US 20070293331A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2007/0293331 A1

Tuxen (43) Pub. Date: Dec. 20, 2007

(54) METHOD OF AND AN APPARATUS FOR DETERMINING INFORMATION RELATING TO A PROJECTILE, SUCH AS A GOLF BALL

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(21) Appl. No.: **11/597,513**

(22) PCT Filed: **May 23, 2005**

(86) PCT No.: **PCT/DK05/00336**

§ 371(c)(1),
(2), (4) Date: **Jul. 31, 2007**

Related U.S. Application Data

(60) Provisional application No. 60/574,231, filed on May 26, 2004.

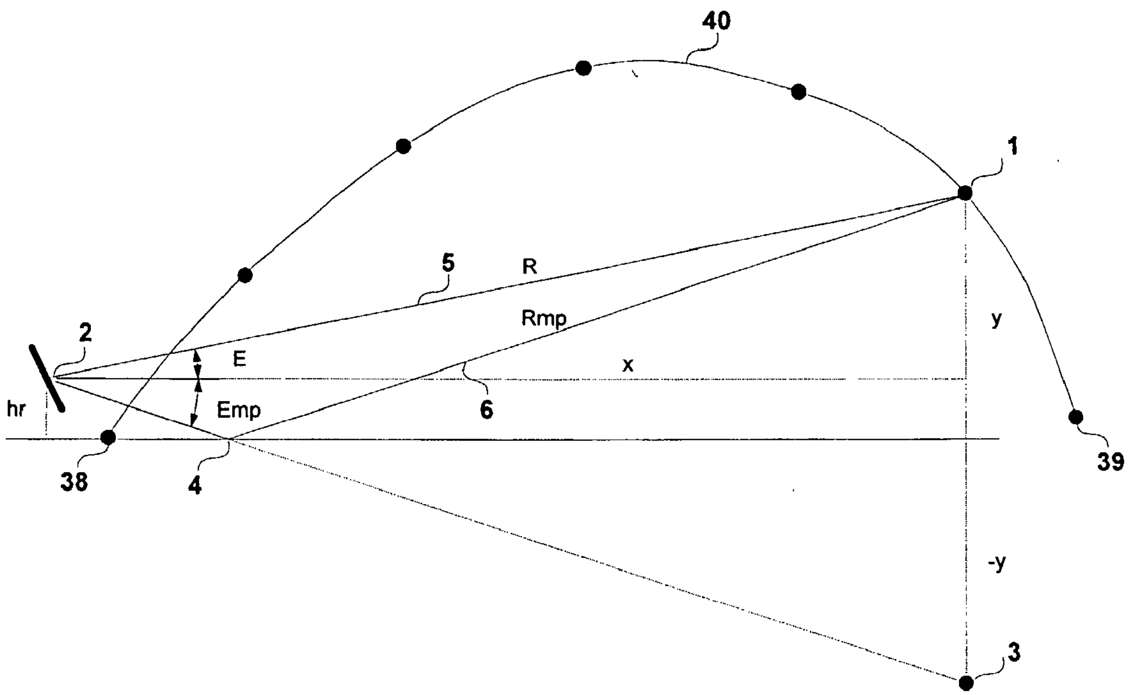
Publication Classification

(51) **Int. Cl.**
A63B 69/36 (2006.01)

(52) **U.S. Cl.** **473/199**

(57) **ABSTRACT**

An apparatus and a method of providing information relating to a projectile, such as a sports ball, such as a golf ball. The apparatus and method provide better estimations of e.g. the landing point of the projectile or its position in general in that an oscillating signal caused e.g. by multiple path reflections of the radiation, is identified and may be removed in order to generate the "true" signal used for the landing point determination. This oscillating signal may be used for quantifying an error of the landing point determination or may be used for providing information relating to the surroundings of the projectile during its flight.



