

Description

This invention relates generally to methods and apparatus for measuring the muzzle velocity of a projectile ejected from a gun barrel, and, more particularly, to methods and apparatus of this kind that measure velocity using Doppler radar.

Apparatus of this particular kind (an example of which is disclosed in US Patent No 3 918 061) are frequently called muzzle velocity chronographs. They include a radar device mounted on the gun barrel for directing a radar signal at the ejected projectile and correlating the radar signal with a reflected return signal, to produce a conventional Doppler signal. Each cycle of the Doppler signal represents movement of the projectile by a distance equal to one-half the wavelength of the radar signal. The typical muzzle velocity chronograph counts the number of cycles occurring in the Doppler signal per unit time, to determine the projectile's velocity. This process is repeated incrementally, to produce a velocity profile, from which the projectile's initial muzzle velocity can be determined.

Chronographs of the kind described above, which utilize time domain processing, are usually effective in measuring a projectile's muzzle velocity. However, such chronographs have not proven to be entirely effective in situations where the return signal from the projectile is relatively weak or where substantial interference is present. This occurs, for example, when certain base-bleed ammunition is used, which produces fragments that are significantly larger than the projectile of interest.

The publication IEEE Transactions on Aerospace and Electronic Systems Vol AES10, No 4, July 1974, pages 479 to 486 suggests a velocity signal detection technique in which each possible frequency for which a signal magnitude exists is used as a test frequency and compared to a signal magnitude at a selected number of adjacent frequencies on either side of the test frequency. The instances in which the test frequency magnitude exceeds the magnitude at an adjacent frequency are counted and a valid velocity signal is assumed when the count exceeds some threshold count value.

While the IEEE article suggests the transformation of radar Doppler signals into the frequency domain it does not suggest use of the transformation for a muzzle velocity radar system. Also, the method suggested would have certain disadvantages if used in conjunction with a muzzle velocity radar system.

It should therefore be appreciated that there is a need for an improved muzzle velocity chronograph that can effectively measure a projectile's muzzle velocity even when the projectile is rela-

tively small and when the projectile is moving in the same direction as larger radar-reflecting fragments.

According to the present invention there is provided Doppler radar apparatus for determining the initial velocity of a projectile ejected from a muzzle, comprising radar means for producing a Doppler signal indicative of movement of the projectile relative to the muzzle; Fourier transform means for operating on the Doppler signal, and detection means responsive to the Fourier transform means to measure the velocity of the projectile characterised in that the Fourier transform means operates on a predetermined plurality of segments of the Doppler signal, each segment representing a separate time period, to produce a corresponding plurality of frequency spectrum signals; and in that the detection means is responsive to the plurality of frequency spectrum signals, for measuring the velocity of the projectile during the time period associated with each successive segment of the Doppler signal; and includes means responsive to the projectile velocities measured for the plurality of successive time periods, for estimating the initial, muzzle velocity of the projectile by extrapolation back to the zero time intercept.

According to the present invention there is further provided a Doppler radar method for determining the initial velocity of the projectile ejected from a muzzle, comprising the step of: producing a Doppler signal indicative of movement of the projectile relative to the muzzle characterised by the steps of operating on a predetermined plurality of segments of the Doppler signal, each segment representing a separate time period, to produce a corresponding plurality of frequency spectrum signals, processing the plurality of frequency spectrum signals to measure the velocity of the projectile during the time period associated with each successive segment of the Doppler signal; and estimating the initial, muzzle velocity of the projectile based on the projectile velocities measured by the step of processing for the plurality of successive time periods and extrapolating back to the zero time intercept.

Methods and apparatus for determining the muzzle velocity from a gun and embodying the invention will now be described by way of example, with reference to the accompanying diagrammatic drawings, in which:

Fig 1 is a simplified block diagram of a Doppler radar apparatus for measuring the initial, muzzle velocity of a projectile ejected from a gun barrel; Fig 2 is a simplified flowchart showing the operational steps performed by the signal processor of Fig 1, in processing the information present in the radar Doppler signal to determine the projectile's muzzle velocity;

Fig 3 is a graph showing the frequency spectrum of one exemplary time segment of a radar Doppler signal processed by the apparatus of Fig 1, a variable threshold being superimposed on the graph and indicating the detection of one projectile and one group of fragments;

Fig 4 is a schematic diagram showing a pair of closely-spaced, sliding windows that are used to produce a constant false alarm rate threshold with which the frequency measurement f_0 is compared by the signal processor of Fig 1.

Fig 5 is an expanded view of the portion of the graph of Fig 3, where the frequency measurements corresponding to the projectile are shown to exceed their respective thresholds; and

Fig 6 is a graph showing the projectile velocity measurements for a number of successive time periods with a least mean square error velocity profile also being shown and extended back to the moment of firing, to indicate the projectile's initial muzzle velocity.

With reference now to the drawings, and particularly to Fig 1, there is shown a chronograph apparatus for estimating the initial, muzzle velocity of a projectile 11 ejected from a gun barrel 13. The apparatus estimates the projectile's muzzle velocity based on a succession of velocity measurements made as the projectile moves rapidly away, to a range of as much as about one thousand meters. The apparatus includes a radar device 15 mounted on the gun and having an antenna 17 for transmitting a radar signal in the expected direction of the ejected projectile. Return signals reflected from the projectile, and any other objects (e.g. fragments 18) located in the path of the radar signals, are received by the same antenna and correlated by the radar device with the original radar signals, to produce a Doppler signal for output on line 19. Return radar signal pulses received from any object moving away from the gun barrel 13 will have a frequency that is lower than the transmit frequency by an amount proportional to the object's instantaneous velocity. The Doppler signal therefore will include a component having a frequency proportional to this difference. In the past, systems of this kind have typically measured this velocity by simply counting the number of cycles occurring in the Doppler signal over a predetermined time period. This has not proven effective, however, in situations where the Doppler signal includes significant frequency components derived from other moving objects 18 in the general direction of the projectile 11 of interest, which can mask the Doppler signal component of interest.

The apparatus of Fig 1 overcomes this deficiency of prior chronograph apparatus by digitally processing the Doppler signal in the frequency domain. Thus, the apparatus includes a level shifter

21 and an analog-to-digital (A/D) converter 23 for converting the Doppler signal on line 19 into a succession of digital words. The level shifter is included merely to ensure that the Doppler signal's voltage levels are compatible with the A/D converter. The level-shifted Doppler signal is transmitted from the level shifter to the A/D converter on line 24. The A/D converter's sample rate is preferably on the order of 300 kilohertz, to ensure that, at the standard radar frequency used, the sample rate is at least twice the highest expected frequency component of interest in the Doppler signal. This prevents aliasing errors that could lead to ambiguities in the projectile velocity measurements.

The successive samples made by the A/D converter 23 are transmitted on lines 25 to a random-access memory that is part of a signal processor 27. Samples are accumulated for approximately 400 milliseconds, after which the signal processor begins processing the samples to determine the projectile's muzzle velocity. After the processing has been completed, the signal processor transmits the muzzle velocity measurement on line 29 to a display device 31, for visible display. In addition, the muzzle velocity measurement can also be transmitted to a fire control apparatus (not shown in the drawings), for adjusting the gun barrel's direction for subsequent firings.

