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ANTI-AIRCRAFT GUN COMPUTER

Filed June 5, 1950 3 Sheets-Sheet 1

Fig.1

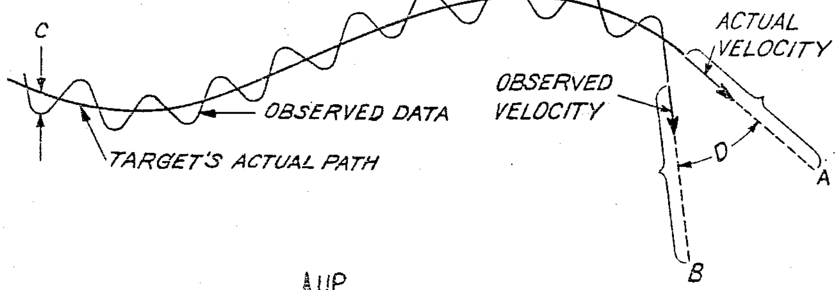


Fig.2

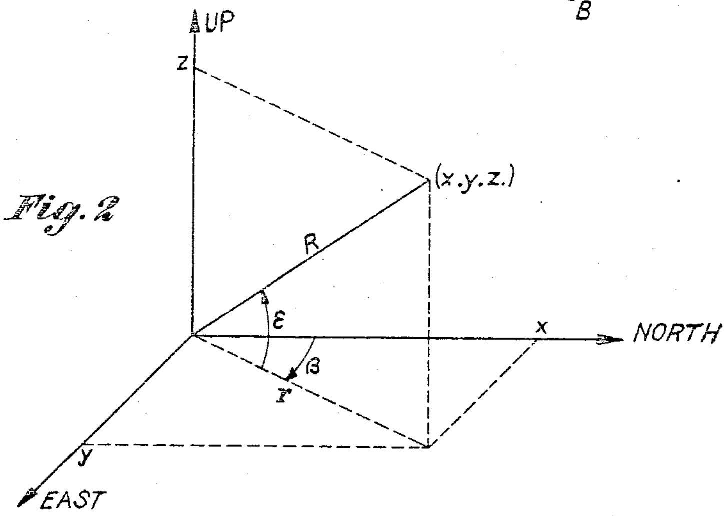
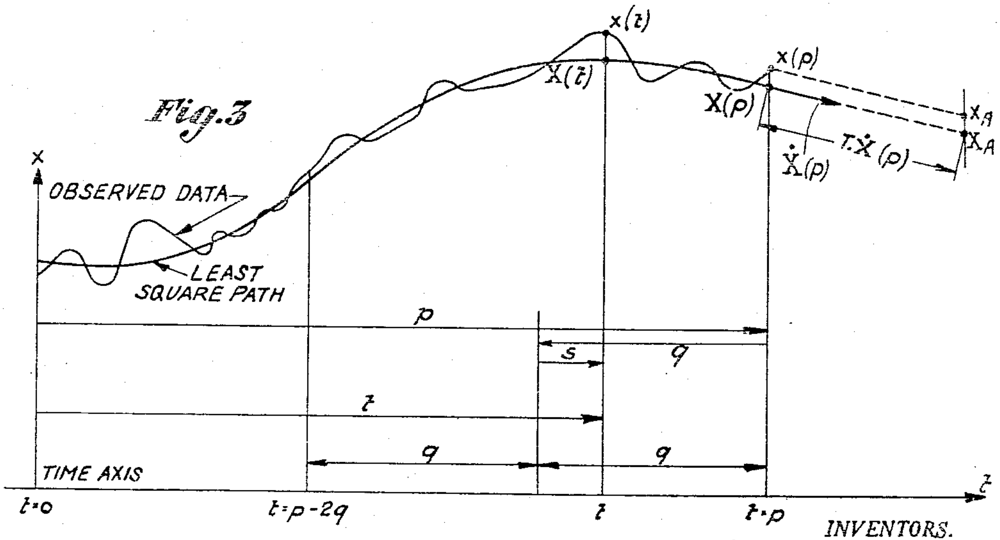


Fig.3



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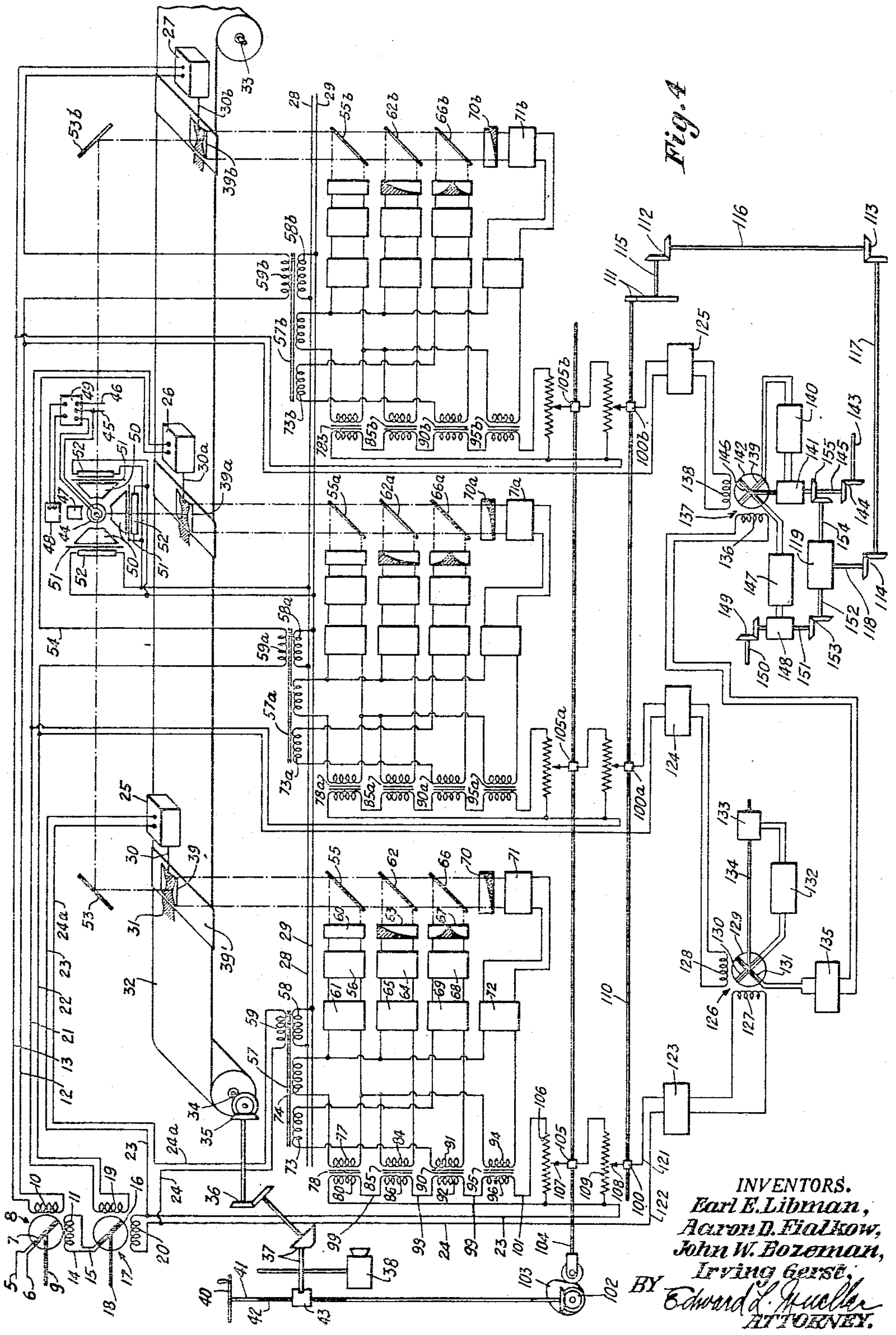