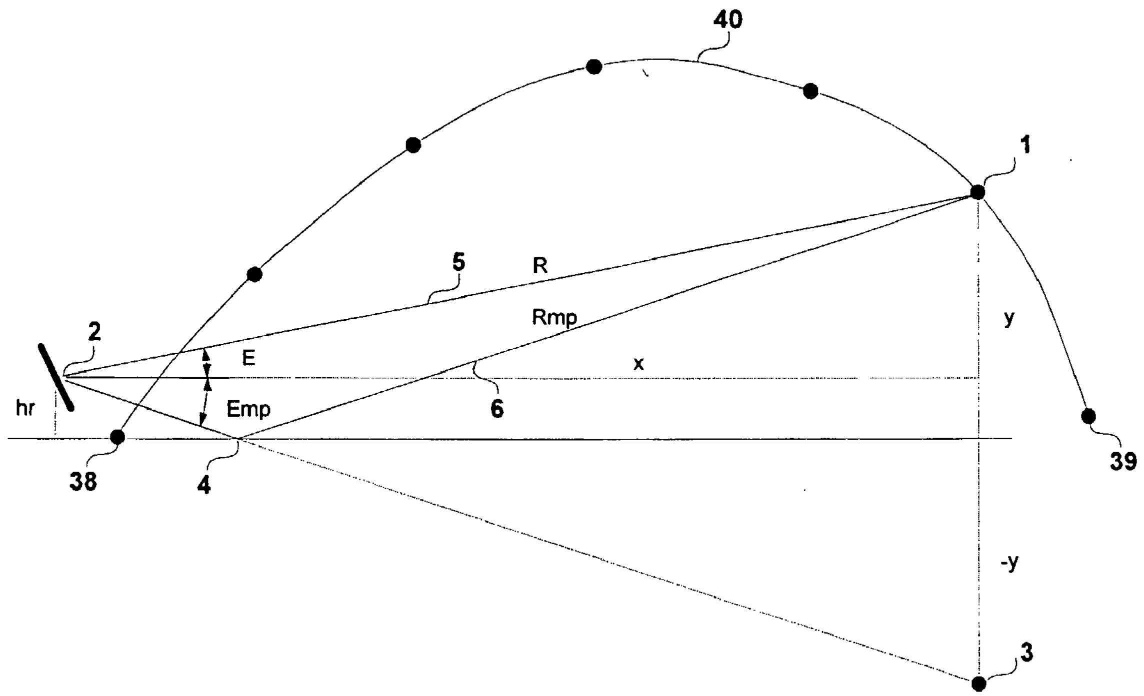


Fig. 1

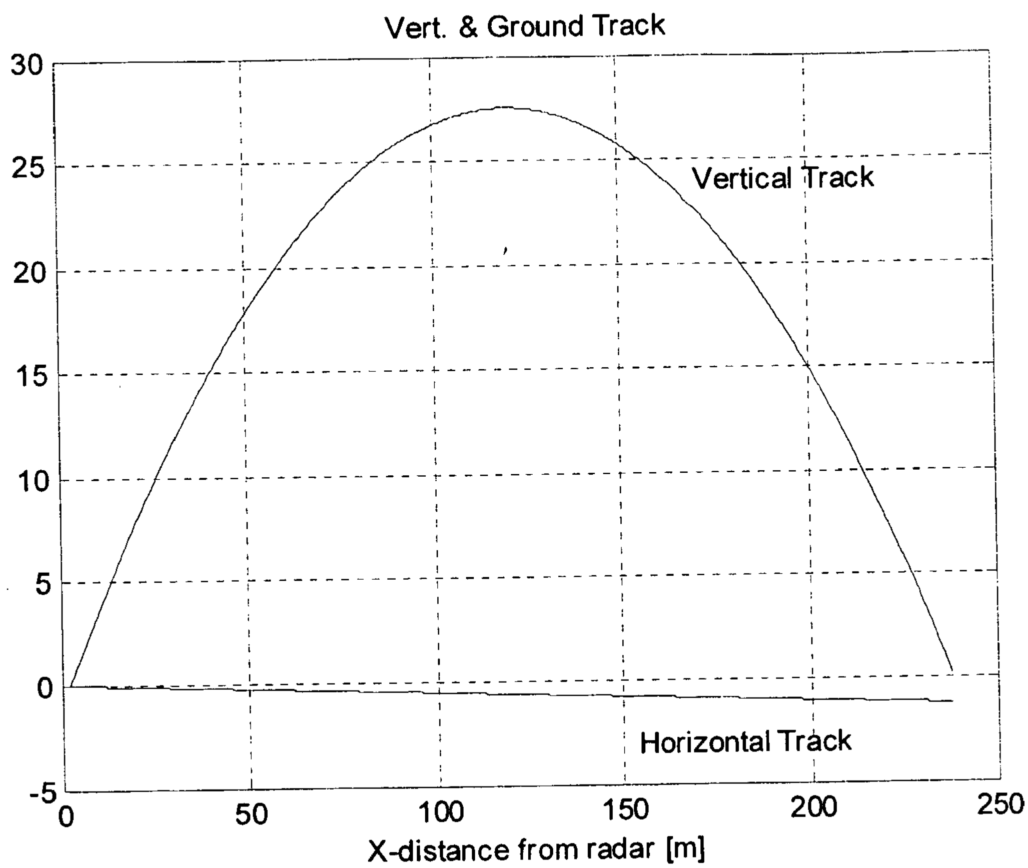

Vert. & Ground Track
30
25
20
15
10
5
0
-5
Vertical Track
Horizontal Track
0
50
100