Firing of the gun 13 creates an ionization of the space immediately surrounding it. This ionization, which has a duration of about 50 to 100 milliseconds, effectively precludes the obtaining of any significant information from the Doppler signal during this period. The apparatus therefore includes a trigger detector 33 and a delay counter 35 for enabling operation of the A/D converter 23 only after the ionization has dissipated. In particular, the trigger detector monitors the Doppler signal present on line 19 and senses any large increase in power, which indicates the firing of the gun. An appropriate trigger signal is then transmitted on line 37 to the delay counter, which times out a predetermined delay on the order of 50 to 100 milliseconds, after which an enable signal is transmitted to the A/D converter on line 39.

As previously mentioned, the signal processor 27 processes the successive Doppler signal samples stored in its random-access memory to determine the projectile's initial, muzzle velocity. A simplified flowchart of the operational steps the signal processor performs is depicted in Fig. 2. In an initial step 41, the Doppler signal samples are arranged into K groups of N time samples each, where K and N are integers, e.g. 30 and 1024 respectively. Each of the K successive groups represents a successive time segment in the Doppler signal. Succeeding steps in the flowchart will measure the projectile's average velocity during

each such time segment. By noting a regular decrease in this velocity with time, a measure of the projectile's initial, muzzle velocity then can be deduced.

After the digitized time samples have been arranged in the predetermined sequence, the signal processor 27, at step 43, selects the first group of samples, which corresponds to the first time segment in the Doppler signal. The processor thereafter enters a loop that will be repeated for each of the K groups of samples.

In an initial step 45 of the program loop, the signal processor 27 computes the fast-Fourier transform of the first group of N time samples. This produces a corresponding number of N frequency measurements, forming a frequency spectrum signal for the first group of samples, and thus for the first time segment of the Doppler signal. Fig. 3 depicts one such set of frequency measurements, for an exemplary group of N Doppler signal samples. Several peaks in the depicted frequency measurements will be noted, one such peak 47 at a relatively low frequency, a second peak 49 at an intermediate frequency, and a third peak 51 at a relatively high frequency. Significant noise is present across the entire frequency range. The low-frequency peak 47 is due principally to the ionization effect that occurs upon firing of the gun 13, as described above. The intermediate-frequency peak 49 is due to the presence of relatively slow-moving fragments 18 (Fig. 1) present in the general direction of the projectile 11 of interest. The relatively high-frequency peak 51 is due to a reflection from the projectile 11 of interest.

In a following step 53, the signal processor 27 detects the presence of peaks in the digital frequency spectrum of Fig 3 by comparing each frequency measurement with a threshold 55 that is specially selected in accordance with the general noise level in its region of the spectrum. This variable threshold can be referred to as a constant false alarm rate (CFAR) threshold. For each frequency, the CFAR threshold is selected to be a certain fraction of the average of a predetermined plurality of frequency measurements immediately both above and below the frequency in question. Preferably, a sliding window gating technique is used, in which the frequency measurements on both sides of the frequency measurement in question, extending from two frequency increments away to eighteen frequency increments away, are averaged. This sliding window gating function is depicted schematically in Fig 4.

The effect of the variable CFAR threshold technique described above is to cause the threshold 55 to be artificially increased for frequencies on both sides of the frequency of the projectile peak 51, because of the contribution of that measurement

peak to those thresholds. This phenomenon is evident in Fig 3, where it is observed that the threshold generally follows the level of the frequency measurements except in the region of peaks, where it increases substantially on each side of the peaks.

In a following step 57 of the program, the signal processor 27 examines the particular frequency measurement that are determined in step 53 to exceed their respective thresholds. Typically, two or three adjacent frequency measurements will exceed their thresholds. One exemplary situation is depicted in Fig 5, where the measurements for several adjacent frequencies are depicted in bar graph form by solid lines 59 and their respective thresholds are depicted by dotted lines 61. In the depicted example, three adjacent frequency measurements exceed their respective thresholds. A more precise measure of the projectile's Doppler frequency, and thus velocity, is obtained by interpolating the three adjacent frequency measurements. In particular, the processor determines the weighted average, or centre of gravity, of those adjacent measurements exceeding the threshold. This weighted average is indicated by the arrow 63 in Fig 5. Interpolating in this fashion yields velocity measurements having a precision at least an order of magnitude greater than that provided by the peak frequency measurements, without interpolation.

In low signal-to-noise ratio situations, such as when the projectile 11 has moved a large distance away from the gun 13, sometimes just a single frequency measurement will exceed its CFAR threshold 55. When that occurs, the interpolation procedure of step 57 is modified to include not only the particular measurement exceeding the threshold, but also the two measurements immediately above and below it.

As previously mentioned, the CFAR thresholds 55 will frequently be exceeded by multiple frequency measurements, which represents not only the projectile 11 of interest, but also slower-moving fragments 18 associated with the projectile. In addition, because of distortion in the Doppler signal produced by the radar device 13, harmonics of these frequencies can sometimes also be present. Sometimes, these harmonics can even be of sufficient magnitude to cause their frequency measurements to exceed the thresholds. The signal processor 27 eliminates these effects in step 65. In particular, the signal processor compares the frequency of each measurement that exceeds its respective threshold with the frequencies of any lower frequency measurements that likewise exceed their respective thresholds. If the frequencies are harmonically related, the higher frequency measurement is disregarded.

Also in step 65, the signal processor 27 associates together each velocity measurement with the corresponding velocity measurements derived from previous groups of data. Of course, in the first pass through the program loop (steps 45-65), there are no such prior velocity measurements available, so this portion of step 65 is bypassed. However, in subsequent passes through the program loop, a separate file will be maintained for the successive velocity measurements derived for each moving object, including the projectile 11 of interest.

The association of each velocity measurement with prior velocity measurements determined to correspond to the same object is achieved by requiring each successive measurement to be within a prescribed percentage (e.g. 2 percent) of the measurement for the next preceding group of data. If the velocities of successive measurements differ by more than this percentage, it is assumed that they relate to different objects.

In a further step 67 of the program loop, the signal processor 27 determines whether or not the current pass through the loop is the last of the K passes. If it is not, the processor increments, at step 69, to the next succeeding group of Doppler signal samples, and makes another pass through the program loop, beginning with step 45.

On the other hand, if it is determined at step 67 that all K groups of Doppler signal samples have been processed, the signal processor 27 proceeds to a number of additional steps in which the successive velocity measurements are further processed to arrive at a precise measure of the projectile's initial, muzzle velocity. At this stage of the processing, it should be noted that a separate file of up to K successive velocity measurements is stored for each object detected by the radar device 15 (Fig 1). Each entry in each file represents the velocity measurement, for a particular object during one of the K successive time periods. Because the velocities of the projectile 11 and fragments 18 generally decrease with time, these velocity measurements determinations should be uniformly decreasing. An example of this decreasing pattern is depicted in Fig 6.

In step 71, the signal processor 27 selects a particular linear curve 72 that best fits the file of generally decreasing velocity measurements, as shown in Fig 6. A least mean square error (LMS) algorithm is preferably used in making this selection. It will be noted in Fig 6 that several of the velocity measurements appear to differ substantially from the LMS linear curve estimate. In one detailed aspect of the invention, the processor disregards these particular velocity measurements and recomputes the linear curve based on the remaining velocity measurements, which are presumably more accurate. This process of eliminat-

ing those particular measurements that are considered to be excessively distant from the LMS curve can continue, in an iteratively, until a final, acceptable LMS curve is derived. This procedure is repeated for each file of velocity measurements, such that a separate LMS curve is derived for all of the moving objects detected, including the projectile 11 and any fragments 18.

After the final LMS curves have been derived, the signal processor 27, at step 73, uses an appropriate regression algorithm to determine the zero intercept of the LMS curve for each file. This corresponds to the initial, muzzle velocities of the projectile 11 and any fragments 18.

