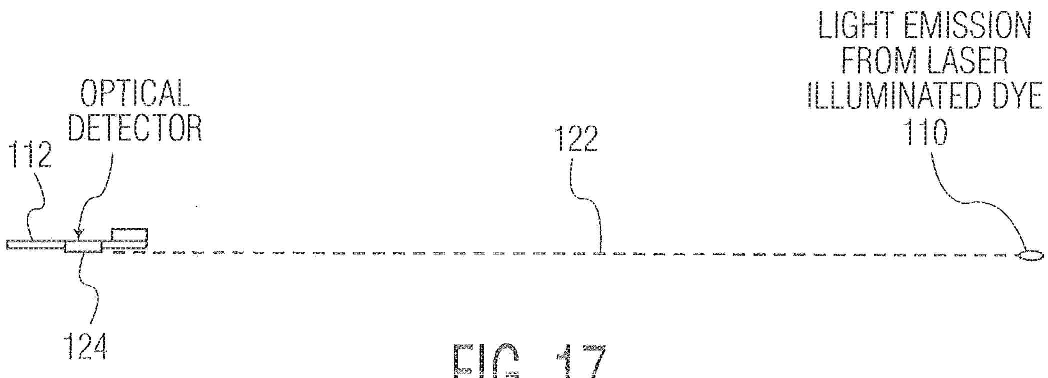

LIGHT EMISSION
FROM LASER
ILLUMINATED DYE
110
OPTICAL
DETECTOR
112
122
124

FIG. 17

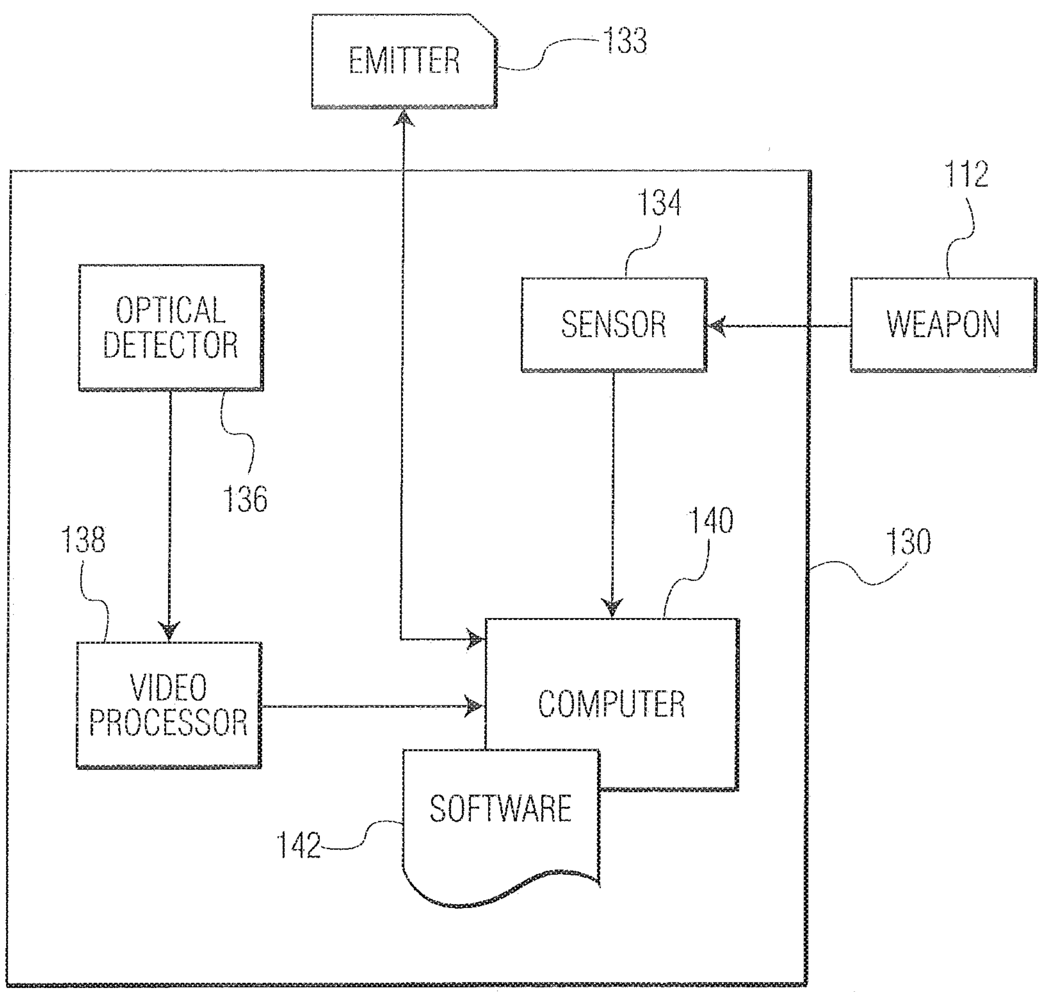

EMITTER
133
134
112
OPTICAL
DETECTOR
SENSOR
WEAPON
136
138
140
130
VIDEO
PROCESSOR
COMPUTER
SOFTWARE
142

FIG. 18

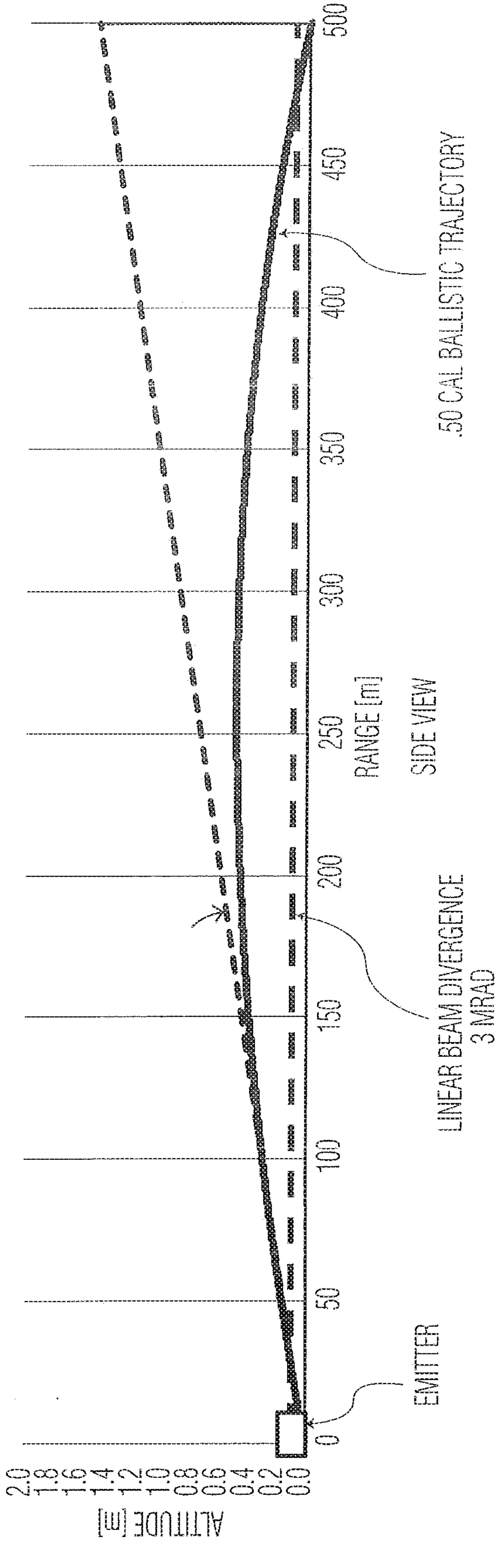

ALTITUDE [m]
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
450
500
RANGE [m]
SIDE VIEW
EMITTER
LINEAR BEAM DIVERGENCE
3 MRAD
.50 CAL BALLISTIC TRAJECTORY

FIG. 19A

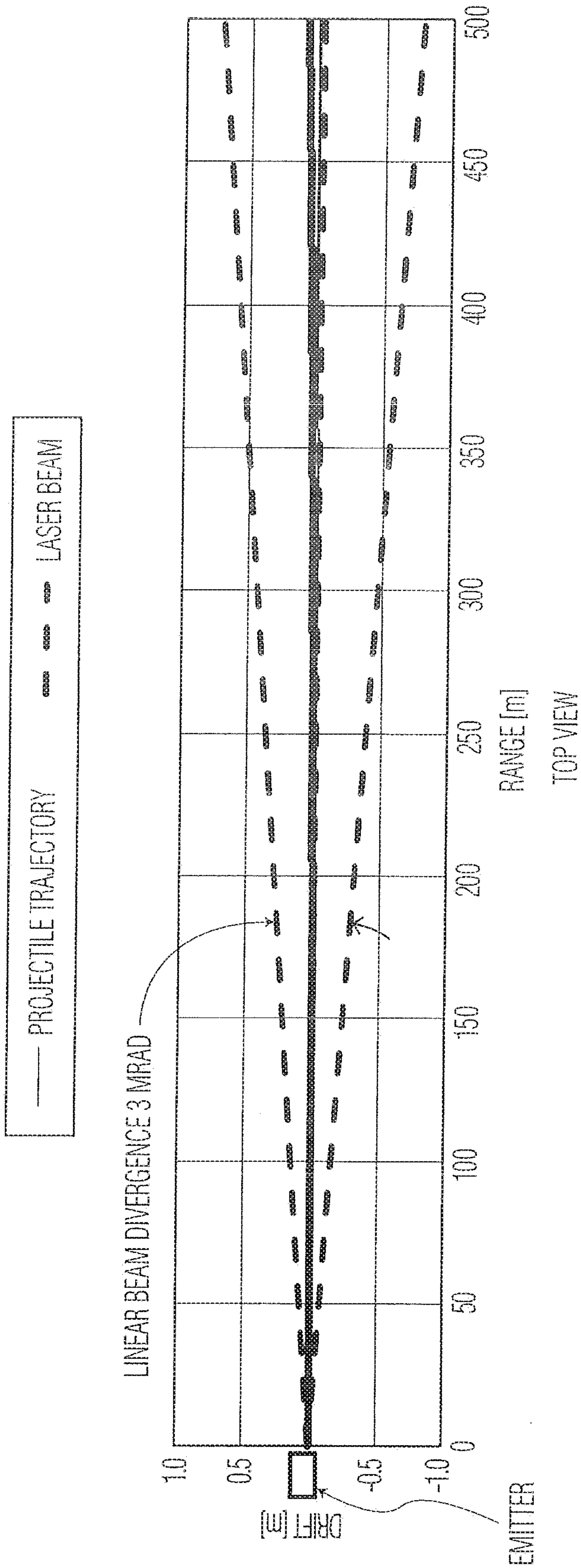

PROJECTILE TRAJECTORY
LASER BEAM
LINEAR BEAM DIVERGENCE 3 MRAD
DRIFT [m]
1.0
0.5
-0.5
-1.0
0
50
100
150
200
250
300
350
400
450
500
RANGE [m]
TOP VIEW
EMITTER