150
200
250
X-distance from radar [m]

Fig. 2

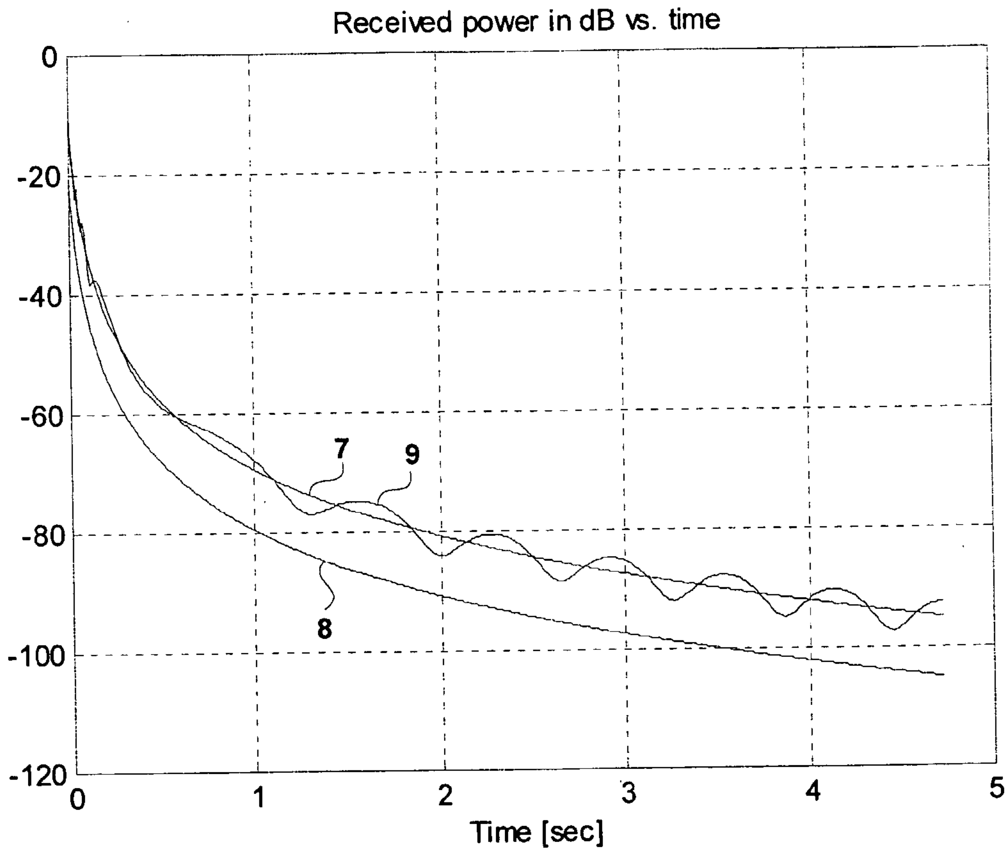

Received power in dB vs. time
0
-20
-40
-60
-80
-100
-120
0
1
2
3
4
5
Time [sec]
7
9
8