After determining the initial, muzzle velocities of the projectile 11 and any fragments 18, the signal processor 27, at step 75, selects the particular one of these determinations that is considered to be most likely that of the projectile 11. This determination can be made in accordance of any of a number of appropriate bases, such as signal strength, expected velocity, etc.

Finally, at step 77, the signal processor 27 displays the projectile's final muzzle velocity determination on the display device 31 (Fig 1). In addition, and as mentioned briefly above, this muzzle velocity determination can be used in a fire control system (not shown in the drawings), in which an adjustment is made to the pointing direction of the gun barrel 13, for succeeding firings.

It should be appreciated from the foregoing description that the present invention provides an effective apparatus and method for accurately and precisely measuring the muzzle velocity of a projectile ejected from a gun barrel. A conventional radar Doppler signal is sampled and digitized and arranged in a succession of groups, each group representing a separate time period. A fast-Fourier transform is then computed for each group of samples, and peak frequency measurements in the transformed data are tracked from one time period to the next. These peaks indicate the velocities of the projectile of interest and any other nearby moving objects. Finally, a least mean square error curve fit and standard regression algorithm are used to deduce the projectile's initial, muzzle velocity. The invention provides accurate muzzle velocity determinations even in circumstances where the Doppler signal contains substantial interference caused, for example, by random noise and the presence of moving fragments in the direction of the projectile.

Claims

1. Doppler radar apparatus for determining the initial velocity of a projectile (11) ejected from a muzzle (13), comprising:

Also in step 65, the signal processor 27 associates together each velocity measurement with the corresponding velocity measurements derived from previous groups of data. Of course, in the first pass through the program loop (steps 45-65), there are no such prior velocity measurements available, so this portion of step 65 is bypassed. However, in subsequent passes through the program loop, a separate file will be maintained for the successive velocity measurements derived for each moving object, including the projectile 11 of interest.

The association of each velocity measurement with prior velocity measurements determined to correspond to the same object is achieved by requiring each successive measurement to be within a prescribed percentage (e.g. 2 percent) of the measurement for the next preceding group of data. If the velocities of successive measurements differ by more than this percentage, it is assumed that they relate to different objects.

In a further step 67 of the program loop, the signal processor 27 determines whether or not the current pass through the loop is the last of the K passes. If it is not, the processor increments, at step 69, to the next succeeding group of Doppler signal samples, and makes another pass through the program loop, beginning with step 45.

On the other hand, if it is determined at step 67 that all K groups of Doppler signal samples have been processed, the signal processor 27 proceeds to a number of additional steps in which the successive velocity measurements are further processed to arrive at a precise measure of the projectile's initial, muzzle velocity. At this stage of the processing, it should be noted that a separate file of up to K successive velocity measurements is stored for each object detected by the radar device 15 (Fig 1). Each entry in each file represents the velocity measurement, for a particular object during one of the K successive time periods. Because the velocities of the projectile 11 and fragments 18 generally decrease with time, these velocity measurements determinations should be uniformly decreasing. An example of this decreasing pattern is depicted in Fig 6.

In step 71, the signal processor 27 selects a particular linear curve 72 that best fits the file of generally decreasing velocity measurements, as shown in Fig 6. A least mean square error (LMS) algorithm is preferably used in making this selection. It will be noted in Fig 6 that several of the velocity measurements appear to differ substantially from the LMS linear curve estimate. In one detailed aspect of the invention, the processor disregards these particular velocity measurements and recomputes the linear curve based on the remaining velocity measurements, which are presumably more accurate. This process of eliminat-

ing those particular measurements that are considered to be excessively distant from the LMS curve can continue, in an iteratively, until a final, acceptable LMS curve is derived. This procedure is repeated for each file of velocity measurements, such that a separate LMS curve is derived for all of the moving objects detected, including the projectile 11 and any fragments 18.

After the final LMS curves have been derived, the signal processor 27, at step 73, uses an appropriate regression algorithm to determine the zero intercept of the LMS curve for each file. This corresponds to the initial, muzzle velocities of the projectile 11 and any fragments 18.

After determining the initial, muzzle velocities of the projectile 11 and any fragments 18, the signal processor 27, at step 75, selects the particular one of these determinations that is considered to be most likely that of the projectile 11. This determination can be made in accordance with any of a number of appropriate bases, such as signal strength, expected velocity, etc.

Finally, at step 77, the signal processor 27 displays the projectile's final muzzle velocity determination on the display device 31 (Fig 1). In addition, and as mentioned briefly above, this muzzle velocity determination can be used in a fire control system (not shown in the drawings), in which an adjustment is made to the pointing direction of the gun barrel 13, for succeeding firings.

It should be appreciated from the foregoing description that the present invention provides an effective apparatus and method for accurately and precisely measuring the muzzle velocity of a projectile ejected from a gun barrel. A conventional radar Doppler signal is sampled and digitized and arranged in a succession of groups, each group representing a separate time period. A fast-Fourier transform is then computed for each group of samples, and peak frequency measurements in the transformed data are tracked from one time period to the next. These peaks indicate the velocities of the projectile of interest and any other nearby moving objects. Finally, a least mean square error curve fit and standard regression algorithm are used to deduce the projectile's initial, muzzle velocity. The invention provides accurate muzzle velocity determinations even in circumstances where the Doppler signal contains substantial interference caused, for example, by random noise and the presence of moving fragments in the direction of the projectile.

Claims

1. Doppler radar apparatus for determining the initial velocity of a projectile (11) ejected from a muzzle (13), comprising:



radar means (15) for producing a Doppler signal (19) indicative of movement of the projectile (11) relative to the muzzle (13);

Fourier transform means (21, 23, 27) for operating on the Doppler signal (19), and detection means (27) responsive to the Fourier transform means (21, 23, 27) to measure the velocity of the projectile (11) characterised in that the Fourier transform means (21, 23, 27) operates on a predetermined plurality of segments of the Doppler signal (19), each segment representing a separate time period, to produce a corresponding plurality of frequency spectrum signals; and in that the detection means (27) is responsive to the plurality of frequency spectrum signals, for measuring the velocity of the projectile (11) during the time period associated with each successive segment of the Doppler signal; and includes means (27) responsive to the projectile velocities measured for the plurality of successive time periods, for estimating the initial, muzzle velocity of the projectile (11) by extrapolation back to the zero time intercept.

2. Doppler radar apparatus according to Claim 1, characterised in that the detection means (27) includes comparator means for comparing each of the plurality of frequency spectrum signals with a prescribed threshold that varies with frequency and with the amount of superimposed noise, the comparator means also determining that portions of the signals exceeding the threshold result from one or more moving objects, including the projectile whose initial, muzzle velocity is being estimated.

Doppler radar apparatus according to Claim 2, characterised in that the detection means further includes threshold means for producing a separate threshold for each of a plurality of frequencies in each of the plurality of frequency spectrum signals, each such threshold being selected in accordance with the levels of the frequency spectrum signal for nearby frequencies.

4. Doppler radar apparatus according to Claim 3, characterised in that:

the Fourier transform means includes analog-to-digital converter means for converting the Doppler signal to a sequence of digital words that are arranged in groups of N digital words each, and

fast-Fourier transform means for operating on the N digital words in each successive group of words, to produce a range of discrete frequency signals for each group, each such

range of discrete frequency measurements being a separate frequency spectrum signal; in that

the threshold means produces a separate threshold for each frequency measurement in each frequency spectrum signal, based on the average values of the discrete frequency measurements for a predetermined plurality of nearby frequencies.