Fig. 4

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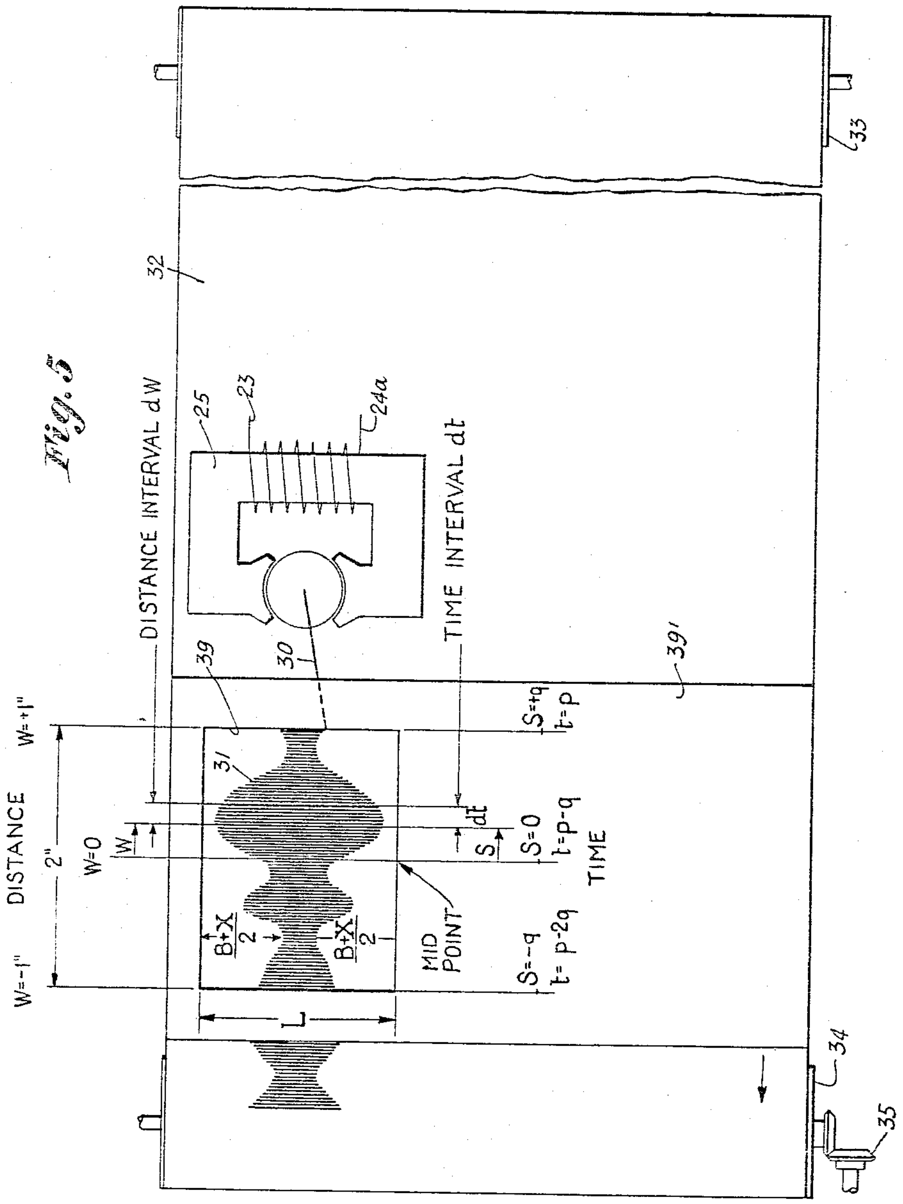
Fig. 5



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ANTI-AIRCRAFT GUN COMPUTER

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Application June 5, 1950, Serial No. 166,192

13 Claims. (Cl. 235—61.5)

This invention relates to computers and has particular reference to a system for computing a forecast of the future position of a moving target and of the direction in which a projectile should be launched so that it will hit that target.

In computers of this nature, the computation of future target position customarily proceeds on the assumption that the target will continue to move from the position it occupies at the moment of projectile launching with the instantaneous velocity and direction it has at said moment, and that the data of instantaneous position, velocity and direction of the target given by a tracking mechanism is adequate. However, the data thus obtained does not necessarily represent the true position, velocity and direction of the target.