FIG. 19B

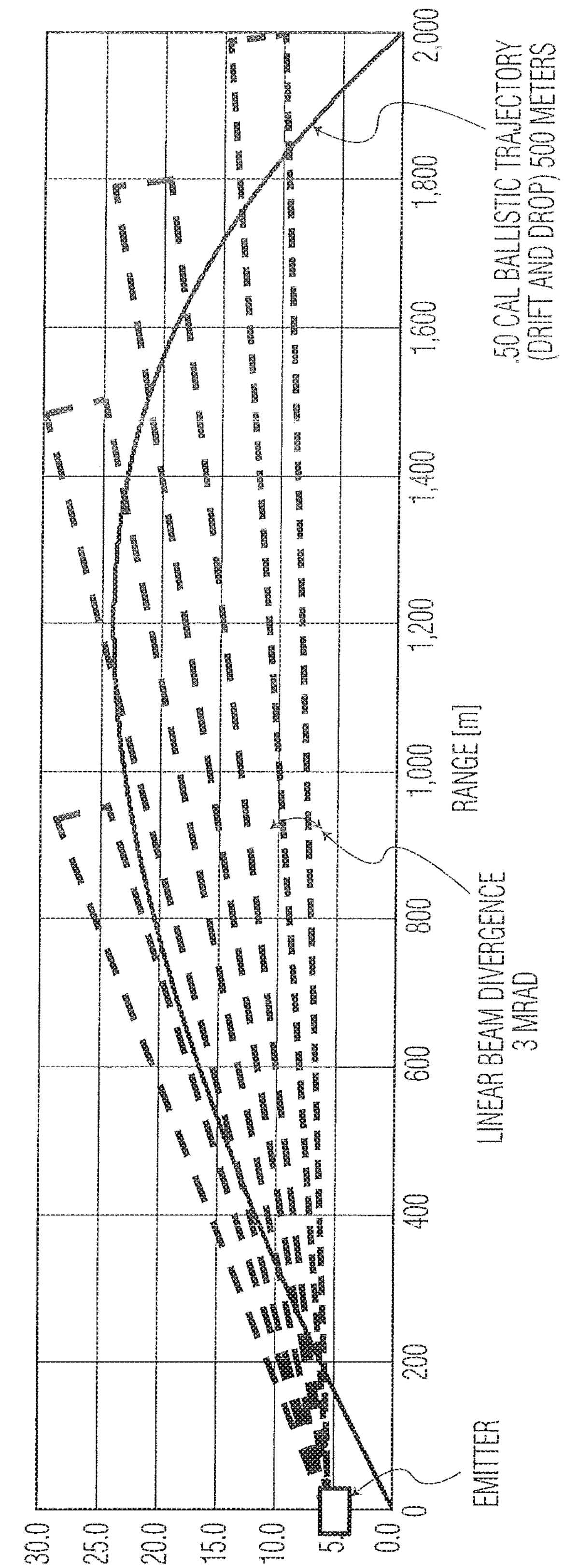

ALTITUDE [m]
30.0
25.0
20.0
15.0
10.0
5
0.0
RANGE [m]
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
EMITTER
LINEAR BEAM DIVERGENCE
3 MRAD
.50 CAL BALLISTIC TRAJECTORY
(DRIFT AND DROP) 500 METERS

FIG. 19C

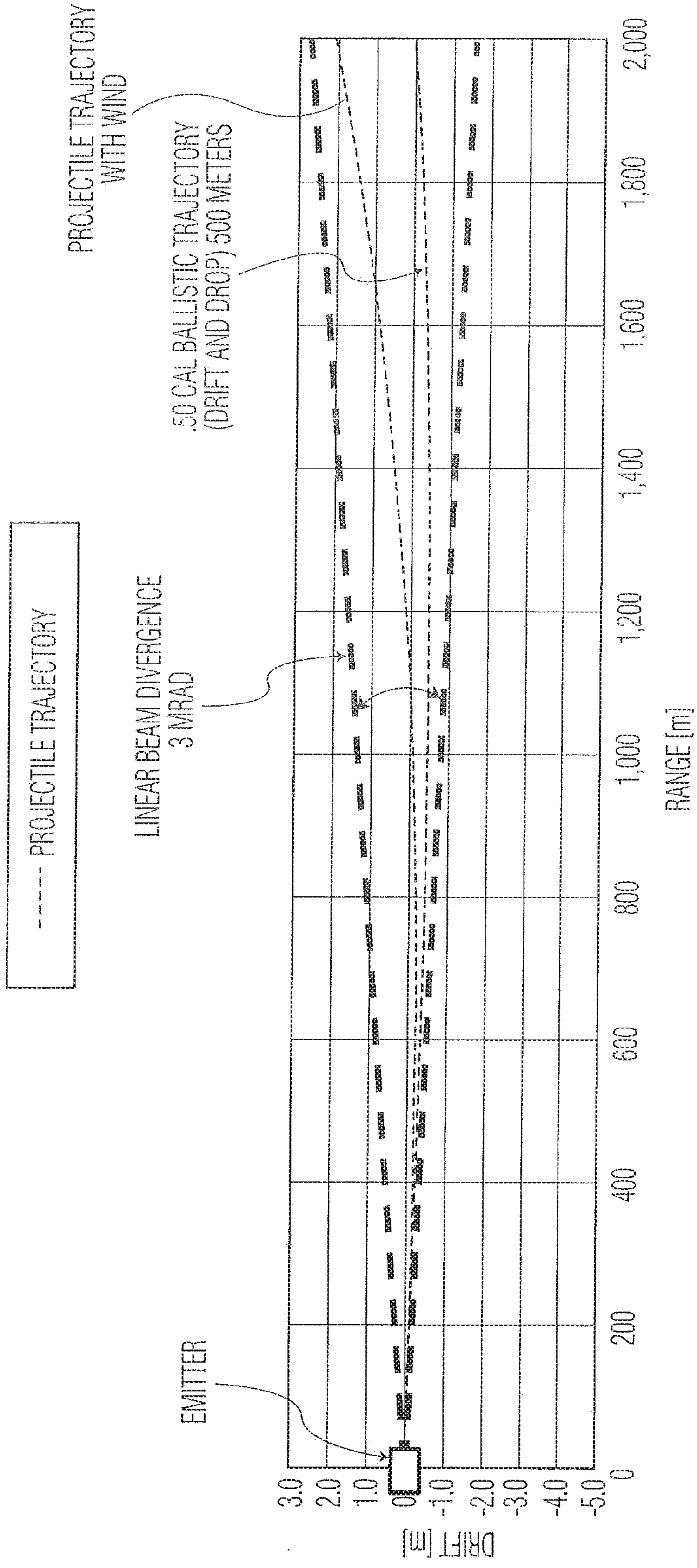

PROJECTILE TRAJECTORY
PROJECTILE TRAJECTORY WITH WIND
.50 CAL BALLISTIC TRAJECTORY (DRIFT AND DROP) 500 METERS
LINEAR BEAM DIVERGENCE 3 MRAD
EMITTER
DRIFT [m]
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
RANGE [m]
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000

FIG. 19D

.50 CAL PROJECTILE		
RANGE [m]	FLIGHT TIME [s]	PROJECTILES IN FLIGHT *
0	0.00	
100	0.12	2
200	0.24	3
300	0.37	5
400	0.50	7
500	0.65	9
600	0.80	11
700	0.97	13
800	1.14	15
900	1.33	18
1000	1.53	20
1100	1.75	23
1200	1.98	26
1300	2.23	30
1400	2.50	33
1500	2.80	37
1600	3.11	41
1700	3.43	46
1800	3.76	50
1900	4.10	55
2000	4.45	59

* AUTOMATIC FIRE OF A .50 CAL FROM A M2 BROWNING MACHINE GUN FIRING 800 rpm

FIG. 20

APPARATUS AND METHODOLOGY FOR TRACKING PROJECTILES AND IMPROVING THE FIDELITY OF AIMING SOLUTIONS IN WEAPON SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from the U.S. Provisional Application No. 61/803,826 filed Mar. 21, 2013; U.S. patent application Ser. No. 14/220,404 filed Mar. 20, 2014; U.S. Provisional Application No. 62/201,255 filed Aug. 5, 2015; and U.S. patent application Ser. No. 15/228,255 filed Aug. 4, 2016, the entireties of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to weaponry and fire control. More specifically, it relates to an apparatus to track ammunition projectiles in ballistic flight. The invention provides an illumination device enabling the tracking of the lateral drift and drop of an illuminated projectile while in ballistic flight. An automated system can measure or register the projectile's actual flight drop and drift to allow for time, space and location measurement of the projectile. The measurement of the actual ballistic path allows for use of manual or automated techniques to improve the precision, accuracy and subsequent aiming of the weapon. More specifically, the system uses a methodology to simplify the tracking of a projectile in flight with a capacity to improve the aiming of subsequent shots.