5. Doppler radar apparatus according to Claim 1 characterised in that the Fourier transform means (21, 23, 27) includes analog-to-digital converter means for converting the Doppler signal to a sequence of digital words, arranged in K successive groups of N digital words each, and

fast-Fourier transform means for operating on the N digital words in each of the K successive groups, to produce a range of discrete frequency measurements for each group, each such range representing the frequency spectrum for a separate time segment of the Doppler signal, and in that the

detection means (27) operates on the range of discrete frequency measurements for each of the K groups, to measure the velocity of the projectile during the time period associated with the corresponding group of N digital words and operates on the K successive projectile velocity measurements, to provide said estimate of the projectile's initial, muzzle velocity.

6. Doppler radar apparatus according to Claim 5, characterised in that the detection means (27) includes comparator means for comparing each of the plurality of frequency measurements with a prescribed threshold that varies in accordance with the levels of frequency measurements for nearby frequencies and for determining that frequency measurements exceeding the threshold result from one or more moving objects, including the projectile whose initial, muzzle velocity is being estimated.

7. Doppler radar apparatus according to Claim 5 or to Claim 6, characterised in that the detection means (27) further includes interpolation means for determining the signals determined by the comparator means to exceed the threshold or their respective thresholds, to determine the average velocity of the projectile during the time period associated with each successive time segment of the Doppler signal.



8. Doppler radar apparatus according to any preceding claim, characterised in that

one or more additional moving objects are located in the direction of the projectile (11); and in that

the detection means includes means for measuring the respective velocities of the projectile and the one or more additional moving objects during the time period associated with each successive segment of the Doppler signal.

9. Doppler radar apparatus according to Claim 8, characterised in that the detection means (27) further includes association means for associating together the particular velocity measurements in each of the successive time periods corresponding to the respective projectile and one or more additional moving objects, the association means including means for comparing each velocity measurement with velocity measurements made for previous time periods, if any.

10. Doppler radar apparatus according to Claim 8, characterised in that the detection means (27) includes means, operable during each time period, for comparing the velocity measurements of the projectile and one or more additional moving objects to each other and for discarding any velocity measurement that is harmonically related to any other velocity measurement.

11. Doppler radar apparatus according to any preceding claim, characterised in that the detection means (27) includes means for defining an initial velocity profile that provides the least mean square error based on the velocity measurements made by the detection means for the plurality of successive time periods.

12. Doppler radar apparatus according to Claim 11, characterised in that the detection means (27) further includes means for discarding any velocity measurements differing by more than a predetermined amount from the initial velocity profile and for redefining the velocity profile based on the velocity measurements remaining.

13. Doppler radar apparatus according to Claim 9 characterised by

harmonic elimination means, operable during each time period, for comparing the velocity measurements of the projectile and one or more additional moving objects to each other and for discarding any velocity measure-

ments that is harmonically related to any other velocity measurement; and regression means for defining an initial velocity profile that provides the least mean square error based on the velocity measurements made by the interpolation means and associations means for the plurality of successive time periods, the regression means including means for discarding any velocity measurements differing by more than a predetermined amount from the initial velocity profile and for redefining the velocity profile based on the velocity measurements remaining, the redefined velocity profile indicating the projectile's initial, muzzle velocity.

14. Doppler radar apparatus according to any preceding claim, characterised in that:

the projectile (11) whose velocity is to be measured is ejected from an explosive gun (13); and in that

the apparatus further includes means (33, 35) for disabling the apparatus from measuring the projectile's velocity for a predetermined time period, until any ionization associated with firing of the gun (13) has substantially dissipated.

15. A Doppler radar method for determining the initial velocity of a projectile (11) ejected from a muzzle (13), comprising the step of:

producing a Doppler signal (19) indicative of movement of the projectile (11) relative to the muzzle characterised by the steps of operating on a predetermined plurality of segments of the Doppler signal (19), each segment representing a separate time period, to produce a corresponding plurality of frequency spectrum signals;

processing the plurality of frequency spectrum signals to measure the velocity of the projectile during the time period associated with each successive segment of the Doppler signal; and

estimating the initial, muzzle velocity of the projectile (11) based on the projectile velocities measured by the step of processing for the plurality of successive time periods and extrapolating back to the zero time intercept.

16. A Doppler radar method according to Claim 15 characterised in that the step of processing includes steps of:

comparing each of the plurality of frequency spectrum signals with a prescribed threshold that varies with frequency and with the amount of superimposed noise; and

determining that portion of the signals exceeding the threshold result from one or more



moving objects, including the projectile whose initial, muzzle velocity is being estimated.

17. A Doppler radar method according to Claim 16, characterised in that the step of processing further includes a step of producing a separate threshold for each of a plurality of frequencies in each of the plurality of frequency spectrum signals, each such threshold being selected in accordance with the levels of the frequency spectrum signal for nearby frequencies.

18. A Doppler radar method according to Claim 17, characterised in that the step of operating includes steps of

converting the Doppler signal (19) to a sequence of digital words that are arranged in groups of N digital words each, and

operating on the N digital words in each successive group of words, to produce a range of discrete frequency measurements for each group, each such range of discrete frequency measurements being a separate frequency spectrum signal; and

the step of producing includes a step of producing a separate threshold for each frequency measurement in each frequency spectrum signal, based on the average values of the discrete frequency measurements for a predetermined plurality of nearby frequencies.

19. A Doppler radar method according to any one of Claims 16 to 18, characterised in that the step of processing further includes a step of interpolating those portions of each of the plurality of frequency spectrum signals that are determined in the step of comparing to exceed the threshold, to determine the average velocity of the projectile (11) during the time period associated with each successive segment of the Doppler signal.

20. A Doppler radar method according to any one of Claims 15 to 19, characterised in that

one or more additional moving objects are located in the direction of the projectile (11); and in that the step of processing includes a step of measuring the respective velocities of the projectile (11) and the one or more additional moving objects during the time period associated with each successive segment of the Doppler signal (19).

21. A Doppler radar method according to Claim 20, characterised in that the step of processing further includes a step of associating together the particular velocity measurements in each of the successive time periods corresponding

to the respective projectile and the one or more additional moving objects, the step of associating including a step of comparing each velocity measurement with velocity measurements made for previous time periods, if any.

22. A Doppler radar method according to Claim 21, characterised in that the step of processing includes a step of comparing the velocity measurements to each other during each time period and discarding any velocity measurement that is harmonically related to any other velocity measurement.

23. A Doppler radar method according to any one of Claims 15 to 22, characterised in that the step of estimating includes a step of defining an initial velocity profile that provides the least mean square error based on the velocity measurements made in the step of processing for the plurality of successive time periods.

24. A Doppler radar method according to Claim 23, characterised in that the step of estimating further includes steps of discarding any velocity measurements differing by more than a predetermined amount from the initial velocity profile, and redefining the velocity profile based on the velocity measurements remaining.

25. A Doppler radar method according to any one of Claims 15 to 24, characterised in that:

the projectile (11) whose velocity is to be measured is ejected from an explosive gun (13); and

in that the method further includes a step of inhibiting the method from measuring the projectile's velocity for a predetermined time period, until any ionization associated with firing of the gun (13) has substantially dissipated.