Therefore, in accordance with the present invention and in order to obtain a more accurate forecast of future target position, the computation of such position, while it proceeds on the first of the above mentioned assumptions that the target will continue to move with the velocity and direction it has at the instant of firing a projectile thereat, further utilizes computed values of target velocity and direction that are obtained by operating upon data received from a tracking mechanism over a period of time just preceding the launching of said projectile.

The above and other objects of the invention will be made apparent from the following description and drawings which illustrate a preferred embodiment of the inventive idea.

In the drawings:

Fig. 1 is a diagram representing the observed data of a target's path, the actual path of the target, and the errors distinguishing these paths from each other;

Fig. 2 is a diagram representing the coordinate axes to which the computation is referred;

Fig. 3 is a diagram showing the time history of one of the observed coordinates of the target path and of the corresponding coordinate of the least squares path, to be hereinafter defined, along with the various symbols used in the computation;

Fig. 4 is a diagrammatic view illustrating the components which comprise a preferred embodiment of the invention; and

Fig. 5 is an enlarged fragmentary plan view of a voltage recording mechanism shown in Fig. 4.

General principles

When a tracking mechanism follows a moving target, it oscillates or hunts about its position, and the data furnished by said mechanism contains errors, and even if the data of position deviates from that target's true position in small measure so that the positional data obtained therefrom can be considered to be quite accurate, the velocity data, especially with reference to direction, may be enormously in error. As illustrated in Fig. 1, the positional error shown at C constantly varies, but, if the tracking device is an accurate one, the position indicated will always be in the immediate neighborhood of the actual position of the target. However, the observed data at the instant of firing indicates a movement of the target toward B which is different from the actual direction of motion of the target toward A. Hence, although the error in position may be very small, the error in direction may, nevertheless, be large, as indicated by the angle D.

In order to make a forecast of the future position of the target (based on the assumptions previously indicated) so that a projectile can be fired to hit the same, it is necessary to know the target position, velocity and direction at the instant said projectile is launched thereat, and a means to make an accurate determination of these quantities is essential. To make such a determination, all that is available is a continuous record of observations of target behavior. From this, by the means hereinafter shown, a path can be determined which closely approximates the true path taken by the target and from which may be determined the direction and velocity information required to launch a projectile at said target in order to hit the same.

Of the methods suited to operate upon the observed data of the target path to obtain a close approximation to the true target's path during the immediate past, and from which the velocity and direction of the target at the instant of projectile launching may be computed, the method and underlying theory utilized in this invention will now be described.

It is shown in the theory of probability that, from a series of observations in which the errors of observation constitute a normal probability distribution, the most probable value of the observed quantity results from the application of the method of least squares. In the present invention, these statistical considerations are applied to the observed path of the target to determine the most probable target path during a time interval in the immediate past.

The target's actual motion during the immediate past can be closely represented by the following set of parametric equations:

$$X(t)=A_0+A_1t+A_2t^2+\ .\ .\ .\ +A_nt^n$$
$$Y(t)=B_0+B_1t+B_2t^2+\ .\ .\ .\ +B_nt^n$$
$$Z(t)=C_0+C_1t+C_2t^2+\ .\ .\ .\ +C_nt^n$$

where the A's, B's and C's are literal coefficients to be determined, by the application of the method of least squares, from the observed data, and t is time measured from some arbitary initial instant. Indeed, for practical military flights, the above set of equations, with $n=3$, is sufficient to closely represent the target's history over a sufficiently small period of time, for $n=3$ is the lowest degree for which the set represents a three-dimensional curve whose curvature and torsion at any point may assume any values. The equations are thus

$$(1)\qquad \begin{aligned} X&=A_0+A_1t+A_2t^2+A_3t^3\\ Y&=B_0+B_1t+B_2t^2+B_3t^3\\ Z&=C_0+C_1t+C_2t^2+C_3t^3 \end{aligned}$$

In order to determine the coefficients by the method of least squares, it is necessary that these values be such that the sum of the squares of the distances at each instant, during a fixed time interval in the immediate past, between the path represented by the equations (which will be called the least squares path) and that represented by the observed data, be a minimum. This may be accomplished by utilizing the mathematical expression for the distance between the observed position of the target at any time and the corresponding point (at that time) on the least squares path. The observed position is known and the expression for the position on the least squares path contains the unspecified coefficients. Thus an expression may be obtained for the square of that distance and by adding together all such expressions during some known interval just prior to firing there is obtained a summation which contains the unspecified coefficients. By well known methods of mathematics, the coefficients may then be so determined that this sum is a minimum. This determination gives the equation of the most probable target path of the type indicated which can be obtained from the observed data.

By mathematical differentiation of the equation of the least squares path, the present target velocity vector is obtained. Then, by extrapolating along that vector for a distance equal to its magnitude multiplied by the time of projectile flight, the advance position of the target is obtained. The usual methods of ballistics may then be used to convert this advance position to the orders required to position the projectile launching device.

Mathematical analysis

Consider the horizontal plane through the present gun position. Choose a set of axes through the gun position such that the positive directions of the axes of x, y and z point North, East and Up, respectively, as shown in Fig. 2. The target at the present instant $t=p$, has the following polar coordinates: present compass bearing β, present elevation above the horizontal ϵ and present range R. These are the observable data which are usually obtained from the sighting mechanism.

Let x, y and z represent the corresponding rectangular coordinates of the target. Then, if r is the projection of R on a horizontal plane,

$$\begin{aligned} r&=R\cos\epsilon \\ x&=r\cos\beta \\ y&=r\sin\beta \\ z&=R\sin\epsilon \end{aligned} \tag{2}$$

Since these are computed from the observed polar coordinates, they may be termed the observed rectangular coordinates.

The following analysis will be carried out for x alone. The analysis for y and for z is exactly similar and need not be repeated.