[0003] Tracer technology was developed by the British defense research establishment in the midst of the 1st World War. The technology continues to be used 100 years later. In machine guns, belts of ammunition are mixed—ball and tracer combinations. Unfortunately the 100 year-old technology has a number of practical drawbacks: (1) The tracer ammunition's ballistics differs from the trajectory of ball ammunition, (2) handling and inclusion of pyrotechnic tracers in ammunition significantly increases the cost of ammunition, (3) tracers cause unwanted range fires in training, (4) the glow emitted by tracers' backlights friendly forces, vehicles, equipment and air-craft and (5) tracers are not optimized for automatic tracking technology.

[0004] Simple Deployment and Use:

[0005] The invention disclosed in this application provides for a system to track projectiles affixed with retro-reflectors that reflect light from an optical strobe emitter. Where the reflected light is in the visual spectrum, a sniper spotter can observe the projectile's path and make adjustments for subsequent shots as the methodology allows a trained spotter to detect the influence of wind on the projectile and to calculate an effective adjustment for the sniper. This technique is also useful where the projectile is illuminated in the the near infra-red (NIR) and the reflected beam is viewed with NIR night vision goggles.

[0006] Use and Deployment on Aircraft:

[0007] It is useful to discuss this methodology if deployed in an air-to-ground applications where the wind wash from helicopter rotors, speed of the aircraft, etc., make it very difficult to correctly place fires from door guns. Current tracer technology emits light during the entire flight path allowing enemy on the ground to quickly locate friendly helicopters. With the approach disclosed in this application, a door gunner with night vision goggle will emit short pulses of NIR laser emissions and the retro-reflectors on the ammunition will allow the gunner to track the path of ammunition. This is done without the backlighting of the helicopter which is created by tracers. The narrow beam of pulsed NIR illumination is almost undetectable and the low power required of emitters coupled with retro-reflectors reduces the signature of the gunner —especially compared to the current technique of firing visible tracer ammunition. The NIR light reflected from a projectile allows the gunner to track the trajectory of ammunition without affording the enemy with a means of detecting the helicopter.

[0008] Retro-Reflection:

[0009] Use of retro-reflectors is ubiquitous in road signs where the technology was invented in the United Kingdom and introduced in the late 1930s. Retro-reflectors reflect light to the emission source with a minimum of scattering. There are three principle types of retro-reflectors: corner cube reflectors, cat eyes and phase conjugated mirrors. The coefficient of luminosity returned in the direction of the emission source is high. In addition to their use on road signs, retro-reflectors are used in safety reflectors, high visibility clothing and surveying. NASA has also used this technology. The Apollo **11**, **14** and **15** missions placed retro-reflectors on the moon surface allowing for precise measurements of the moon.

[0010] Automated Tracking, Shot Registration:

[0011] In addition to providing improved techniques to visually track the trajectory of ammunition in flight, one can also add an optical, imager or laser tracker (detector) coupled to a fire control system to further automate the system. In some cases it is useful to pulse the laser light emission to simplify the automated optical detection. Each method of automated tracking allows for "registration" of the shot at specific way points along the trajectory, when coupled to a fire control computer utilizing a regressive ballistic algorithm. Alternatively, the detector can use a MEMS steered laser tracking system where the optical detector steers the laser to maintain illumination of a retro-reflector affixed to the ammunition. In this case, the MEMS steered device measures the X and Y changes of the projectile during the entire flight path. Optical detection of MEMS steered laser emitters allow for automation so that real time "registered" data is collected.

[0012] Regressive Ballistic Algorithm and Improved Shot Placement:

[0013] An automated system can utilize acquired real time "registered" data with a regressive algorithm. A regressive algorithms use statistical processes to estimate relationships among variables and with a pattern. The algorithm improves the fidelity of predictive fire control to correct for unmeasured aiming errors due to wind turbulence, altitude-dependent wind conditions, lot-to-lot ammunition irregularities, bore sight misalignment and the like, for use when firing subsequent projectiles. Using this methodology, the merging of registered actual shot data with fire control algorithms provides for improved solution fidelity with better placement of the subsequent shot.

Prior Art

[0014] The U.S. Pat. No. 8,074,555, and its predecessor Provisional Application No. 61/803,826, disclose a system for tracking the lateral drift and vertical drop of an ammunition projectile while in flight to provide a precise aim point for firing one or more subsequent projectiles. With this system, a projectile is provided with an optical emitter on the rear of the projectile housing which produces optical strobe signals at predetermined times (T**1**, T**2**, T**3** . . .) following firing of the projectile (at time T**0**). An optical detector receives the optical signals and an image processor determines the lateral drift (i.e. X**1**, X**2**, X**3** . . .) and vertical drop (i.e. Y**1**, Y**2**, Y**3** . . . of the projectile at the predetermined times (T**1**, T**2**, T**3** . . .) following time T**0**. The subject matter of this patent is incorporated herein by reference.

[0015] This prior art uses the real time data to correct for aiming errors due to gun jump, wind turbulence, altitude-dependent wind conditions, lot-to-lot ammunition irregularities, bore sight misalignment and the like, for use when firing subsequent projectiles. This system is optimized to function with projectiles that have adequate energy to power LED's to emit strobe light and where the ballistic trajectory angles are significant (e.g., with mortars, artillery and 40 mm systems).

SUMMARY OF THE INVENTION

[0016] The principal object of the present invention is to improve the precision and accuracy of weaponry systems by providing an improved system and method of projectile tracking.

[0017] It is a further object of the invention to provide a method that avoids the drawbacks of firing conventional tracer ammunition.

[0018] It is another object of the present invention to improve precision of weapon fires and improve the capability of fire control devices.

[0019] It is another object of the present invention to improve the fire control device of the type disclosed in the U.S. Pat. No. 8,074,555 to render it more reliable and less expensive.

[0020] It is still another object of this invention to improve the fire control device disclosed in the U.S. Pat. No. 8,074,555 to minimize power consumption of projectile-borne batteries, used for example in projectile fuses, and to simplify the sensor array (detector) that views the projectile.

[0021] These objects, as well as still further objects which will become apparent from the discussion that follows, are achieved, in accordance to the present invention by providing an otherwise conventional ammunition projectile with methods and apparatus that use a pulsing electro-optical emitter and an optical tracking device to locate a radiated projectile in flight.

[0022] In one preferred embodiment of the invention, retro-reflectors are affixed, coated or otherwise fitted to a projectile's rear surface provide for reflection of light that can be viewed by electro-optical devices in the vicinity of the weapon firing said projectile. The radiated light emission from the laser emitter may be in the UV, visual, NIR or MWIR spectrum. The light reflected from the retro-reflective material may be in the UV, visual, NIR or MWIR spectrum.

[0023] The provision of projectiles with retro-reflectors according to the invention allows for use of a range of emission devices and is useful without specialized detectors so the fielding of the technology is straightforward. Accordingly, the system will function in the current spectrum of night vision equipment and can be readily integrated into existing sniper's kit when fitted with a laser emitter that reflects from retro-reflectors on a projectile.

[0024] With respect to retro-reflection and recent prior art for tracers, U.S. Pat. No. 5,267,014 provided a methodology for non-contact measurement to obtain 6DOF measurement in objects by means of a retro-reflector. Earlier work in this field developed the principles of 3DOF measurement of objects by means of retro-reflectors. U.S. Pat. No. 6,097,491 identified a method to use beam splitting for measurement. Using the prior work, Ruag GmbH in Germany has developed a family of training devices incorporating retro-reflections on targets as disclosed in U.S. Pat. No. 6,139,323, allowing for realistic military training. 3M holds number patents for retro-reflective manufacture and design that are instructive and several patents disclose methods to limit the retro-reflector's performance spectrum as is disclosed in U.S. Pat. No. 8,567,964. U.S. Pat. No. 6,808,467 describes a covert tracer projectile to determine aiming error using an optical collimator to steer a projectile to an illuminated target. U.S. Pat. No. 8,402,892 describes a method of producing covert tracers. U.S. Pat. No. 8,168,804 identifies types of dyes that can provide a NIR response with a Stoke's shift response.

[0025] Configuration:

[0026] The selection and orientation of the retro-reflectors affixed or coated on the projectile provides geometric line of site from the projectile's base or projectile body such that light is reflected rearward, toward the origin of the projectile's flight. The retro-reflective material is positioned and oriented on the projectile to allow for the rearward travel of light, notwithstanding that a flying projectile is subject to a yawing motion and angular flight characteristics associated with a particular projectile. The present invention provides that either a spotter or automated tracking system corrects the aim of a weapon adjusting or updating the ballistic firing solution.

[0027] Cone of Illumination:

[0028] Preferably the radiation source is laser source adapted to be affixed to the weapon so that the cone of illumination of the laser source intersects with the ballistic path of the projectile. The cone of laser light dispersion should encompass the ballistic path of the flight and also allow for post shot movement of the laser affixed to the weapon.