Patentansprüche

1. Dopplerradarvorrichtung zur Bestimmung der Anfangsgeschwindigkeit eines aus einer Mündung (13) austretenden Projektils (11) mit Radarmittel (15) zur Erzeugung eines Dopplersignals (19), das die Bewegung des Projektils (11) relativ zu der Mündung (13) anzeigt, das Dopplersignal (19) verarbeitende Fourier-Transformationsmittel (21, 23, 27) und auf die Fourier-Transformationsmittel (21, 23, 27) zur Messung der Geschwindigkeit des Projektils (11) empfindliche Detektionsmittel (27), dadurch gekennzeichnet, daß das Fourier-Transformationsmittel (21, 23, 27) eine vorbestimmte Vielzahl von Abschnitten des Doppler-



signals (19) bearbeitet, wobei jeder Abschnitt einen selbständigen Zeitraum darstellt, um eine entsprechende Vielzahl von Frequenzspektrumssignalen zu erzeugen, daß das Detektionsmittel (27) empfindlich auf die Vielzahl der Frequenzspektrumssignale ist, um die Geschwindigkeit des Projektils (11) während der mit jedem aufeinanderfolgenden Abschnitt des Dopplersignals verbundenen Zeitdauer zu messen und schließt für die Vielzahl der aufeinanderfolgenden Zeitdauern gemessenen Projektilgeschwindigkeiten empfindliche Mittel (27) ein, um die anfängliche Mündungsgeschwindigkeit des Projektils (11) durch Rückextrapolation auf den Schnittpunkt mit der Startzeit abzuschätzen.

2. Dopplerradarvorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß das Detektionsmittel (27) Vergleichsmittel einschließt, um jedes der Vielzahl von Frequenzspektrumssignalen mit einem vorbestimmten Schwellwert zu vergleichen, der mit der Frequenz und der Stärke des überlagerten Rauschens variiert, wobei die Vergleichsmittel ebenso bestimmen, daß die den Schwellwert überschreitenden Signale von einem oder mehr sich bewegenden Objekten stammen, welche das Projektil, dessen anfängliche Mündungsgeschwindigkeit zu bestimmen ist, einschließen.

3. Dopplerradarvorrichtung nach Anspruch 2, dadurch gekennzeichnet, daß das Detektionsmittel weiterhin Schwellwertmittel einschließt, um für jede der Vielzahl von Frequenzen in jedem der Vielzahl von Frequenzspektrumssignalen einen eigenen Schwellwert zu erzeugen, wobei dieser Schwellwert in Übereinstimmung mit den Signalpegeln des Frequenzspektrumssignals für benachbarte Frequenzen auswählbar ist.

4. Dopplerradarvorrichtung nach Anspruch 3, dadurch gekennzeichnet, daß das Fourier-Transformationsmittel Analog-zu-Digital-Wandler einschließt, um das Dopplersignal in eine Abfolge von digitalen Datensätzen umzuwandeln, die in Gruppen von N digitalen Datensätzen angeordnet sind, und Mittel zur schnellen Fourier-Transformation, um die N digitalen Datensätze in jeder aufeinanderfolgenden Gruppe der Datensätze zu verarbeiten, so daß ein Bereich von diskreten Frequenzsignalen für jede Gruppe erzeugbar ist, wobei jeder Bereich der diskreten Frequenzmessungen ein einzelnes Frequenzspektrumssignal ist, daß das Schwellwertmittel für jede Frequenzmessung in jedem Frequenzspektrumssignal einen einzelnen

Schwellwert erzeugt, der aus dem Mittelwert von diskreten Frequenzmessungen für eine vorbestimmte Vielzahl von benachbarten Frequenzen gebildet ist.

5. Dopplerradarvorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß das Fourier-Transformationsmittel (21, 23, 27) Analog-zu-Digital-Wandler einschließt, welche das Dopplersignal in eine Abfolge von digitalen Datensätzen umwandeln, welche in K aufeinanderfolgende Gruppen von jeweils N digitalen Datensätzen angeordnet sind, und Mittel zur schnellen Fourier-Transformation zum Bearbeiten der N digitalen Datensätze in jeder der K aufeinanderfolgenden Gruppen, um einen Bereich von diskreten Frequenzmessungen für jede Gruppe zu erzeugen, wobei jeder Bereich ein Frequenzspektrum für einen einzelnen Zeitabschnitt des Dopplersignals darstellt und daß die Detektionsmittel (27) den Bereich der diskreten Frequenzmessungen für jeder der K Gruppen bearbeitet, um die Geschwindigkeit des Projektils während des mit der entsprechenden Gruppe von N digitalen Datensätzen verbundenen Zeitabschnittes zu messen und daß die Detektionsmittel die K aufeinanderfolgenden Projektilgeschwindigkeitsmessungen bearbeiten, um die anfängliche Mündungsgeschwindigkeit des Projektils abzuschätzen.

6. Dopplerradarvorrichtung nach Anspruch 5, dadurch gekennzeichnet, daß das Detektionsmittel (27) Vergleichsmittel einschließt, um jede der Vielzahl von Frequenzmessungen mit einem vorbestimmten Schwellwert zu vergleichen, der in Übereinstimmung mit den Signalstärken von Frequenzmessungen benachbarter Frequenzen variiert, und um zu bestimmen, daß den Schwellwert überschreitende Frequenzmessungen von einem oder mehreren bewegten Objekten stammen, welche das Projektil, dessen anfängliche Mündungsgeschwindigkeit zu bestimmen ist, einschließen.

7. Dopplerradarvorrichtung nach Anspruch 5 oder Anspruch 6, dadurch gekennzeichnet, daß das Detektionsmittel (27) weiterhin Interpolationsmittel zum Bestimmen der durch die Vergleichsmittel nach Überschreiten des Schwellwertes oder ihrer jeweiligen Schwellwerte bestimmten Signale einschließt, um die mittlere Geschwindigkeit des Projektils während der mit jedem aufeinanderfolgenden Zeitabschnitt des Dopplersignals verbundenen Zeitdauer zu bestimmen.