As shown in Fig. 3, which figure is a plot of the variations in x with respect to time, the difference at any instant t between the observed x coordinate and the corresponding X coordinate of the least squares path is $X(t)-x(t)$. The sum of the squares of these differences over an arbitrary period of $2q$ seconds just prior to the present instant $t=p$ is equal to the integral

$$\int_{t=p-2q}^{t=p}[X(t)-x(t)]^2dt \tag{3}$$

The most probable value of the X-coordinate at a given time "p" is determined by selecting values for the coefficients A_0, A_1, A_2 and A_3 in Equations 1 such that

$$\int_{t=p-2q}^{t=p}[X(t)-x(t)]^2dt=\text{minimum} \tag{4}$$

The velocity of a target flying along the least squares path at instant t is $X(t)$ where $X(t)$ is intended to mean

$$\frac{dX(t)}{dt}$$

and its velocity at the present instant $X(p)$.

The advance position, that is, point A (Fig. 1) toward which it is desired that the projectile be fired at the time $t=p$ to obtain a hit has, therefore, the x-coordinate $X(p)+T\cdot X(p)$ where T is time of projectile flight; $X(p)$ being, of course, the present X coordinate of the least squares path. However, since $X(p)$ and $x(p)$ have a relatively small positional error (as may be seen from Fig. 3), considerable simplification results if instead of $X(p)$, which must be computed, $x(p)$, which is known, is used, so that the projectile is actually directed to hit the point whose x-coordinate is

$$x_A=x(p)+T\cdot X(p) \tag{5}$$

The target's least squares path is given by Equations 1.

If, for convenience, time is measured from an arbitrarily chosen instant q seconds prior to the present instant and this time is indicated by the variable s, there is obtained, by substituting $t=p-q+s$ (Fig. 3) in Equations 1, the following expression for $X(t)$ and, of course, similar expressions for $Y(t)$ and $Z(t)$,

$$X(t)=a_0+a_1s+a_2s^2+a_3s^3 \tag{6}$$

where the a's are functions of p and q.

Similar substitution in equation 4 gives:

$$\int_{s=-q}^{s=+q}[a_0+a_1s+a_2s^2+a_3s^3)-x(t)]^2\cdot ds=\text{minimum} \tag{7}$$

The values of the a's that make the integral a minimum are, by the well known methods of calculus:

$$\begin{cases} a_0=\frac{3}{8}[3K_0-5K_2] \\ a_1=\frac{525}{8q}\left[\frac{1}{7}K_1-\frac{1}{5}K_3\right] \\ a_2=\frac{15}{8q^2}[3K_2-K_0] \\ a_3=\frac{525}{8q^3}\left[\frac{1}{3}K_3-\frac{1}{5}K_1\right] \end{cases} \tag{8}$$

where

$$\begin{cases} K_0=\int_{-1}^{+1}x\,dw \\ K_1=\int_{-1}^{+1}xw\,dw \\ K_2=\int_{-1}^{+1}xw^2dw \\ K_3=\int_{-1}^{+1}xw^3dw \end{cases} \tag{9}$$

and

$$w=\frac{s}{q} \tag{10}$$

From the observed x's and the chosen q, the K's are known by Equations 9, and from Equations 8 all of the a's are known and, therefore, the coefficients in the Equation 6 for the X coordinate of the least squares path are now known. Differentiation of Equation 6 with respect to t gives

$$\dot{X}(p)=\frac{15}{q}\left[-\frac{1}{4}K_0-2K_1+\frac{3}{4}K_2+\frac{7}{2}K_3\right] \tag{11}$$

and so by Equation 5, x_A is known.

Following an analogous process for Y and Z, Y_A and Z_A are obtained which give the rectangular coordinates of the advanced point at which the projectile is launched to obtain a hit. By converting these back into polar coordinates, the data, after ballistic corrections, for training and elevating a gun or other projectile launching apparatus, and the range for which the fuse of the projectile should be set, are known.

The computer

In actual practice, target range, elevation and bearing may be obtained from a tracking device such as a radar, or an optical sight and range finder. The elevation and bearing thus obtained will be available, mechanically, as angular displacements from the axes of the tracking device. From a radar, the range will be available as a voltage; and from an optical range finder, as a mechanical angular displacement which may be converted to a voltage.

The voltage representing range is introduced into the computer by way of the leads **5** and **6** (Fig. 4) thus energizing the rotor **7** of the resolver **8**, which rotor is positionable by means of the shaft **9** with respect to the mutually perpendicular stator coils **10** and **11**. The shaft of the resolver **8** is positioned by the mechanical input of target elevation and, therefore, the voltage induced from the rotor into the stator coils will be, respectively,

$$R \sin \epsilon = z,$$

and

$$R \cos \epsilon = r$$

which outputs are respectively on the leads **12**, **13** and **14**, **15**.

The voltage on leads **14** and **15**, proportional to r, is introduced into the rotor **16** of the resolver **17** which is similar in construction to the resolver **8** and whose shaft **18** receives the mechanical input of target bearing and positions the rotor **16**. The voltages then induced in the stator windings **19** and **20** are

$$r \sin \beta = y$$

and

$$r \cos \beta = x$$

Thus, there is obtained the rectangular coordinates x, y and z of the target's present position.

Since the subsequent operations performed by the computer are the same for each of the coordinates x, y and z it will be sufficient, as before, to trace the operations performed upon the x coordinate alone, it being understood that similar treatment is accorded the y and z coordinate data before they are recombined finally at the output.

To the voltage representing the instantaneous value of x from leads **23** and **24**, is added a biasing voltage of magnitude $(L-B)$ by placing the secondary **59** of transformer **57** in series between leads **24** and **24***a*, where L is the window width and B is a quantity of magnitude greater than the maximum negative value of x and is such that $L-(B+x)$ and $B+x$ are always positive. The alternating voltage on the primary **58** of transformer **57** is supplied by leads **28** and **29** from the same source as that supplied to leads **5** and **6** of resolver **8**.