[0029] Spectrum:

[0030] Depending upon the type of laser and retro-reflectors, the illumination frequency may be in one of the UV, visual, and IR spectral bands. Both the laser source and radiation detector may utilize narrow pass filters to allow for stealth in illuminating the projectile and simplified signal processing and detector construction. To add stealth, a dye coating can be applied to the retro-reflective surface to use a well-known "stokes shift" to shift the return signal's frequency from a high energy state UV to a lower energy state NIR. Thus it may be possible to illuminate the projectile with UV laser light while detecting the re-emitted light in the NIR spectrum. One should note that this feature does reduce the reflected light as the "stokes effect" consumes energy when light shifts from a higher energy wavelength to a lower energy wavelength and this approach is not currently supportable using off the shelf retro-reflective supplies.

[0031] Detectors:

[0032] An automated system's radiation detector can be included in a spotting scope allowing a sniper's spotter to manually calculate the azimuth and elevation of the next shot. Preferably the radiation detector is an optical detector or digital camera that measures the ballistic path of the projectile at pre-set intervals.

[0033] Laser Emission and Reflection for Tracking:

[0034] The aim-correcting system preferably includes the following components:

[0035] (1) An emission source of short (strobe) radiation directed to illuminate the ballistic path of the projectile. It may be desirable to pulse emissions at predetermined times (T**1**, T**2**, T**3** . . .) following firing of the projectile (at time T**0**).

[0036] (2) A projectile in flight affixed with retro-reflectors on the rear of the projectile body.

[0037] It is possible to use the two steps above for a visual observation of the illuminated shot by a spotter in a sniper-spotter team. It is also useful to provide automated tracking and use that feature to provide for improved ballistic aiming solutions using regressive analysis using prior shot data.

[0038] Automated Tracking:

[0039] It is desirable to further automate the system. One approach to automate tracking is a system with the following additional elements (3 to 6):

[0040] (3) A radiation detector for receiving strobe radiation at times (T**1**, T**2**, T**3** . . .) where retro-reflectors reflect the light along the angle of incidence, returning the light to the vicinity of the weapon or spotter scope.

[0041] (4) A signal processor, coupled to the radiation detector, for processing the electronic signals produced by the detector to determine the lateral (X) and vertical (Y) coordinates of the projectile during flight at such times (T**1**, T**2**, T**3** . . .) where retro-reflectors are affixed to the projectile and where the retro-reflectors reflect light at time T**1**, T**2**, T**3** . . .). It may be useful to utilize a beam-splitting technique for optical detection.

[0042] (5) A computer, coupled to the processor, for calculating a lateral correction and a vertical correction in the aim of the weapon.

[0043] (6) An output device, coupled to a ballistic calculator or computer, to calculate an aiming adjustment of the weapon to re-aim the next shot placement.

[0044] As an alternative automated system to the system described above it is possible to use an automated system comprising the following elements (7 to 9):

[0045] (7) A steerable laser beam that searches an area controlled by a fast CPU and software algorithm, causing the laser to illuminate a corner cube or cat's eye on the projectile.

[0046] (8) A CPU and algorithm, coupled to an imaging device, which fixes the azimuth and elevation of the return reflection tracking and further adjusts the azimuth and elevation of the laser to maintain a track on the illuminated corner cube or cat's eye.

[0047] (9) An electronic sensor on the laser beam which detects or otherwise measures the lateral and horizontal position and movement changes from the time the projectile's position (X and Y) is acquired through the projectile's ballistic flight.

[0048] Using the actual measurements, an automated device utilizes a regressive ballistic algorithm, coupled with a computer to calculate an improved aim point for subsequent shots of ammunition. Additional shooting allows for repeated regressive analysis to improve the aim-point.

[0049] The output device of the system may provide an automated adjusted aiming point to the operator or a spotter.

[0050] Alternatively, the output device may allow for the manual computation of an adjusted aim point by the spotter or gunner.

[0051] In another preferred embodiment of the present invention an otherwise conventional ammunition projectile is provided with a coating of fluorescent dye material, on or near its rear surface, whereby the dye re-emits radiation in response to excitation by laser light.

[0052] The fluorescent dye, optimized to luminance in response to laser radiation, exploits a natural phenomenon known as "laser-induced-fluorescence." The dye is coated on an external rear surface of the projectile. The coating is preferably covered by a transparent shield or coating and, for example, it may be disposed on the inside surface of a transparent window on the rear of the projectile.

[0053] The present invention thus provides a system for correcting the aim of a weapon that is operative to launch such a fluorescent dye enhanced projectile on a ballistic path toward a target. The aim-correcting system preferably includes the following components:

[0054] (1) A source of short (strobe) radiation pulses directed toward the ballistic path of the projectile for excitation of the fluorescent dye material on the projectile, such pulses being emitted at predetermined times (T**1**, T**2**, T**3** . . .) following firing of the projectile (at time T**0**).

[0055] (2) A radiation detector for receiving strobe radiation re-emitted by the fluorescent dye on the projectile allowing for the vertical and lateral measurement of the projectile's position at times (T**1**z, T**2**z, T**3**z . . .), where "z" is the time delay of re-emission after excitation.

[0056] (3) A signal processor, coupled to the radiation detector, for processing the electronic signals produced by the detector to determine the lateral (X) and vertical (Y) coordinates of the projectile at such times (T**1**z, T**2**z, T**3**z . . .) during flight.

[0057] (4) A computer, coupled to the processor, for calculating a lateral correction and a vertical correction in the aim of the weapon.

[0058] (5) An output device, coupled to the computer, for facilitating an adjustment in the aim of the weapon toward the target, prior to firing the next projectile.

[0059] Using this aim-correcting device the aim of the weapon may be adjusted after the launch of one projectile to compensate for aiming errors prior to the next launch of another projectile.

[0060] By means of this system, either the signal processor or the computer calculates the lateral drift and the vertical drop of the projectile at the predetermined times.

[0061] Preferably the radiation source is laser source adapted to be affixed to the weapon so that the cone of illumination of the laser source intersects with the ballistic path of the projectile and excites the photo-luminescent material.

[0062] Preferably the radiation detector is a digital camera for producing an image of the ballistic path of the projectile.

[0063] Depending upon the type of fluorescent dye material, the frequency of the excitation radiation may be in one of the UV, visual and IR spectral bands.

[0064] Both the laser source and radiation detector may utilize narrow pass filters that provide for stealth in illuminating the projectile and simplified signal processing and optical detector construction as the technique provides for optimized signal to noise ratios.

[0065] The radiation source preferably includes a narrow band-pass filter for selectively passing a narrow spectrum of laser light to the projectile to excite the fluorescent dye. The radiation detecting device preferably also includes a narrow band pass filter allowing only the re-emitted light from the fluorescent dye to pass to the detector, thereby minimizing the data processing required of the detector output.

[0066] The output device of the system may be a display for the operator who manually adjusts the aim in the weapon's bore sight or it may automatically adjust the aim of the weapon, for example by passing the projectile drift and drop data to the fire control device of the weapon.

[0067] For a full understanding of the present invention, reference should now be made to the following detailed description of the preferred embodiments of the invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0068] FIGS. **1**A, **1**B and **1**C illustrate a Monte Carlo simulation of the impact location (against a vertical target) of shots for traced and untraced 0.308 projectiles fired at a range of 1500 meters. The figures show how the impact points for a number of tracer shots differ from the impact points for projectiles with standard pyrotechnic tracers.

[0069] FIGS. **2**A and **2**B depict an ammunition projectile with retro-reflectors affixed at the rear and the sides of the projectile body. that reflects incident light rearward.

[0070] FIG. **2**C is a detailed illustration of retro-reflectors, as applied to a projectile, that reflect incident light rearward.

[0071] FIG. **2**D illustrates how retro-reflectors are affixed to compensate for the conning motion in projectiles in ballistic flight.

[0072] FIG. **3** is a diagram showing a weapon and the trajectory of a projectile fired from a weapon.

[0073] FIG. **4** is a diagram showing a cone of illumination of strobe light emitted by a laser source that intersects the ballistic flight path of a projectile fired from a weapon.

[0074] The laser aim is slightly depressed from the bore sight for optimized intersection with the projectile's trajectory within the dispersion of the light cone.

[0075] FIG. **5** is a diagram showing a radiation (e.g., optical) detector which receives a light reflection from a retro-reflector on the projectile.

[0076] FIGS. **6**A and B are perspective views of a weapon having a laser source illuminating the projectiles in flight and a detector for receiving reflected radiation.

[0077] FIG. **7** is a representational diagram showing an error imparted by a fire control device which uses ballistic tables and metrological sensors to calculate a predicted hit point (gunner aiming point). Typically, a sniper will observe the impact point of a shot and provide an improved shot placement for a subsequent shot.

[0078] FIG. **8** is a representational diagram showing how the system of the present invention identifies the X and Y location of the detected reflected signals against the sky or backdrop.

[0079] FIG. **9** is a representational diagram showing how the system of the present invention (the view from fire control device at gunner's position) using reflected laser light to allow for registration of the prior shot. The image shows how the an accelerometer or other sensors measures post shot movement of the optical detector such that post shot movement is measured and the actual X and Y coordinates of an observed shot are corrected.

[0080] FIG. **10** is a representational diagram showing how the system of the present invention is used, post firing, to shift fields of view. The system measures the angular changes of the platform or camera at the same moment that the tracer's strobe signal is detected.

[0081] FIG. **11** is a representational diagram showing how the fire control computer calculates a new aiming solution after measuring actual drift and drop of an observed "strobe tracer" projectile.

[0082] FIGS. **12** and **13** are block diagrams of two systems, respectively, that use an algorithm to compute a bore sight adjustment and/or automatically adjust the aim point of subsequently fired projectiles.

[0083] FIGS. **14**A-**14**E are detailed diagrams of a projectile with a retro-reflective rear surface.

[0084] FIG. **15** is a time diagram of laser-induced fluorescence showing the delay in response to excitation.

[0085] FIG. **16** is a representational diagram showing an ammunition projectile having a fluorescent dye at its rear surface.