8. Dopplerradarvorrichtung nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß ein oder mehrere zusätzliche bewegte Objekte in Richtung des Projektils (11) festgestellt sind und daß das Detektionsmittel Mittel zum Messen der jeweiligen Geschwindigkeit des Projektils und des einen oder der mehreren zusätzlichen bewegten Objekte während der mit jedem aufeinanderfolgenden Abschnitt des Dopplersignals verbundenen Zeitdauer einschließt.
9. Dopplerradarvorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß das Detektionsmittel (27) weiterhin Verknüpfungsmittel zum Miteinanderverknüpfen der einzelnen dem jeweiligen Projektil und dem oder den zusätzlichen bewegten Objekten entsprechenden Geschwindigkeitsmessungen in jeder der aufeinanderfolgenden Zeitdauern einschließt, wobei die Verbindungsmittel Mittel zum Vergleich jeder Geschwindigkeitsmessung mit, falls vorhanden, für vorangehende Zeitdauern durchgeführte Geschwindigkeitsmessungen einschließt.
10. Dopplerradarvorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß das Detektionsmittel (27) in jeder Zeitdauer betreibbare Mittel zum Vergleich der Geschwindigkeitsmessungen des Projektils und des oder der zusätzlichen bewegten Objekte untereinander und zum Verwerfen jeder Geschwindigkeitsmessung, die als harmonische zu jeder anderen Geschwindigkeitsmessung verbunden ist, einschließt.
11. Dopplerradarvorrichtung nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß das Detektionsmittel (27) Mittel zum Definieren eines anfänglichen Geschwindigkeitsprofils einschließt, das den kleinsten mittleren quadratischen Fehler bestimmt, der auf den durch das Detektionsmittel für die Vielzahl von aufeinanderfolgenden Zeitdauern vorgenommenen Geschwindigkeitsmessungen gebildet ist.
12. Dopplerradarvorrichtung nach Anspruch 11, dadurch gekennzeichnet, daß das Detektionsmittel (27) weiterhin Mittel zum Verwerfen jeder Geschwindigkeitsmessung aufweist, die mehr als einen vorbestimmten Betrag von dem anfänglichen Geschwindigkeitsprofil abweicht, und zum Rückdefinieren des auf den verbleibenden Geschwindigkeitsmessungen gebildeten Geschwindigkeitsprofils einschließt.
13. Dopplerradarvorrichtung gemäß Anspruch 9, gekennzeichnet durch während jeder Zeitdauer anwendbare Eliminierungsmittel für Harmonische zum Vergleich der Geschwindigkeitsmessungen des Projektils und des oder der zusätzlichen sich bewegenden Objekte untereinander und zum Verwerfen jeder Geschwindigkeitsmessung, die harmonisch mit einer anderen Geschwindigkeitsmessung in Beziehung steht und Regressionsmittel zum Definieren eines anfänglichen Geschwindigkeitsprofils, das den kleinsten quadratischen Fehler liefert, der auf den durch die Interpolationsmittel und Verbindungsmittel für eine Vielzahl von aufeinanderfolgenden Zeitdauern durchgeführten Geschwindigkeitsmessungen gebildet ist, wobei das Regressionsmittel Mittel zum Verwerfen jeder Geschwindigkeitsmessung, die mehr als einen vorbestimmten Betrag von dem anfänglichen Geschwindigkeitsprofil abweicht, und zum Rückdefinieren des auf den verbleibenden Geschwindigkeitsmessungen gebildeten Geschwindigkeitsprofils einschließt, wobei das rückdefinierte Geschwindigkeitsprofil die anfängliche Mündungsgeschwindigkeit des Projektils anzeigt.
14. Dopplerradarvorrichtung nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß das Projektil (11), dessen Geschwindigkeit zu messen ist, von einer Feuerwaffe (13) abgeschossen ist und daß die Vorrichtung weiterhin Mittel (33, 35) zum Sperren der Vorrichtung für das Messen der Geschwindigkeit des Projektils für eine vorbestimmte Zeitdauer einschließt, bis eine mit dem Abfeuern der Waffe (13) verbundene Ionisation im wesentlichen verschwunden ist.
15. Dopplerradarverfahren zur Bestimmung der Anfangsgeschwindigkeit eines aus einer Mündung (13) austretenden Projektils (11) mit dem Schritt des Erzeugens eines die Bewegung des Projektils (11) relativ zu der Mündung anzeigenden Dopplersignales (19), gekennzeichnet durch die Schritte des Bearbeitens einer Vielzahl von Abschnitten des Dopplersignals (19), wobei jeder Abschnitt eine einzelne Zeitdauer darstellt, um eine entsprechende Vielzahl von Frequenzspektrumssignalen zu erzeugen, des Weiterverarbeitens der Vielzahl von Frequenzspektrumssignalen, um die Geschwindigkeit des Projektils während der mit jedem aufeinanderfolgenden Abschnitt des Dopplersignals verbundenen Zeitdauer zu messen und des Abschätzens der anfänglichen Mündungsgeschwindigkeit des Projektils (11), das auf den durch die Schritte des Wei-



terverarbeitens der Vielzahl von aufeinanderfolgenden Zeitdauern und der Rückextrapolation auf den Schnittpunkt mit der Startzeit gebildet wird.

16. Dopplerradarverfahren nach Anspruch 15, dadurch gekennzeichnet, daß der Schritt des Weiterverarbeitens Schritte des Vergleichens jedes der Vielzahl von Frequenzspektrumssignalen mit einem vorgesetzten Schwellwert, der mit der Frequenz und mit der Stärke des Überlagerten Rauschens variiert, und des Bestimmens des Anteils der Signale einschließt, die von dem oder den sich bewegenden Objekten ausgehen, die das Projektil, dessen anfängliche Mündungsgeschwindigkeit abzuschätzen ist, einschließen.

17. Dopplerradarverfahren nach Anspruch 16, dadurch gekennzeichnet, daß der Schritt des Weiterverarbeitens weiterhin einen Schritt des Erzeugens eines einzelnen Schwellwertes für eine Vielzahl von Frequenzen in jeder der Vielzahl von Frequenzspektrumssignalen aufweist, wobei jeder der Schwellwerte in Übereinstimmung mit der Signalstärke des Frequenzspektrumssignals für benachbarte Frequenzen ausgewählt wird.

18. Dopplerradarverfahren nach Anspruch 17, dadurch gekennzeichnet, daß der Schritt des Bearbeitens die Schritte des Umwandels des Dopplersignals (19) in eine Abfolge von digitalen Datensätzen, die in Gruppen von jeweils N digitalen Datensätzen angeordnet sind, und des Bearbeitens der N digitalen Datensätze in jeder aufeinanderfolgenden Gruppe der Datensätze ausweist, um einen Bereich von diskreten Frequenzmessungen für jede Gruppe zu erzeugen, wobei jeder Bereich der diskreten Frequenzmessungen ein einzelnes Frequenzspektrumssignal ist, aufweist, und daß der Schritt des Erzeugens einen Schritt des Erzeugens eines einzelnen Schwellwertes für jede Frequenzmessung in jedem Frequenzspektrumssignal, der auf den Mittelwerten der diskreten Frequenzmessungen für eine vorbestimmte Vielzahl von benachbarten Frequenzen gebildet ist.

19. Dopplerradarverfahren nach einem der Ansprüche 16 bis 18, dadurch gekennzeichnet, daß der Schritt des Weiterverarbeitens weiterhin einen Schritt des Interpolierens derjenigen Anteile jedes der Vielzahl von Frequenzspektrumssignalen einschließt, die in dem Schritt des Vergleichens zum Überschreiten des Schwellwertes bestimmt wurden, um die mittlere Ge-

schwindigkeit des Projektils (11) während der mit jedem aufeinanderfolgenden Abschnitt des Dopplersignals verbundenen Zeitdauer zu bestimmen.

20. Dopplerradarverfahren nach einem der Ansprüche 15 bis 19, dadurch gekennzeichnet, daß ein oder mehrere zusätzliche sich bewegenden Objekte in der Richtung des Projektils (11) festgestellt sind und daß der Schritt des Weiterverarbeitens einen Schritt des Messens der jeweiligen Geschwindigkeit des Projektils (11) und des einen oder der mehreren zusätzlichen, sich bewegenden Objekte während der mit jedem aufeinanderfolgenden Abschnitt des Dopplersignals (19) verbundenen Zeitdauer einschließt.

21. Dopplerradarverfahren nach Anspruch 20, dadurch gekennzeichnet, daß der Schritt des Weiterverarbeitens weiterhin einen Schritt des miteinander Verbindens der einzelnen Geschwindigkeitsmessungen in jedem der dem jeweiligen Projektil und dem einen oder den mehreren zusätzlichen sich bewegenden Objekten entsprechenden Geschwindigkeiten einschließt, wobei der Schritt des Verbindens einen Schritt des Vergleichs jeder Geschwindigkeitsmessung mit den für vorangehende Zeitdauern durchgeführten Geschwindigkeitsmessungen einschließt.