The voltage $L-(B+x)$ actuates the galvanometer **25** and causes its pen **30** to trace an opaque area **31** on a transparent surface or ribbon **32** of width $L-(B+x)$. Since the window **39** in the mask **39'** directly above the surface **32** is of width L, there is then left a transparent portion whose width is $B+x$. The ribbon **32** is carried by the rollers **33** and **34** and is of sufficient width to accommodate without overlapping the three traces made by the galvanometers **25**, **26** and **27**. The roller **34** is driven under the window **39**, whose length is two inches, at the rate

$$\frac{1}{q}$$

inches per second by means of the gears **35** and **36**, the speed selector **37** into which q is set, and the time motor **38**. This quantity q, which is arbitrarily chosen, may be of the order of seconds, and is introduced by means of the hand wheel **40**, which turns the shaft **41** whose threaded portion **42** causes the traveling nut **43** to vary the position of the elements of the selector **37**, and thus the speed of the drive to roller **34**.

Since the ribbon **32** is running at a speed of

$$\frac{1}{q}$$

inches per second, the time it requires to move two inches is $2q$, so that the window **39** covers the sampling time $2q$. By Figs. 3 and 5, s is time measured from the midpoint of the sampling time interval $2q$, and the ribbon running at the speed

$$\frac{1}{q}$$

moves relative to the midpoint of the window and in the time s will move the distance

$$s \cdot \frac{1}{q}$$

which, by Equation 10 is w. Therefore, it follows from Figs. 3 and 5 that w measures the distance along the window **39** from the midpoint to the point on the said ribbon corresponding to the instant t.

In the time dt, the strip moves a distance

$$\frac{1}{q} \cdot dt$$

which equals dw from Equation 10 (Fig. 5). In an elementary piece of the ribbon at distance w from the center line of the window and of width dw, the transparent area is $(B+x).dw$.

A light source **44** is energized by way of the leads **45** and **46**. This light source must be of constant intensity. Of the various ways for obtaining such constancy the following is given as an illustration. The lens system **47** focuses the light upon the photocell **48** that controls the activity of the amplifier **49**, which amplifier controls the power delivered to the light source. This arrangement causes the power delivered to said source to vary in such a way as to maintain its brightness constant. In order to electrically manipulate the computing devices receiving the light after transmission through the ribbon **32**, it is desired that the light be modulated with the line frequency. The following is given as an illustration of one way to secure this desideratum.

A lens system **50** causes a part of the light from the source to be columnated and these parallel rays are transmitted through three sets of polarizing filters **51** and associated polarizing cells **52**, said sets being angularly disposed relative to each other about the light source **44** and each being individual to one of the coordinates x, y and z. Two of said sets direct their rays, respectively, to the mirrors **53** and **53***b* and thence to the windows **39** and **39***b* while the rays from the third set are transmitted directly to the window **39***a*. Each polarizing cell is activated by connection to leads **28** and **29** so that the light therethrough changes its plane of polarization at line frequency, and the combined filter **51** and cell **52** of each set therefore modulates the parallel rays in intensity at the rate at which the cell **52** is caused to change its plane of polarization. The parallel rays emanating from the three lens systems **50** are thus caused to pass through the windows **39**, **39***a* and **39***b* to the associated mirrors **55**, **55***a* and **55***b* of the three optical systems shown; and since the computations for the coordinates x, y and z are effected in the same manner, the following detailed description will be confined to the optical system obtaining its light through the window **39**.

The amount of light coming through this window will be determined by the transparent area which, in turn, is the entire window area diminished by the opaque portion written into that area by the galvanometer pen **30**. It has been shown that the light through the narrow ribbon of width dw (Fig. 4) is $(B+x)dw$ and thus the light through the entire window is

$$(12) \qquad \int_{-1}^{+1} [B+x]dw$$

This light is caused to fall on the mirror **55**, which mirror is so constituted as to permit ¾ of the light incident thereon to be transmitted therethrough and the remaining ¼ to be reflected therefrom. The reflected light passes through the uniform filter **60** and falls on a photoelectric cell **56**. The voltage produced thereby is proportional to the integral (12). This integral is, by Equation 9,

$$(13) \qquad 2B+\int_{-1}^{+1} x\,dw=2B+K_0$$

which is the entire light falling on photocell **56** and is therefore the voltage output of amplifier **61**.

The remainder of the light, which was transmitted through the mirror **55**, falls upon the mirror **62**, which mirror is similar to the mirror **55** in that part of the light incident thereupon is transmitted and the remainder is reflected. One-third of the light incident upon the mirror **62** is reflected therefrom. That passing through the ribbon of width dw at distance w from the window midpoint point is, as before, proportional to $(B+x)\ dw$ which light then passes through the filter **63** whose transmission varies along its vertical length, so that at a point distance w from its midpoint it transmits the fraction ½ $(1+w)$ of the light falling upon it. Since w lies in value between $+1$ and -1, it follows that ½$(1+w)$ is always positive and not greater than 1. Thus the light $(B+x)dw$ from the ribbon of width dw, after passing through the filter, is ½$(1+w)(B+x)dw$, and the entire light through filter **63** is, by Equation 9.

$$(14) \qquad \tfrac{1}{2}\int_{-1}^{+1} (B+x)(1+w)dw=\tfrac{1}{2}[K_1+(K_0+2B)]$$

which is the entire light that falls upon the photocell **64** and the voltage output of amplifier **65** is $K_1+(K_0+2B)$.

The remaining two-thirds of the light transmitted through the mirror **62** is incident upon the mirror **66** which, like the foregoing mirrors, transmits one part and reflects another part of the light incident thereon. One-half of the light incident thereon is reflected and passes through a filter **67** whose transmission, at a point distance w from its midpoint, is the factor w^2 of the incident light so that the entire light falling on the photocell **68** is proportional to

$$(15) \qquad \int_{-1}^{+1} (B+x)w^2dw=K_2+\tfrac{2}{3}B$$

by Equation 9. This is, therefore, the output of amplifier **69**.

The remainder of the light transmitted through the mirror **66** causes the image in the window **39** to fall upon the filter **70** whose transmission at any point distance w from the midpoint is the fraction ½$(1+w^3)$ of the incident light so that the entire light falling on photocell **71** is

$$(16) \qquad \tfrac{1}{2}\int_{-1}^{+1} (B+x)(1+w^3)dw=\tfrac{1}{2}[K_3+(K_0+2B)]$$

by Equation 9. Thus, the output of amplifier **72** is $K_3+(K_0+2B)$.