[0086] FIG. **17** is a diagram showing an optical detector which receives a light emission from a laser-illuminated fluorescent dye on an ammunition projectile.

[0087] FIG. **18** is a block diagram of the system, similar to the systems of FIGS. **12** and **13**, which uses an algorithm to compute a solution for bore sight adjustment and/or automatically adjusts the aim point of subsequently fired projectiles.

[0088] FIGS. **19**A and **19**B depict the linear beam divergence (in side view and top view) of 3 m rads and the ballistic trajectory of a .50 caliber (12.7 mm) projectile fired at 500 meters.

[0089] FIGS. **19***c* and **19**D depict the transposed linear beam divergence (side view and top view) of 3 m rads and the ballistic trajectory of a .50 caliber (12.7 mm) projectile fired at 2000 meters.

[0090] FIG. **20** is a table illustrating the time of flight of a projectile to a target at ranges from 100-2000 meters. The 3rd column identifies the number of projectiles in an automatic volley when a machine gun is firing at 800 shots per minute rate of fire.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0091] The preferred embodiments of the present invention will now be described with reference to FIGS. **1-20** of the drawings. Identical elements in the various figures are designated with the same reference numerals.

First Preferred Embodiment

[0092] According to a first preferred embodiment of the present invention, a projectile is fitted with retro-reflectors on its rear surface. An emitter is incorporated into a weapon system or into a stand-alone a spotter's scope. The emitter is slightly depressed from the axis of the barrel and focuses a cone of light in a tight beam that coincides with the ballistic trajectory of the projectile. The emitter illuminates the projectile's path in the spectrum allowing a spotter or sensors to precisely measure the ballistic trajectory. The system may also provide the capability to use automated tracking of the retro-reflectors affixed to a projectile. The invention is a kit that when mounted or incorporated into a weapon or spotting scope provides a methodology to adjust fires.

[0093] Cone of Illumination and Retro-Reflectors:

[0094] An illuminator emits UV, visual, NIR or MWIR light that illuminates the ballistic trajectory of the projectile. When attached to a weapon, the axis of the cone of illumination is slightly depressed from the center of axis of the barrel. When using the technique to illuminate an entire cone of light, the dispersion of the light emission and the angle of depression illuminate the projectiles ballistic flight path. The resulting depressed angle and dispersion is calculated for the caliber of the weapon system. Where a MEMs steerable laser beam is used, the laser search zone is limited to the light cone intersecting the ballistic path of the projectile. When incorporated into a sniper's scope the scope is pointed at the target and the zone of illumination is elevated above the target. The optical radiation traverses the space between the emitter and the projectile and light is reflected from reflected off the retro-reflectors affixed to the projectile. The retro-reflectors are affixed to the trajectory to with a geometry to return the incidence of light rearward during the trajectory of flight considering the yaw of the projectile and angle of attack. The signal may be continuous or emitted and reflected from the cat's eye or corner cube retro-reflective material affixed to the projectile.

[0095] Automated Optical Detection with Pulsed Signals:

[0096] Where the signals are pulsed at predetermined times (T**1**, T**2**, T**3**, etc.) following the time of firing (T**0**), an optical detector incorporated into the weapon or aligned with the spotting scope detects the angular geometry (projectile location in the sky) of the radiation reflected from the projectile as well as the duration (time length) of this reflected strobe in its field of view. The laser strobe emitter emits light at precise time intervals after launch or cartridge setback. The computer calculates the actual flight position at these precise post-firing intervals to the location that is forecasted by the original solution algorithm. The collected image is digitally processed and X and Y coordinates of the projectile's reflected strobe signal are identified by the laser's illumination of the projectile at predetermined time intervals. The "delta" positions are recorded (stored/registered). When a gunner subsequently wishes to engage new targets, the computer associated with the system uses an algorithm to identify a precise aim point solution using the observed trajectory of previous shots, thereby re-measuring and re-calibrating the distance and relative target elevation for subsequent firing of the weapon.

[0097] Table 1 is a time diagram illustrating the sequence of tracking when using strobe illumination signals where a shot where p is the required processing time for a subsequent fire control solution.

TABLE 1

Sequence of Measurements with Pulsed Signals Sequence of Measurement Methodology	
T0 − a	Fire Control Displays solution or aim point provided to gunner.
T0 − b	Measurement of (a) radial Azimuth/Elevation Barrel Centerline and (b) elevation of barrel/fire control if not aligned
T0 − c	Firing Pin Trigger pull (or hammer fall sensor) where a, b and c are lengths of time before T0
T0	Set Back of Cartridge Launch
T1	Laser emits short pulse Retro-reflectors on the projectile reflect light back in the general direction of the origin of the shot The illuminated retro-reflectors on the projectile are observed.
T1 + p	If an automated system is utilized, the system provides an improved firing solution for the next shot.
T2	Laser emits short pulse Retro-reflectors on the projectile reflect light back in the general direction of the origin of the shot The illuminated retro-reflectors on the projectile are observed.
T2 + p	If an automated system is utilized, the system provides an improved firing solution for the next shot.
T3	Laser emits short pulse Retro-reflectors on the projectile reflect light back in the general direction of the origin of the shot The illuminated retro-reflectors on the projectile are observed.
T3 + p	If an automated system is utilized, the system provides an improved firing solution for the next shot.

[0098] Automated Optical Detection with Continuous Signal Tracing:

[0099] New tracking technology includes MEMS steerable lasers that allow for continuous X and Y adjustment of a micro laser illuminating a projectile affixed with a retro-reflector.

[0100] FIGS. **1A**-**1C** respectively show a Monte Carlo simulation of sierra ball and tracer 0.308 bullets. Tracer bullets are normally fired in a set mix ball to tracer. The mean impact points and dispersion of tracers differs from ball projectiles. FIG. **2A** shows the dispersion with standard 0.308 cartridge ammunition without tracers. FIG. **2B** shows the dispersion of 0.308 ball tracer cartridges. FIG. **2C** shows the dispersion with a mixed ball and tracer cartridge combination.

[0101] FIG. **2A** depicts an ammunition projectile **10** having a retro-reflective coating at (**42**) the base of the projectile or a set of retro-reflectors (**43**) inset into the projectile body.

[0102] FIG. **2B** depicts a projectile **10** having a retro-reflective coating (**42**) and (**43**) in ballistic flight where the projectile exhibits both conning motion comprised of pitch and yaw amplitude that vary over the flight time (**44**). The retro-reflectors (**45**) affixed to the projectile are positioned so that a sufficient surface area of the retro-reflectors have, during ballistic flight, a rearward angle of incidence to light emitted from the location of the weapon thereby reflecting light beams (**46**) to return to the vicinity of the weapon system or spotting scope. The positioning of retro-reflectors accommodates the normal pitch and yaw of a projectile.

[0103] FIG. **2C** shows a detail of the retro-reflectors.

[0104] FIG. **2D** is a perspective view depicting an emitter **18**, illuminating a light cone **20** that intersects the ballistic path of a projectile in flight **10**. The reflected incident light **46** is returned to the optical detector **24**.

[0105] The system of the present invention is shown generally in FIGS. **3**, **4** and **5**. FIG. **3** shows a weapon **12** capable of firing projectiles in the direction of a target **14**. The projectiles impact in the region of the target in a dispersion zone **16**. FIG. **4** shows a laser source **18** mounted on the barrel of the weapon emitting light in a cone of illumination **20** that intersects the projectile **10**. FIG. **5** shows light **22** reflected from the retro-reflectors **42**, **43** on projectile reaching an optical detector **24** on or near the weapon **12**. This arrangement is illustrated in perspective in FIGS. **6**A and **6**B.

[0106] FIG. **6**A illustrates how a narrow beam emitter or laser **18** illuminates a conical area **20** illuminating the projectile **10**. The retro-reflectors affixed to the projectile **10** reflects light rearward from the projectile to return to the vicinity of the shot. In this perspective the emitter **18** and the detector **24** are mounted on the weapon **12**.

[0107] FIG. **6**B illustrates how a MEMS steered laser beam **19** is emitted in a light cone **20** illuminating the projectile **10**. The retro-reflectors affixed to the projectile **10**. Light from the retro-reflectors affixed to the projectile (not show) reflect light rearward from the projectile to return to an optical detector **24**. In this perspective the emitter **18** and the detector **24** are mounted on the weapon **12**.

[0108] FIG. **7** depicts a solution and actual impact generated by current generation of fire-control devices use ballistic tables and limited metrological sensors to calculate a predicted hit point (gunner aiming point). Some fire control systems allow users to input manual drift and elevation offsets, but these manual offsets are generally linear. Unsolved contributing errors that diminish the fidelity of fire control solutions as many unmeasured errors are omitted from the aiming solution. The omitted aiming errors devices include (a) bore sight misalignment, (b) lot-to-lot errors, (c) occasion-to-occasion errors and (d) limitations in existing wind sensor technology. The inability to measure unsolved errors degrades the accuracy and precision of weapon fire control solutions, as illustrated in FIG. **7**.

[0109] FIGS. **8**, **9**, **10** and **11** depict use of a pulsed technique (from the viewpoint of the gunner or optical detector) where a pulsed light strobe signal is emitted at predetermined times after set back during the flight path of the projectile and reflected back to the location of the gunner or spotter. The fire control device associated with the weapon optically identifies the x and y position during ballistic flight. Where a strobe technique is utilized, the measured time is at T**1**, T**2**, T**3**, Tn. Post firing resonance depicted in FIG. **10** can create shifting fields of view so a system will measures the angular changes of the platform or optical detector at the same moment that the projectile's strobe signal is recorded.