22. Dopplerradarverfahren nach Anspruch 21, dadurch gekennzeichnet, daß der Schritt des Weiterverarbeitens einen Schritt des Vergleichs der Geschwindigkeitsmessungen miteinander während jeder Zeitdauer und des Verwerfens jeder Geschwindigkeitsmessung, die harmonisch mit einer anderen Geschwindigkeitsmessung verbunden ist, einschließt.

23. Dopplerradarverfahren nach einem der Ansprüche 15 bis 22, dadurch gekennzeichnet, daß der Schritt des Abschätzens den Schritt eines Definierens eines anfänglichen Geschwindigkeitsprofils aufweist, das den kleinsten quadratischen Fehler liefert, der auf den in dem Schritt des Weiterverarbeitens der Vielzahl von aufeinanderfolgenden Zeitdauern vorgenommenen Geschwindigkeitsmessungen gebildet ist.

24. Dopplerradarverfahren nach Anspruch 23, dadurch gekennzeichnet, daß der Schritt des Abschätzens weiterhin Schritte des Verwerfens jeder Geschwindigkeitsmessung, die um mehr als einen vorbestimmten Betrag von dem anfänglichen Geschwindigkeitsprofil abweicht,



und des Rückdefinierens des auf die verbleibenden Geschwindigkeitsmessungen gebildeten Geschwindigkeitsprofils einschließt.

25. Dopplerradarverfahren nach einem der Ansprüche 15 bis 24, dadurch gekennzeichnet, daß das Projektil (11), dessen Geschwindigkeit zu messen ist, von einer Feuerwaffe (13) austritt und daß das Verfahren weiterhin einen Schritt des Unterbleibens des Verfahrens für die Messung der Geschwindigkeit des Projektils für eine vorbestimmte Zeitperiode aufweist, bis eine mit dem Abfeuern der Waffe (13) verbundene Ionisation im wesentlichen verschwunden ist.

Revendications

- Appareil à radar Doppler pour déterminer la vitesse initiale d'un projectile (11) éjecté du tube d'un canon (13), comprenant :
- des moyens de radar (15) pour produire un signal Doppler (19) indicatif du mouvement du projectile (11) par rapport à la bouche (13);
 - des moyens de transformation de Fourier (21, 23, 27) pour opérer sur le signal Doppler (19), et des moyens de détection (27) sensibles au signal de sortie des moyens de transformation de Fourier (21, 23, 27) pour mesurer la vitesse du projectile (11), caractérisé en ce que les moyens de transformation de Fourier (21, 23, 27) opèrent sur une pluralité de segments du signal Doppler (19), chaque segment représentant une période de temps distincte, pour produire une pluralité correspondante de signaux à spectre de fréquences; et en ce que les moyens de détection (27) sont sensibles à la pluralité de signaux à spectre de fréquences, pour mesurer la vitesse du projectile (11) pendant la période de temps associée à chaque segment successif du signal Doppler; et inclut des moyens (27) sensibles aux vitesses du projectile mesurées pendant la pluralité de périodes de temps successives, pour estimer la vitesse initiale du projectile (11) par extrapolation en arrière à l'instant zéro d'interception.
2. Appareil à radar Doppler selon la revendication 1, caractérisé en ce que les moyens de détection (27) incluent des moyens de comparaison pour comparer chacun des signaux d'une pluralité de signaux à spectre de fréquences à un seuil prescrit qui varie avec la fréquence et

avec l'amplitude du bruit superposé, les moyens de comparaison déterminant également que les parties des signaux dépassant le seuil résultent d'un ou plusieurs objets en mouvement incluant le projectile dont la vitesse initiale est estimée.

3. Appareil à radar Doppler selon la revendication 2, caractérisé en ce que les moyens de détection incluent en outre des moyens de fixation de seuil pour produire un seuil distinct pour chacune des fréquences d'une pluralité de fréquences dans chacun des signaux de la pluralité de signaux à spectre de fréquences, chacun de ces seuils étant sélectionné selon les niveaux du signal à spectre de fréquences pour des fréquences proches.
4. Appareil à radar Doppler selon la revendication 3, caractérisé en ce que :
- les moyens de transformation de Fourier incluent des moyens de conversion analogique/numérique pour convertir le signal Doppler en une suite de mots numériques qui sont organisés en groupes de N mots numériques chacun, et
 - des moyens de transformation de Fourier rapide pour opérer sur les N mots numériques dans chaque groupe successif de mots pour produire une série de signaux à fréquences discrètes pour chaque groupe, chacune de ces séries de signaux à fréquences discrètes constituant un signal distinct à spectre de fréquences; et en ce que
 - les moyens de fixation de seuil produisent un seuil distinct pour chaque mesure de fréquence dans chaque signal à spectre de fréquences sur la base des valeurs moyennes des mesures de fréquences discrètes pour une pluralité prédéterminée de fréquences proches.
5. Appareil à radar Doppler selon la revendication 1, caractérisé en ce que les moyens de transformation de Fourier (21, 23, 27) incluent des moyens de conversion analogique/numérique pour convertir le signal Doppler en une suite de mots numériques organisés en K groupes successifs de N mots numériques chacun, et
- des moyens de transformation de Fourier rapide pour opérer sur les N mots numériques dans chacun des K groupes successifs pour produire une série de mesures de fréquences discrètes pour chaque groupe, chacune de ces séries représentant le spectre de fréquences pour un segment de temps distinct du signal



Doppler; et en ce que

- les moyens de détection (27) opèrent sur la série de mesures de fréquences discrètes pour chacun des K groupes pour mesurer la vitesse du projectile pendant la période de temps associée au groupe correspondant de N mots numériques et opèrent sur les K mesures successives de la vitesse du projectile pour fournir ladite estimation de la vitesse initiale du projectile.

6. Appareil à radar Doppler selon la revendication 5, caractérisé en ce que les moyens de détection (27) incluent des moyens de comparaison pour comparer chacune des mesures de la pluralité de mesures de fréquence à un seuil prescrit qui varie avec les niveaux des mesures de fréquence pour les fréquences proches et pour déterminer que les mesures de fréquence dépassant le seuil résultent d'un ou plusieurs objets en mouvement incluant le projectile dont la vitesse initiale est estimée.

7. Appareil à radar Doppler selon la revendication 5 ou 6, caractérisé en ce que les moyens de détection (27) incluent en outre des moyens d'interpolation pour déterminer les signaux déterminés par les moyens de comparaison comme dépassant le seuil ou leurs seuils respectifs, pour déterminer la vitesse moyenne du projectile pendant la période de temps associée à chaque segment de temps successif du signal Doppler.

8. Appareil à radar Doppler selon l'une des revendications précédentes caractérisé en ce que

- un ou plusieurs objets en mouvement supplémentaires sont situés dans la direction du projectile (11); et en ce que
- les moyens de détection incluent des moyens pour mesurer les vitesses respectives du projectile et des un ou plusieurs objets en mouvement supplémentaires pendant la période de temps associée à chaque segment successif du signal Doppler.

9. Appareil à radar Doppler selon la revendication 8, caractérisé en ce que les moyens de détection (27) incluent en outre des moyens d'association pour associer ensemble les différentes mesures de vitesse dans chacune des périodes de temps successives correspondant respectivement au projectile et aux un ou plusieurs objets en mouvement supplémentaires les moyens d'association incluant des moyens

pour comparer chaque mesure de vitesse à des mesures de vitesse effectuées pour des périodes de temps antérieures, s'il y en a.

5 10. Appareil à radar Doppler selon la revendication 8, caractérisé en ce que les moyens de détection (27) incluent des moyens pouvant fonctionner pendant chaque période de temps pour comparer les mesures de vitesse du projectile et des un ou plusieurs objets en mouvement supplémentaires entre elles et pour rejeter toute mesure de vitesse qui est liée harmoniquement à une autre mesure de vitesse.