The transformer **57** has two additional windings **73** and **74**, the winding **74** yielding a voltage 2B and the winding **73**

$$\frac{2B}{3}$$

The output voltage K_0+2B of amplifier **61** in opposition series with the output voltage 2B of secondary **74** of transformer **57** puts voltage K_0 across the primary **77** of transformer **78**. This transformer having a 4:1 winding ratio, the voltage

$$\frac{-K_0}{4}$$

appears on its secondary **80**.

The output voltage K_0+2B of amplifier **61** in opposition series with the output voltage $K_1+(K_0+2B)$ of amplifier **65**, puts voltage K_3 across the primary **84** of transformer **85**. This transformer having a 1:2 winding ratio yields on its secondary **86** the voltage $-2K_1$.

The output voltage $K_2+\tfrac{2}{3}B$ of amplifier **69** in opposition series with the output voltage ⅔B of the secondary **73** puts voltage K_2 across the primary **91** of transformer **90**. This transformer having a 4:3 winding ratio, the voltage ¾K_2 appears on its secondary **92**.

The output voltage $K_3+(K_0+2B)$ of amplifier **72** in opposition series with the output voltage K_0+2B of amplifier **61** puts voltage K_3 across the primary **94** of transformer **95**. This transformer having a 2:7 winding ratio yields on its secondary **96** the voltage $7/2K_3$.

By means of the leads **99**, the secondaries **96**, **92**, **86** and **80** are placed in series so that the voltage which appears across the leads **23** and **101** is equal to

$$\left[-\frac{K_0}{4}-2K_1+\frac{3}{4}K_2+\frac{7}{2}K_3\right]$$

This expression is multipled by

$$\frac{15}{q}$$

by means of the shaft **41**, the gears **102** and the cam **103**, whose cam surface has for its generating expression

$$\frac{15}{q}$$

and is driven by the shaft **41**.

The follower **104** whose position is then proportional to

$$\frac{15}{q}$$

carries the sliding contact **105** of a potentiometer **106** which is joined at its ends to the leads **23** and **101**. The voltage from the tap **107** to the lead **23** will therefore be the voltage across the entire potentiometer multiplied by the factor

$$\frac{15}{q}$$

i. e., giving

$$(17) \qquad \dot{x}(p)=+\frac{15}{q}\left[-\frac{K_0}{4}-2K_1+\frac{3}{4}K_2+\frac{7}{2}K_3\right]$$

This voltage is then multiplied by the time of flight T, as required by Equation 5, giving $T\cdot X(p)$, by means of the positionable tap **108** of potentiometer **109** which connects the tap **107** to lead **23**. The position of tap **108** is made proportional to time of flight T by being driven by the traveling nut **100** on the shaft **110** which, by means of the gears **111**, **112**, **113**, **114** and the shafts **115**, **116**, **117**, is turned proportionally to T by the output shaft **118** of the time of flight computer **119** which may be of a construction similar to that shown in U. S. Patent 2,403,543, dated July 9, 1946.

The voltage thus obtained across leads **121** and **122** is $T\cdot\dot{X}(p)$ and this, in series with the voltage x available from the resolver **17** on the leads **23** and **24**, yields the sum $T\cdot\dot{X}(p)+x(p)$ which, by Equation 5, is x_a which is the rectangular cordinate of the target position at the time T in the future.

The mechanism above described for the computation of x is duplicated in Fig. 4 for y and z which are converted into Y_a and Z_a, and like numerals are employed to designate similar parts with the addition to said numerals of the subscripts a and b denoting the different portions of the mechanism for the computation of y and z, respectively.

The voltages represented by x_a, y_a and z_a are amplified, respectively, in the amplifiers **123**, **124** and **125**. The amplified voltages representative of x_a and y_a are combined in the combining mechanism **126** which has two field coils **127** and **128** so arranged as to have their respective fields at right angles to each other. The rotor

129 has two coils **130** and **131** and the voltage induced in said rotor is amplified in amplifier **132** and used to excite the motor **133** to drive the shaft **134** which positions said rotor. If any voltage is induced in the coil **130**, the motor will be energized and will continue to drive the shaft **134** until said coil is so positioned that the voltage induced therein is zero; that is to say, it is parallel to the resultant field produced by x_a and y_a. The coil **131** will therefore be at right angles thereto and have an output voltage proportional to this resultant field which from equations similar to (2), but with subscripts *a*, corresponds to r_a and the position of the shaft **134** by the same equations will be proportional to the advance bearing β_a.

The voltage proportional to r_a on coil **131** is amplified in the amplifier **135** and energizes winding **136** of the combining mechanism **137** whose remaining winding **138** is energized by z_a. In the same way as for the element **126**, the winding **139** whose output is amplified in the amplifier **140** will drive the motor **141** which in turn will position the rotor **142** until the coil **139** has no voltage induced therein. The position of the shaft **143**, which is coupled by means of the gears **144** and shaft **145** to the motor **141**, will therefore represent ϵ_a and the output of the coil **146**, the advance range R_a to the target.

The advance target range R_a is amplified in amplifier **147** and is used to position a servomotor **148** making this range available as a displacement by means of gears **149** on the shaft **150**.

The time of projectile flight is a function of the advance target range and elevation. Since this is a function of two variables, a three-dimensional cam is generally employed, although this is not the only method available, to compute the time of projectile flight from such data. The mechanism **119** represents such a time of flight computer which may employ any of the well known methods of taking into account such characteristics and when operated by range R_a, as supplied by servomotor **148**, by way of shafts **151** and **152** and gears **153**, and advance elevation by way of shafts **145**, **154** and gears **155**, it will compute the time of flight for the projectile so that it may be launched on a collision trajectory. The time of flight thus computed is the time of flight which, by way of shaft **118**, gears **114**, etc., is introduced into the computation of the coordinates on shaft **110** to position the variable taps of potentiometers **109**, **109*a*** and **109*b***.