[0110] It should be noted, that the human in the loop remains a formable influence as spotters remain critical to the sniper profession. Accordingly, where manual calculations are used the invention provides for improving the observation and registration of shots as the methodology of reflecting optical emission from a projectile in flight until impact enhanced the spotter and sniper's ability to observe and correct errors using current practices. The registered information provides both an improved manual shooting technique and, where automation is available a methodology to track the projectile and improve the placement of subsequent shots.

[0111] FIG. **12** depicts the system for an automated system where the optical detector **36** and image processor **38** register the X and Y observation positions and where a sensor **34** measures the shot and post shot positions of the optical detector. A clock **48** initiates emitter illumination. The projectiles reflect the emission at T**1**, T**2**, T**3**, Tn and are reflected to the optical detector **36**. The computer **40** and software **42**, calculate the actual registered X and Y position of the ammunition at specific time. The device is equipped with a fast clock **48** to time stamp shot, images and sensor measurements. Fire control computer calculates a new fire control solution after measuring actual drift and drop of an observed "strobe tracer" projectile, as illustrated in FIG. **10**. Sensor **34** may include air temperature, pressure, firing geometry and standard muzzle velocity. The measurement of observed projectile drift and vertical drop are obtained by an image processor **38** to isolate the strobe tracer's position. Simultaneously, angular changes in the detector are measured by sensors **34**. The image processor search and detects the strobe images at pre-set intervals after firing. The optical detector **40** can be any type of image capturing device, for example a CCD, video camera, infrared camera or the like. It produces electronic signals representing the images and passes them to a signal processor **42**. The processor **42** determines X,Y location and as well as the time duration of each received response from a projectile in flight. This information is passed to the computer **40** for calculating a lateral correction and a vertical correction in the aim of the weapon **12**. An algorithm **46** written in the software code **42** computes a solution for bore sight adjustment and/or automatically adjusts the aim point of subsequently fired projectiles. The adjusted aim point is calculated and rendered in an output **51**.

[0112] FIG. **13** shows an alternative to the manual measurements or optical strobe measurements, wherein the system can use a steerable MEMs laser, where a laser initiates a search pattern within a zone corresponding to the ballistic flight path and, when illuminating the retro-reflectors, an optical detector.

[0113] The system allows the fire control computers to readily observe and calculate fire control solutions that reduce or eliminate (1) occasion-to-occasion errors, (2) ammunition lot-to-lot errors, and (3) bore sight misalignment.

[0114] Fire control computers can readily adjust aim points using sensors to measure air temperature, pressure, firing geometry and standard muzzle velocities; however, practical considerations still limit the accuracy of calculated solutions. Lot-to-Lot ammunition variations along with occasions-to-occasion errors still result in limitations in the accuracy of fire control solutions. These errors also include those errors that result from varying wind conditions. Hence, measurement of the actual observed projectile drift and drop is necessary to allow fire control systems to provide improved aiming solutions.

[0115] System Overview:

[0116] As illustrated in FIG. **8**, the system according to the invention reflects strobe laser light emissions at predetermined post firing (post set-back or launch) time windows. The retro-reflectors reflect light pulses that are collected by the radiation detector **24** (e.g. a camera, spotting scope or optical detector) and are manually or digitally recorded. At each pre-set time window the device records changes in the X and Y orientation of the reflected light. The system's image processing software measures the X and Y location of the optical strobe emission at the pre-set time window.

[0117] The system's signal processor identifies the X,Y location of the detected strobe signal against the sky or backdrop, as shown in FIGS. **9** and **10**, thereby determining the actual drift and drop of the projectile **10** as seen from the gunner's position.

[0118] The measurement of observed projectile drift and vertical drop are obtained by an image processor to isolate the strobe tracer's position. Simultaneously, angular changes in the detector are measured. The image processor search and detects the strobe images at pre-set intervals after firing.

[0119] After detecting the actual observed azimuth drift and drop of a cartridge with an emitted light (FIG. **9**), a spotter, gunner or the weapon's fire control system can utilize multiple methodologies to provide improved fire control solutions. The fire control system can (1) reset subsequent fire control solutions to use actual observed drift and drop, or (2) establish a correction factor which modifies the calculated fire control solution. Hence, use of actual observed data provides for a more accurate fire control solution.

[0120] Fire control computer calculates a new fire control solution after measuring actual drift and drop of an observed "strobe tracer" projectile, as illustrated in FIG. **10**.

[0121] The diagram of FIG. **11** shows projectile strobe signals from the next subsequently fired projectile as viewed from a gunner's position with the hit point corresponding to aim point.

[0122] The system and methodology according to the invention allow fire control devices to adjust the aim point (in azimuth and elevation) so that subsequently fired cartridges hit the intended target by using actual observed azimuth drift and vertical drop. With the actual drift observed by the fire control's optical sensor, the fire control computer calculates improved solutions for new engagements. As subsequent volleys are fired, the coded regressive algorithm improves the fire control solution as it repeatedly measures the actual trajectory of cartridge with an increasing sample size.

[0123] One should also note that the invention can be incorporated into spotting scopes where the observed shot methodology and hand-held calculators currently used by snipers is also improved.

[0124] In the system shown in FIGS. **12** and **13** an algorithm **46** coded to software **42** with a computer **40** refines the aiming solution.

[0125] FIGS. **12** and **13** show a system comprising an emitter **33**, **61** one or more sensors **34**, an optical detector **36**, an image or signal processor **38**. The sensors **34** identify various parameters of the weapon **12**. A clock, 48 time stamps all inputs. Such sensors may include various types including position sensors, sensors for gun elevation and the like. In FIG. **12**, the emitter **33** is either a focused light source or laser which is triggered by the computer **40** to produce a strobe of light.

[0126] In FIG. **13**, after a projectile is fired, a sensor initiates a search track for the MEMS laser emitter **61**. When the MEMS emitter **61** initiates searches a pattern illuminating a narrow beam in a cone **20** until it receives reflected light from the projectile's retro-reflector **10**, **42**, **43**.

[0127] After acquiring the target, the computer **40** and software **42** directs the steerable MEMS laser **61**. During the projectile's flight, the laser X and Y azimuth and elevation corresponds to the steered MEMS laser **61**. The X and Y location of the X and Y MEMS laser azimuth and elevation is recorded with specific clock time (**48**) stamps. The computer then runs a coded sub-routine with the regressive algorithm and passes "registration" data output **51** to the fire control device for refinement of the aim point for the next projectile to be fired. Where a return is lost, the device reinitiates a search track from the vicinity of the previous contact in a pattern in the cone **20**.

[0128] FIGS. **14**A-**14**E show a projectile **60** which may be used with the system in accordance with this first preferred embodiment of this invention.

[0129] FIG. **14**A depicts the projectile with a tapered section **61** in the rear. As shown in FIG. **14**B the rear surface of the projectile is covered a removable disc **62** which, when removed prior to firing, reveals a retro-reflector **64**.

[0130] FIG. **14**C shows the projectile in flight with the retro-reflective surface **64**. As indicted in the enlarged view of FIG. **14**D, the retro-reflector is formed in a pattern that generally reflects light in the direction from whence it came. This pattern, shown in greater detail in FIG. **14**E, comprises a grid of star shapes surrounded by diamond shaped patterns of reflective planes. The retro-reflector is held in place on the projectile **60** by four tabs **66**.

Second Preferred Embodiment

[0131] According to a second preferred embodiment of the present invention, the projectile has a layer of photo-luminescent material, instead of retro-reflective material, on its rear surface. This embodiment of the invention provides for a method and means collecting optical location signals emitted by the luminescent material on the projectile while in flight after firing from a weapon, and for simultaneously recording movement and/or acceleration. These optical signals are transmitted from a projectile in either the visual, ultraviolet and infra-red spectrum. The signals are re-emitted from the projectile at predetermined times (T**1**z, T**2**z, T**3**z, etc.) following the time of firing (T**0**). An optical detector incorporated into the weapon launcher or on an associated platform detects the angular geometry (projectile location in the sky) of the radiation re-emitted by the photo-luminescent material on the projectile as well as the duration (time length) of this re-emitted strobe in its field of view.

[0132] FIG. **15** is a time diagram illustrating the time delay of fluorescence in response to excitation by laser light. As may be seen, there is a delay of about 3 milliseconds between excitation and response. This period of delay is designated hereinafter by the letter "z".

[0133] The operating sequence of the system according to the invention is depicted in Table 1 below.

TABLE 2

Sequence of Measurements Sequence of Measurement Methodology	
T0 – a	Fire Control Displays solution based on solution derived from algorithm (based on previous measurement)
T0 – b	Measurement of (a) radial Azimuth/Elevation Barrel Centerline and (b) elevation of barrel/fire control if not aligned
T0 – c	Firing Pin Trigger pull (or hammer fall sensor) where a, b and c are lengths of time before T0

TABLE 2-continued

Sequence of Measurements
Sequence of Measurement Methodology

T0	Set Back of Cartridge Launch
T1	Laser emits short pulse
T1 + z	Response of dye on projectile time z later
T1 + z	Camera image (x1, y1) of strobe response and camera position (xx1, yy1)
T2	Laser emits short pulse
T2 + z	Response of dye on projectile time z later
T2 + z	Camera image (x2, y2) of strobe response and camera position (xx2, yy2)
T3	Laser emits short pulse
T3 + z	Response of dye on projectile time z later
T3 + z	Camera image (x3, y3) of strobe response and camera position (xx3,yy3)
Tn + z etc.	Camera image (xn, yn) of strobe response and camera position (xxn, yyn)

[0134] FIG. **16** shows an ammunition projectile **110** having a fluorescent dye **111** applied to its rear surface. The fluorescent dye preferably has a transparent or translucent coating to protect against damage or it is covered by a plastic shield or the like attached to the rear of the projectile.