15 11. Appareil à radar Doppler selon l'une des revendications précédentes, caractérisé en ce que les moyens de détection (27) incluent des moyens pour définir un profil de vitesse initiale qui fournit l'erreur selon la méthode des moindres carrés sur la base des mesures de vitesse effectuées par les moyens de détection pour la pluralité de périodes de temps successives.

25 12. Appareil à radar Doppler selon la revendication 11, caractérisé en ce que les moyens de détection (27) comprennent en outre des moyens pour rejeter toute mesure de vitesse différant de plus d'une quantité prédéterminée du profil de vitesse initiale et pour redéfinir le profil de vitesse sur la base des mesures de vitesse restantes.

35 13. Appareil à radar Doppler selon la revendication 9, caractérisé en ce qu'il inclut :

- des moyens d'élimination d'harmoniques, pouvant fonctionner pendant chaque période de temps pour comparer les mesures de vitesse du projectile et des un ou plusieurs objets en mouvement supplémentaires entre eux et pour rejeter toute mesure de vitesse qui est liée harmoniquement à une autre mesure de vitesse; et
- des moyens de régression pour définir un profil de vitesse initiale qui fournit l'erreur selon la méthode des moindres carrés sur la base des mesures de vitesse effectuées par les moyens d'interpolation et les moyens d'association pour la pluralité de périodes de temps successives, les moyens de régression incluant des moyens pour rejeter toute mesure de vitesse différant de plus d'une quantité prédéterminée du profil de vitesse initiale et pour redéfinir le profil de vitesse sur la base des mesures de vitesse restantes, le profil de vitesse redéfini indi-



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quant la vitesse initiale du projectile.

14. Appareil à radar Doppler selon l'une des revendications précédentes, caractérisé en ce que

- le projectile (11) dont la vitesse est à mesurer est éjecté d'un canon à explosif (13); et en ce que
- l'appareil inclut en outre des moyens (33, 35) pour empêcher l'appareil de mesurer la vitesse du projectile pendant une période de temps prédéterminée, jusqu'à ce que toute ionisation associée au tir par le canon (13) se soit sensiblement dissipée.

15. Procédé à radar Doppler pour déterminer la vitesse initiale d'un projectile (11) éjecté par une bouche de tir (13), comprenant l'étape consistant à :

- produire un signal Doppler (19) indicatif du mouvement du projectile (11) par rapport à la bouche, caractérisé en ce qu'il comprend les étapes consistant à
- opérer sur une pluralité de segments du signal Doppler (19), chaque segment représentant une période de temps distincte, pour produire une pluralité de signaux à spectre de fréquences;
- traiter la pluralité de signaux à spectre de fréquences pour mesurer la vitesse du projectile pendant la période de temps associée à chaque segment successif du signal Doppler; et
- estimer la vitesse initiale du projectile (11) sur la base des vitesses du projectile mesurées dans l'étape de traiter pour la pluralité de périodes de temps successives, et
- extrapoler en arrière à l'instant zéro d'interception.

16. Procédé à radar Doppler selon la revendication 15, caractérisé en ce que l'étape de traiter comprend les étapes consistant à :

- comparer chacun des signaux de la pluralité de signaux à spectre de fréquences à un seuil prédéterminé qui varie avec la fréquence et avec l'amplitude du bruit superposé; et
- déterminer que la partie des signaux dépassant le seuil résulte d'un ou plusieurs objets en mouvement incluant le projectile dont la vitesse initiale est estimée.

17. Procédé à radar Doppler selon la revendication 16, caractérisé en ce que l'étape de traiter

inclut en outre une étape consistant à produire un seuil distinct pour chacune des fréquences d'une pluralité de fréquences dans chacun des signaux d'une pluralité de signaux à spectre de fréquences, chacun de ces seuils étant sélectionné selon les niveaux du signal à spectre de fréquences pour les fréquences proches.

18. Procédé à radar Doppler selon la revendication 17, caractérisé en ce que l'étape d'opérer inclut les étapes consistant à :

- convertir le signal Doppler (19) en une suite de mots numériques qui sont organisés en groupes de N mots numériques chacun; et
- opérer sur les M mots numériques de chaque groupe successif de mots pour produire une série de mesures de fréquences discrètes pour chaque groupe, chacune de ces séries de mesures de fréquences discrètes constituant un signal distinct à spectre de fréquences; et
- l'étape de produire inclut une étape consistant à produire un seuil distinct pour chaque mesure de fréquence dans chaque signal à spectre de fréquences sur la base des valeurs moyennes des mesures de fréquences discrètes pour une pluralité prédéterminée de fréquences proches.

19. Procédé à radar Doppler selon l'une des revendications 16 à 18, caractérisé en ce que l'étape de traiter inclut en outre une étape consistant à interpoler les parties de chacun des signaux de la pluralité de signaux à spectre de fréquences qui sont déterminées dans l'étape de comparer comme dépassant le seuil, pour déterminer la vitesse moyenne du projectile (11) dans la période de temps associée à chaque segment successif du signal Doppler.

20. Procédé à radar Doppler selon l'une des revendications 15 à 19, caractérisé en ce que

- un ou plusieurs objets en mouvement supplémentaires sont situés dans la direction du projectile (11); et en ce que
- l'étape de traiter inclut une étape consistant à mesurer les vitesses respectives du projectile (11) et des un ou plusieurs objets en mouvement supplémentaires pendant la période de temps associée à chaque segment successif du signal Doppler (19).



21. Procédé à radar Doppler selon la revendication 20, caractérisé en ce que l'étape de traiter inclut en outre une étape consistant à associer ensemble les différentes mesures de vitesse dans chacune des périodes de temps successives correspondant respectivement au projectile et aux un ou plusieurs objets en mouvement supplémentaires, l'étape d'associer incluant une étape consistant à comparer chaque mesure de vitesse à des mesures de vitesse effectuées pour des périodes de temps antérieures, s'il y en a. 5 10
22. Procédé à radar Doppler selon la revendication 21, caractérisé en ce que l'étape de traiter inclut une étape consistant à comparer les mesures de vitesse entre elles pendant chaque période de temps et rejeter toute mesure de vitesse qui est liée harmoniquement à une autre mesure de vitesse. 15 20
23. Procédé à radar Doppler selon l'une des revendications 15 à 22, caractérisé en ce que l'étape d'estimer inclut une étape consistant à définir un profil de vitesse initiale qui fournit l'erreur selon la méthode des moindres carrés sur la base des mesures de vitesse effectuées dans l'étape de traiter pour la pluralité de périodes de temps successives. 25 30
24. Procédé à radar Doppler selon la revendication 23, caractérisé en ce que l'étape d'estimer inclut en outre des étapes consistant à rejeter toute mesure de vitesse différant de plus d'une quantité prédéterminée du profil de vitesse initiale, et à redéfinir le profil de vitesse sur la base des mesures de vitesse restantes. 35
25. Procédé à radar Doppler selon l'une des revendications 15 à 24, caractérisé en ce que : 40
- le projectile (11) dont la vitesse est à mesurer est éjecté par un canon à explosif (13); et en ce que
 - le procédé inclut en outre une étape consistant à empêcher le procédé de mesurer la vitesse du projectile pendant une période de temps prédéterminée, jusqu'à ce que toute ionisation associée au tir du canon (13) se soit sensiblement dissipée. 45 50

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