To avoid complicating the drawings with mechanisms old in the art, no means are shown for the usual corrections required in ballistics for wind velocity, change in projectile launching velocity, superelevation and the like. Means to accomplish these functions may be driven by the outputs of future target coordinates as they are produced by the mechanism disclosed, and the manner of their accomplishment is immaterial to the manner in which these future target coordinates are evolved.

The realization of the gun positions by the use of the principles described above to the known positions occupied by the target may be accomplished by means other than those specifically disclosed herein. The required integrations might, for example, be performed by ball and table integrators and the required multiplications, divisions, additions and subtractions by means of linkages, potentiometers or other means known to the computing art. The embodiment herein shown and described, together with the method of computation, constitutes the invention, and said embodiment is intended merely to illustrate rather than to limit and define the mode of realization and scope of the invention, reference being had to the appended claims for that purpose.

What is claimed is:

1. An apparatus for computing the direction in which a projectile launching device must point in order that a projectile launched therefrom will score a hit on a moving target, said apparatus comprising input means for the observed spherical coordinates of target position, computing means coacting with said input means for continuously determining, by computations effected by said computing means and depending upon the coordinates of every observed position that the target occupies during an arbitrary interval in the immediate past, the most probable actual path being followed by said target and the velocity of said target in said most probable path, said computing means including, in combination, means responsive to said input means for resolving said observed data of every target position into rectangular coordinates, means for forming a continuous record of each of said rectangular coordinates of target position so resolved, means for sensing the entire record of each of said recorded rectangular coordinates of target positions as recorded over said arbitrary interval in the immediate past, optical means including a system of associated light reflectors and filter elements coacting with said sensing means, means responsive to said optical means for converting each of said sensed records to yield one component of the velocity of the target in said most probable path, means to utilize the components thus obtained for extrapolating along the line parallel to the tangent of said most probable path and through the observed position of the target at the instant of projectile launching to determine a point whose distance along said tangent from said observed target position at said instant is the product of the time of projectile flight and of the velocity of said target in said computed path, means for computing the projectile time of flight, and means to convert the coordinates of said extrapolated point into range and angles of train and elevation for the projectile launching device.

2. An apparatus for computing the direction in which a projectile launching device must point in order that a projectile launched therefrom will score a hit on a moving target, said apparatus comprising input means for the observed spherical coordinates of target position, computing means coacting with said input means to continuously determine, by computations depending upon the coordinates of every observed position that the target occupies during an arbitrary interval in the immediate past, the most probable path of said target during said interval, said computing means including, in combination, means responsive to said input means for resolving said observed data of every target position into rectangular coordinates, means for forming a continuous record of each of said rectangular coordinates of target position so resolved, photometric means including coacting light filters and photo cells for sensing the entire record of each of said recorded rectangular coordinates of target positions as recorded over said past arbitrary interval, optical means including a system of associated light reflectors and filtering elements coacting with said sensing means, means responsive to said optical means for converting each of said sensed records to yield one component of the velocity of the target in said most probable path, means to utilize the components thus obtained for extrapolating along the line parallel to the tangent of said most probable path and through the observed position of the target at the instant of projectile launching to determine a point whose distance along said tangent from said observed target position at said instant is the product of the time of projectile flight and of the velocity of said target in said computed path, means for computing the projectile time of flight, and means to convert the coordinates of said extrapolated point into range and angles of train and elevation for the projectile launching device.

3. The method of computing the most probable advanced coordinates of a target's position at a time of flight T in the future, which method consists in continuously observing and recording the observed instantaneous coordinates (x, y, z) of a target's position, deter-

mining the values of the coefficients A_i, B_i, C_i ($i=1, 2, \ldots n$) of a computed curve of the form

$$X(t)=A_0+A_1t+A_2t^2+ \ldots +A_nt^n$$
$$Y(t)=B_0+B_1t+B_2t^2+ \ldots +B_nt^n$$
$$Z(t)=C_0+C_1t+C_2t^2+ \ldots +C_nt^n$$

so that said curve best represents the actual positions of the target, determining from the computed curve the instantaneous rate of change of target position X, Y, Z on that curve and extrapolating at the determined rate of change and for the time T along a line through the observed target position at the present instant and parallel to the tangent to the computed curve at that instant to obtain the most probable target coordinates at said time of flight in the future.

4. The method of computing the most probable advanced coordinates of a target position at a time of flight T in the future which consists in continuously observing and recording the instantaneous observed coordinates (x, y, z) of a target's position, determining the values of the coefficients A_i, B_i, C_i ($i=1, 2, \ldots n$) of a computed curve of the form

$$X(t)=A_0+A_1t+A_2t^2+ \ldots +A_nt^n$$
$$Y(t)=B_0+B_1t+B_2t^2+ \ldots +B_nt^n$$
$$Z(t)=C_0+C_1t+C_2t^2+ \ldots +C_nt^n$$

so that the sum of the squares of the differences between the coordinates represented by said computed curve at any instant and the corresponding coordinates of the observed target position at that instant over an arbitrary interval of time in the immediate past is a minimum, determining from the computed curve the instantaneous rate of change of target position along that curve, and extrapolating at the determined rate of change and for the time T along a line through the observed target position at the present instant and parallel to the tangent to the computed curve at that instant to obtain the most probable target coordinates at said time of flight in the future.

5. The method of computing the most probable advanced coordinates of a target's position at a time of flight T in the future which consists in continuously observing and recording the observed instantaneous coordinates (x, y, z) of a target's position, determining the values of the coefficients A_i, B_i, C_i ($i=1, 2, \ldots n$) of a computed curve of the form

$$X(t)=A_0+A_1t+A_2t^2+ \ldots +A_nt^n$$
$$Y(t)=B_0+B_1t+B_2t^2+ \ldots +B_nt^n$$
$$Z(t)=C_0+C_1t+C_2t^2+ \ldots +C_nt^n$$

so that the sum of the squares of the differences between the coordinates represented by said computed curve at any instant and the corresponding coordinates of the observed target position at that instant over an arbitrary interval of time in the immediate past is a minimum with the value of n being restricted to $n \leqq 3$, determining from the computed curve the instantaneous rate of change of target position along that curve, and extrapolating at the determined rate of change and for the time T along a line through the observed target position at the present instant and parallel to the tangent to the computed curve at that instant to obtain the most probable target coordinates at said time of flight in the future.