[0135] The system according to the invention has the capability to detect the laser-induced fluorescence ("LIF") of a projectile while in flight. The re-emission in response to the LIF occurs the short period of time (z) after transmission of the laser strobe excitation.

[0136] When a phosphor is included with the projectile dye, the system can utilize phosphor thermometry. By measuring this re-emitted light duration (z) the system can use temperature differences observed on projectiles in flight to further differentiate between and among the locations of multiple projectiles when the rate of fire is such that multiple projectiles are in flight at the same time.

[0137] The system of the present invention is shown generally in FIG. **17**. FIG. **17** shows light **122** re-emitted by the fluorescent dye **111** on the projectile **110**, reaching an optical detector **124** on or near the weapon **112**.

[0138] The laser strobe emits light at precise time intervals after launch or cartridge setback. The weapon fire control system compares the actual flight position at these precise post-firing intervals to the location that is forecasted by the original solution algorithm. The "delta" positions are recorded (stored/registered) and the fire control provides a gunner with new "corrected" aim points using the registered shots.

[0139] The optical signals emitted by the fluorescent dye material on the projectile are collected by an optical detector, such as an IR camera, co-located with the weapon. The image is digitally processed and X and Y coordinates of the projectile's strobe signal are identified by collection at the predetermined time intervals. When a gunner subsequently wishes to engage new targets, the computer associated with the system uses an algorithm to identify a precise aim point solution using the observed trajectory of previous shots, thereby re-measuring and re-calibrating the distance and relative target elevation for subsequent firing of the weapon.

[0140] Optical emissions include light in the ultraviolet, infra red and visual wavelengths. The weapon's fire control unit has the capability to emit a cone of light (modulated to strobe at a set time) that intersects with the ballistic path of the projectile. Normally, the laser emission will be aligned vertically. The laser's horizontal alignment will drop slightly at an inclination so the top edge of the laser light illumination cone is aligned horizontally with the centerline of the barrel. This geometry allows the laser light cone to cover the entire ballistic drop of the projectile.

[0141] The laser emitter adjacent the weapon transmits a short, intense light strobe signal at predetermined times after set back during the flight path of the projectile. This occurs at T**1**=(time of emission+z), T**2**=(time of emission+z), T**3**=(time of emission+z), Tn=(time of emission+z) where z is the time delay in milliseconds. Using this technique it is possible to select dye combinations where the laser strobe transmits strobe signals at a given frequency and the dye's optical response differs in its response frequency. This is used by the optimize system to preclude detection by potential adversaries. It is possible, in fact, to harness the heat of the projectile to change the spectral response of the dye.

[0142] The transmission of electromagnetic (optical) signals differs under certain atmospheric conditions and frequencies. The delay (z) between the laser's production of a light strobe and the tracer's fluoresced re-emitted response, as well as the length (duration) of the response signal, are used by the fire-control detection software to eliminate detection of stray reflective light that occurs when the laser beam strobe signal reflects off of objects and to distinguish between multiple projectiles.

[0143] Projectile flight geometry provides for reflection of light rearward to the gunner's position at pre-set intervals though the entire flight path. The fire control device associated with the weapon optically identifies the position (T**1**=position x**1**, y**1**, T**2**=position x**2**, y**2**, T**3**=position x**3**, y**3**, . . . Tn=position xn, yn) of the projectile at set intervals.

[0144] The invention provides for a system to collect optical location signals from a projectile in flight which are excited by an optical light source (visual, ultraviolet and infra-red). The fire control uses observed time-location and angular observation data to compute an improved ballistic solution.

[0145] The system allows the fire control computers to readily observe and calculate fire control solutions that reduce or eliminate (1) occasion-to-occasion errors, (2) ammunition lot-to-lot errors, and (3) bore sight misalignment.

[0146] Fire control computers can readily adjust aim points using sensors to measure air temperature, pressure, firing geometry and standard muzzle velocities; however, practical considerations still limit the accuracy of calculated solutions. Lot-to-Lot ammunition variations along with occasions-to-occasion errors still result in limitations in the accuracy of fire control solutions. These errors also include those errors that result from varying wind conditions. Hence, measurement of the actual observed projectile drift and drop is necessary to allow fire control systems to provide improved aiming solutions.

[0147] The current generation of fire-control devices use ballistic tables and metrological sensors to calculate a predicted hit point (gunner aiming point). Some fire control systems allow users to input manual drift and elevation offsets, but these manual offsets are generally linear. Hence, the current generation fire control devices continue to provide inaccurate aim points due to the fact that they only calculate a limited number of inputs while many "unsolved" sources of errors are not factored in. Unsolved errors include (a) bore sight misalignment, (b) lot-to-lot errors, (c) occasion-to-occasion errors and (d) limitations in existing wind sensor technology. All unsolved errors degrade the accuracy and precision of weapon fire control solutions.

[0148] The projectile's stimulated dye response occurs at discrete intervals (at T**1**+z, T**2**+z, T**3**+z, . . . Tn+z, where z is the response delay) that are observed by fire control devices equipped with optical sensors. The dye's strobe response to laser illumination identifies the position of the projectile at set time intervals after set-back (time T**0**). The system according to the invention optically collects the strobe light emissions at predetermined post firing (post set-back or launch) time windows. The projectile's fluorescent dye emits light strobe pulses that are collected by an optical detector (e.g. a camera) and digitally recorded. At each pre-set time window the device also records changes in the X and Y orientation of dye emission. The system's image processing software measures or signal processing algorithms calculate the X and Y location of the optical strobe emission at the pre-set time window.

[0149] The system's signal processor identifies the X,Y location of the detected dye strobe signal against the sky or backdrop, thereby determining the actual drift and drop of the projectile as seen from the gunner's position.

[0150] The measurement of observed projectile drift and vertical drop are obtained by an image processor to isolate the strobe tracer's position. Simultaneously, angular changes in the detector are measured. The image processor search and detects the strobe images at pre-set intervals after firing. Alternatively, the signal processor detects the signal at pre-set intervals after firing.

[0151] Post firing resonance can create shifting fields of view. The system measures the angular changes of the platform or optical detector (camera) at the same moment that the projectile's strobe signal is recorded.

[0152] After detecting the actual observed azimuth drift and drop of a cartridge, a weapon's fire control system can utilize two methods to provide improved fire control solutions. The fire control system can (1) reset subsequent fire control solutions to use actual observed drift and drop, or (2) establish a correction factor which modifies the calculated fire control solution. Hence, use of actual observed data provides for a more accurate fire control solution.

[0153] Fire control computer calculates a new fire control solution after measuring actual drift and drop of an observed "strobe tracer" projectile.

[0154] The system and methodology according to the invention allow fire control devices to adjust the aim point (in azimuth and elevation) so that subsequently fired cartridges hit the intended target by using actual observed azimuth drift and vertical drop. With the actual drift observed by the fire control's optical sensor, the fire control computer calculates improved solutions for new engagements. As subsequent volleys are fired, the fire control may use commonly known mathematical algorithms to further improve the precision of the corrected aim point as it repeatedly measures the actual position of cartridge drift and azimuth with a larger sample size.

[0155] In the system shown in FIG. **18** an algorithm computes a solution for bore sight adjustment and/or automatically adjusts the aim point of subsequently fired projectiles. The algorithm develops fire control solutions (aim points) using actual, observed azimuth and elevation.

[0156] FIG. **18** shows a system **130** according to the invention for a weapon **112** comprising an emitter **133**, one or more sensors **134**, an optical detector (e.g. camera) **136**, a signal processor **138** and a computer **140** operating with software **142**.

[0157] The sensors **134** are used to identify various parameters of the weapon **112**. Such sensors can be of various types, for example, position sensors, sensors for gun elevation, optical sensors and the like. The emitter **133** is a high-powered laser which is triggered by the computer **140** to produce a strobe of light.

[0158] The optical detector **136** can be any type of image capturing device, for example a video camera, infrared camera or the like. It produces electronic signals representing the images and passes them to a signal processor **138**. The processor **138** determines X,Y location and as well as the time duration of each received response from a projectile in flight. This information is passed to the computer **140** for calculating a lateral correction and a vertical correction in the aim of the weapon **112**.

[0159] The fire control device measures the angular position of the weapon **112** when the weapon fires a projectile aimed at a target. This angular position information includes a radial azimuth/elevation barrel centerline and elevation of barrel/fire control elevation, The angular position is measured by the sensors **134** and this information is also passed to the computer **140**.

[0160] The computer determines the drift and drop of the fired projectile and passes this data to the fire control device for adjusting the aim point of for the next projectile to be fired.

[0161] The time delay (z) of the re-emitted signal allows the computer **140** to disregard reflections received by the detector **138** from stray objects. The time duration of the re-emitted signal allows the computer to distinguish between multiple projectiles in flight which have been rapidly fired successively by the weapon **112**. Closer (and therefore hotter) projectiles will have shorter duration re-emissions that the projectiles that are further away (and therefore cooler).

Comparison of Systems in First and Second Embodiments

[0162] The first embodiment of the present invention concerns an apparatus and methodology for improving the fidelity of aiming solutions in weapons using projectiles with one or more retro-reflectors. In the second preferred embodiment the apparatus and methodology use projectiles illuminate and track projectiles with with photo-luminescent material (e.g., a fluorescent dye) applied to the projectile body to provide laser-induced fluorescence.

[0163] In the discussion above, when referring to times T**1**+z, T**2**+z, TN+z, z was the time addition (in milliseconds) from re-emission delay, post illumination of the laser induced fluorescence. When applying the same methodology to retro-reflective tracers it is possible to use the same formulas, but in such a case it is useful to use a definition of "z" whereby z is the time it takes for light to travel (2× back and forth) over the distance after emission. For example, the light from an emitter (with a target at 500 meters) will travel back and forth (1000 meters) in 3.33 micro-seconds. In this circumstance, the technique allows for obtaining distinct range data of the projectiles (in flight) which can be useful for regressive algorithms. This is also useful for distinguishing among the many projectiles in flight with a machine gun firing continuously at 800 rounds per second (rate of fire).