Fig. 3

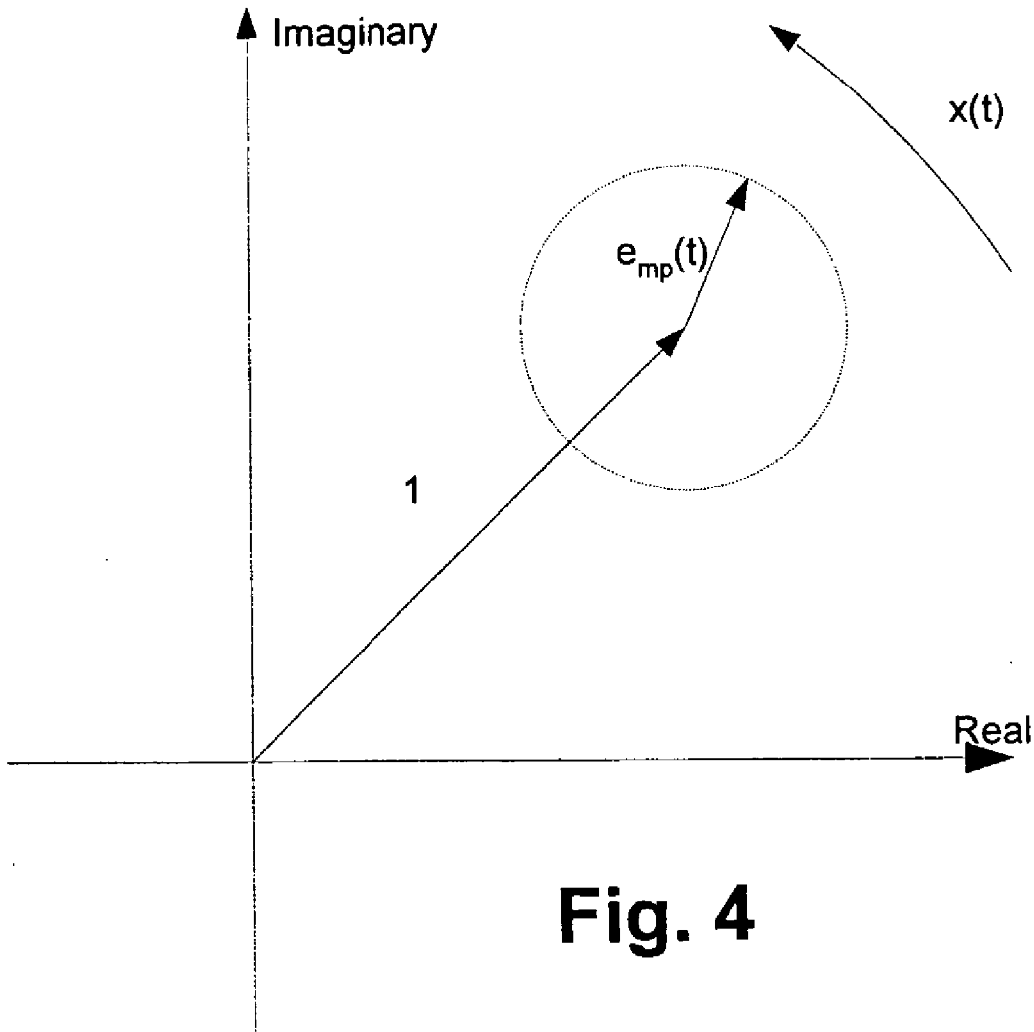


Fig. 4

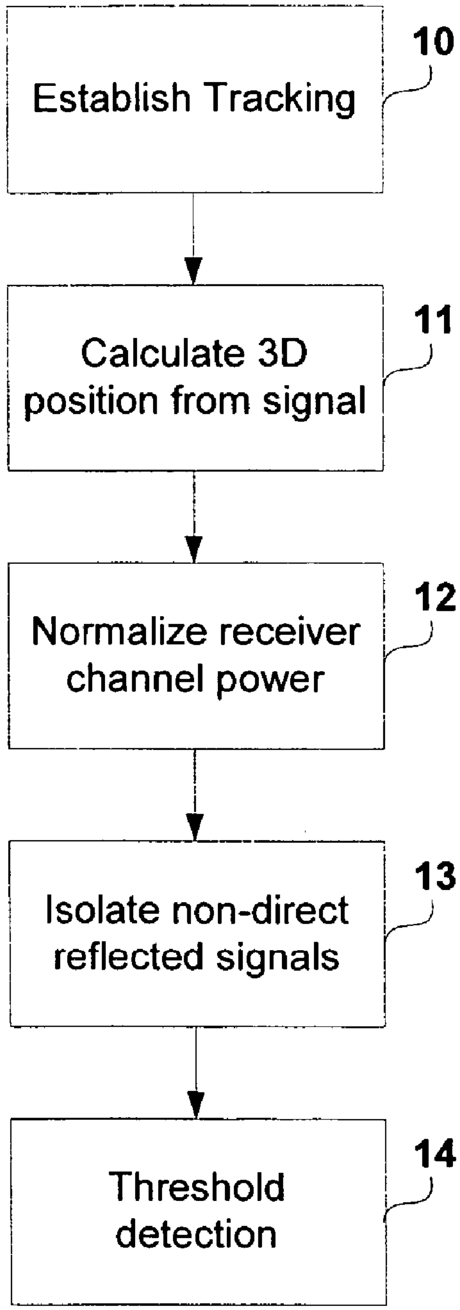

Establish Tracking
10
Calculate 3D position from signal
11
Normalize receiver channel power