6. The method of computing the most probable advanced coordinates of a target position at a time of flight T in the future which consists in continuously observing and recording the instantaneous observed coordinates (x, y, z) of a target's position, determining the values of the coefficients A_i, B_i, C_i ($i=1, 2, \ldots n$) of a computed curve of the form

$$X(t)=A_0+A_1t+A_2t^2+ \ldots +A_nt^n$$
$$Y(t)=B_0+B_1t+B_2t^2+ \ldots +B_nt^n$$
$$Z(t)=C_0+C_1t+C_2t^2+ \ldots +C_nt^n$$

so that the sum of the squares of the differences between the coordinates represented by said curve at any instant and the corresponding coordinates of the observed target position at that instant over an arbitrary interval of time in the immediate past is a minimum with the value of n being restricted to $n \leqq 3$, determining from the computed curve the instantaneous rate of change of X, Y, Z and considering the same to be the target velocity at that instant, and extrapolating at the determined rate of change and for the time T along a line through the observed target position at the present instant and parallel to the tangent to the computed curve at that instant to obtain the most probable target coordinates at said time of flight in the future.

7. An apparatus for computing the direction in which a projectile launching device must point in order that a projectile launched therefrom will score a hit on a moving target, said apparatus comprising input means for the observed data of target position, computing means coacting with said input means for continuously determining, by computations depending upon the coordinates of every observed position that the target occupies during an arbitrary interval in the immediate past, the most probable path of said target during said interval, said computing means including, in combination, means responsive to said input means for resolving said observed data into rectangular coordinates, means to form a continuous record of each coordinate, photometric means for simultaneously sensing the entire records of all said coordinates during said past arbitrary interval, optical means including a system of associated light reflectors and filtering elements coacting with said sensing means, said light reflectors each reflecting a portion of the light from said sensed records, a plurality of transformers having windings connected to said optical means for converting said sensed records to yield the various components of target velocity in said most probable path, means connected to said transformers for utilizing said various components to extrapolate along a line parallel to the tangent of said most probable path and through the observed position of the target at the instant of projectile launching to determine a point whose distance along said tangent from said observed target position at said instant is the product of the time of projectile flight and of the velocity of said target in said computed path, means for computing the projectile time of flight, and means to convert the coordinates of said extrapolated point into range and angles of train and elevation for the projectile launching device.

8. In an apparatus for determining the most probable position of a moving object from approximate observations of its variable coordinates, a recording device adapted to produce a record of the approximate observations of one of said coordinates over a given time interval, filter means, input means for effectively presenting to said filter means the record produced by said recording device, said filter means having portions thereof with relatively different transmission properties and being adapted to respond in non-uniform fashion to different portions of the record presented by said input means according to predetermined functional relationships consistent with the method of least squares, and output means responsive to the intelligence transmitted by said filter means and adapted to combine the variant effects thereof according to predetermined relationships consistent with the method of least squares for providing an output signal which represents the most probable value of said one coordinate of said object as of a selected instant.

9. In an apparatus for determining the most probable position of a moving object from approximate observations of its variable coordinates, a recording device adapted to produce a record of the approximate observations of one of said coordinates over a given time interval, filter means comprising a plurality of filters, input means for effectively presenting to each of said filters the record produced by said recording device, said filters having

relatively different transmission properties, and at least some of said filters being adapted to respond in non-uniform fashion to different portions of the record presented by said input means, all according to predetermined relationships consistent with the method of least squares, and output means responsive to the intelligence transmitted by said filter means and adapted to combine the variant effects of each filter and the outputs of the several filters according to predetermined relationships consistent with the method of least squares for providing an output signal which represents the determined rate at which said one coordinate of said object is varying at a selected instant.

10. In an apparatus for determining the most probable position of a moving object from approximate observations of its variable coordinates, recording means adapted to produce individual records of the approximate observations of the respective coordinates over a given time interval, filter means, input means for effectively presenting to said filter means the records produced by said recording means, said filter means comprising a plurality of filter devices, one for each of said records, each of said filter devices having portions thereof with relatively different transmission properties and being adapted to respond in non-uniform fashion to different portions of its respective input record according to predetermined relationships consistent with the method of least squares, and output means responsive to the intelligence transmitted by each of said filter devices and adapted to combine the variant effects thereof according to predetermined relationships consistent with the method of least squares for providing output voltages that respectively represent the determined rates at which the coordinates of said object are varying at a selected instant.

11. In an apparatus for determining the most probable position of a moving object as of a given time from approximate observations of the variable coordinates defining the instantaneous position of the object, recording means adapted to produce individual records of the approximate observations of the respective coordinates over a given time interval, filter means, input means for effectively presenting to said filter means the records produced by said recording means, said filter means comprising a plurality of filter devices, one for each of said records, each of said filter devices having portions thereof with relatively different transmission properties and being adapted to respond in non-uniform fashion to different portions of its respective input record according to predetermined relationships consistent with the method of least squares, and output means responsive to the intelligence transmitted by each of said filter devices and adapted to combine the variant effects thereof according to predetermined relationships consistent with the method of least squares for providing output voltages that respectively represent the most probable coordinates of said object at a selected instant.

12. In an apparatus for determining the most probable value of a variable from approximate observations thereof over a given time interval, a record medium, a recording device movable relative to said medium for graphically recording thereon the approximate observations of said variable in spaced relationship, function filter means for deriving from the record on said medium a predetermined interval function of the recorded values, and means for limiting at both extremities thereof the portion of said record which is effectively presented to said function filter means.

13. In an apparatus for determining the most probable position of a moving object from approximate observations of its variable coordinates over a given time interval, a record medium, a recording device movable relative to said medium for graphically recording thereon the approximate observations of at least one of said coordinates in spaced relationship, function filter means for deriving from the record on said medium a predetermined integral function of the recorded values according to the method of least squares, and means for limiting at both extremities thereof the portion of said record which is effectively presented to said function filter means.

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