[0164] FIGS. 19A and 19B illustrate linear beam divergence (in side view and top view) for a .50 caliber projectile fired at a target at 500 meters. FIGS. 19C and 19D illustrate linear beam divergence for a .50 caliber projectile aimed at a target 2000 meters away. As may be seen, the system employed in FIGS. 19C and 19D has a steerable MEMS laser emitter that follows the path of the projectile in flight.

[0165] FIG. 20 is a table illustrating the time of flight of a projectile to a target at ranges from 100-2000 meters. The third column identifies the number of projectiles in a automatic volley when a machine gun is firing at an 800 shots per minute rate of fire.

[0166] There has thus been shown and described a novel apparatus and methodology for tracking projectiles and improving the fidelity of aiming solutions in weapon systems which fulfills all the objects and advantages sought therefor. Many changes, modifications, variations and other uses and applications of the subject invention will, however, become apparent to those skilled in the art after considering this specification and the accompanying drawings which disclose the preferred embodiments thereof. All such changes, modifications, variations and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention, which is to be limited only by the claims which follow.

What is claimed is:

1. A system located in the vicinity of a weapon having a barrel for firing a succession of projectiles that follow extenuated curved ballistic trajectories toward a distant target, said system being operative when each projectile is fired from the weapon to record its changing vertical and lateral positions over its ballistic path during its ballistic flight after barrel exit, said system comprising, in combination;

a radiation source at the location of the weapon for transmitting radiation toward the rear surface of the projectile during its ballistic flight, where said radiation source is a steerable laser beam with a control for causing the radiation emitted from the laser to intersect with the ballistic path of the projectile;

a radiation detector at the location of the weapon for detecting return radiation received from the rear surface of the projectile in response to said radiation emitted by said radiation source and capturing said changing vertical and lateral positions of the projectile during its ballistic flight, said detector producing measurable output signals representing said changing vertical and lateral positions of the projectile; and

an output device, coupled to the radiation detector and receiving said output signals, for recording said changing vertical and lateral positions of the projectile as it exits the barrel transitioning to the apogee, and for calculating an adjustment in the aim of the weapon toward the target, prior to firing a subsequent projectile, the output device further comprising a sensor measuring drop and drift of the projectile, wherein the sensor tracks said extenuated ballistic curve.

2. The system defined in claim **1**, wherein said output device comprises:

a) a signal processor, coupled to the radiation detector, for processing said electronic signals to determine the spatial (X and Y) coordinates of the projectile during flight; and

b) a computer, coupled to the signal processor and to the output device, for calculating a lateral correction and a vertical correction in the aim of the weapon;

wherein said output device facilitates the lateral and vertical correction in the aim of the weapon.

3. The system defined in claim **1**, wherein the output device produces a lateral and vertical correction to the aim of the weapon.

4. The system defined in claim **1**, wherein the output device allows for adjustment of the aim of the weapon by imparting, post firing, lateral and vertical corrections to the aim.

5. The system defined in claim **2**, wherein one of the signal processor and the computer calculates the lateral drift and the vertical drop of the projectile during its ballistic flight.

6. The system defined in claim **1**, wherein the radiation emitted from the laser source is diffused and directed to optimize illumination of the projectile's flight path.

7. The system defined in claim **1**, wherein the radiation detector is a digital video camera for capturing an image of the ballistic path of the projectile.

8. The system defined in claim **1**, wherein the radiation detector includes a filter, allowing the radiation received from the projectile to be selectively received and other radiation excluded.

9. The system defined in claim **1**, wherein the frequency of said radiation is in one of the UV, visual and IR spectral bands.

10. The system defined in claim **1**, wherein said output device includes a display showing said vertical and lateral positions of the projectile.

11. The system defined in claim **9**, wherein said output device includes a aiming device allowing an operator to adjust the aim of the weapon.

12. The system defined in claim **1**, wherein the radiation source emits timed radiation signals at specific time intervals.

13. The system defined in claim **1**, wherein said radiation source is a source of pulsed radiation directed toward the ballistic path of the projectile and emitted at predetermined times (T**1**, T**2**, T**3** . . . Tn) following firing of the projectile (at time T**0**) and wherein said radiation detector receives radiation signals retro-reflected from the projectile at times (T**1***z*, T**2***z*, T**3***z* . . . Tnz) and produces electronic signals representing the vertical and lateral positions of the projectile at said times (T**1***z*, T**2***z*, T**3***z*, . . . Tnz), where "z" is a round trip transmission time of the radiation and T**1***z*, T**2***z*, T**3***z* . . . Tn are the respective times T**1**, T**2**, T**3**, . . . Tn each delayed by amount z.

14. The system defined in claim **1**, wherein said projectile has an elongate circular body with side and rear surfaces and a photo-luminescent material, disposed on the rear surface, that re-emits radiation at when excited by receipt of radiation from the radiation source.

15. The system defined in claim **14**, wherein said photo-luminescent material is additionally disposed on a side surface of the projectile body.

16. The system defined in claim **14**, wherein said photo-luminescent material is a fluorescent dye.

17. The system defined in claim **1**, wherein said projectile has an elongate circular body with side and rear surfaces a retro-reflective element, disposed on the rear surface, that reflects radiation received from a radiation source in the direction of the radiation source.

18. The system defined in claim **17**, wherein said retro-reflective element is additionally disposed on a side surface of the projectile body.

19. The ammunition projectile defined in claim **17**, wherein said retro-reflective element is affixed to the projectile body.

20. The ammunition projectile defined in claim **17**, wherein said retro-reflective element is coated on the projectile body.

21. The system defined in claim **17**, wherein said retro-reflective element is positioned and oriented on the projectile body to allow for the rearward travel of reflected light, notwithstanding a yawing motion of the projectile during flight.

22. The system defined in claim **17**, wherein said retro-reflective element is selected from the group consisting of corner cube reflectors, cat eyes and phase conjugated mirrors.

23. A system for correcting the aim of a weapon which is operative to launch a projectile from a barrel on a ballistic path toward a target, the projectile having an elongate housing with a rear end and fluorescent dye material disposed on the rear end that produces radiation at a first frequency when excited by receipt of radiation at a second frequency, said aim correcting system comprising, in combination;

(1) a radiation source of pulsed light at said first frequency directed toward the ballistic path of the projectile and emitted at predetermined times (T**1**, T**2**, T**3** . . .) following firing of the projectile (at time T**0**);

(2) a radiation detector at the location of the weapon for receiving light radiation signals re-emitted by the fluorescent dye on the projectile at times (T**1***z*, T**2***z*, T**3***z* . . . Tnz) and producing electronic signals representing the vertical and lateral positions of the projectile at said times (T**1***z*, T**2***z*, T**3***z*, . . . Tnz), where "z" is a re-emission delay and T**1***z*, T**2***z*, T**3***z* . . . are the respective times T**1**, T**2**, T**3**, . . . Tn each delayed by amount z;

(3) a signal processor, coupled to the radiation detector, for processing said electronic signals to determine the spatial (X and Y) coordinates of the projectile at said times (T**1***z*, T**2***z*, T**3***z*, . . . Tn) during flight;

(4) a computer, coupled to the processor, for calculating a lateral correction and a vertical correction in the aim of the weapon; and

(5) an output device, coupled to the computer, for facilitating an adjustment in the aim of the weapon toward the target, prior to firing the next projectile;

wherein said aim of the weapon may be adjusted after launch of the projectile to compensate for errors prior to launch of another projectile.

24. The system defined in claim **23**, wherein one of the signal processor and the computer calculates the lateral drift and the vertical drop of the projectile at said predetermined times.

25. The system defined in claim **23**, wherein said radiation source is laser source, configured to be affixed to the weapon so that a cone of illumination of the laser source intersects with the ballistic path of the projectile and excites the fluorescent dye material.

26. The system defined in claim **25**, wherein said laser source transmits light through a narrow band-pass filter so that the cone of illumination in a narrow frequency range intersects the ballistic path of the projectile and excites the fluorescent dye material.

27. The system defined in claim **23**, wherein the radiation detector is a digital camera for producing an image of the ballistic path of the projectile.

28. The system defined in claim **23**, wherein the radiation detector includes a narrow band-pass filter, allowing re-emitted light from the fluorescent dye material to be selectively received and other light excluded.

29. The system defined in claim **26**, wherein said fluorescent dye on the rear surface of the projectile responds preferentially to the laser light illumination in the narrow frequency range.

30. The system defined in claim **23**, wherein said fluorescent dye on the rear of the projectile has a protective transparent coating.

31. The system defined in claim **23**, wherein said first frequency is in one of the UV, visual and IR spectral bands.

32. The system defined in claim **23**, wherein said output device is a display.

33. The system defined in claim **32**, wherein said output device includes a aiming device allowing an operator to adjust the aim of the weapon.

34. The system defined in claim **23**, wherein the output device allows for adjustment of the aim of the weapon by imparting, post firing, lateral and vertical corrections.

35. The system defined in claim **23**, wherein the signal processor determines the time duration of the radiation signals received at said second frequency in response to radiation pulses emitted at said first frequency, and wherein said computer distinguishes the signals received from each projectile from among signals received from other, successively fired projectiles in dependence upon said time duration.

36. The system defined in claim **35**, further comprising an electronic control circuit with a clock that modulates the radiation source to emit radiation with specific time durations at specific times, thereby producing a strobe effect, illuminating the projectile's ballistic path along the projectile's ballistic flight to the target.

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