12
Isolate non-direct reflected signals
13
Threshold detection
14

Fig. 5

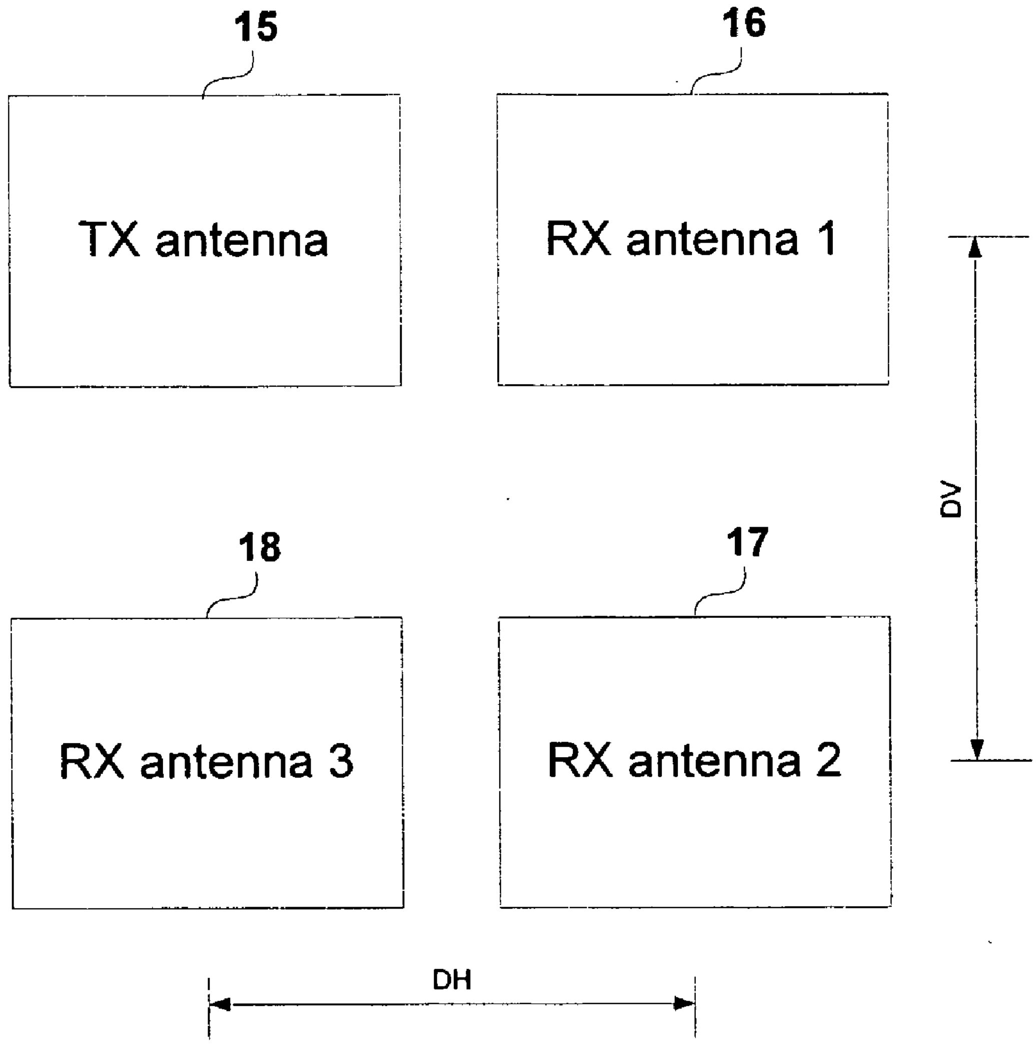

15
16
TX antenna
RX antenna 1
DV
18
17
RX antenna 3
RX antenna 2
DH

Fig. 6

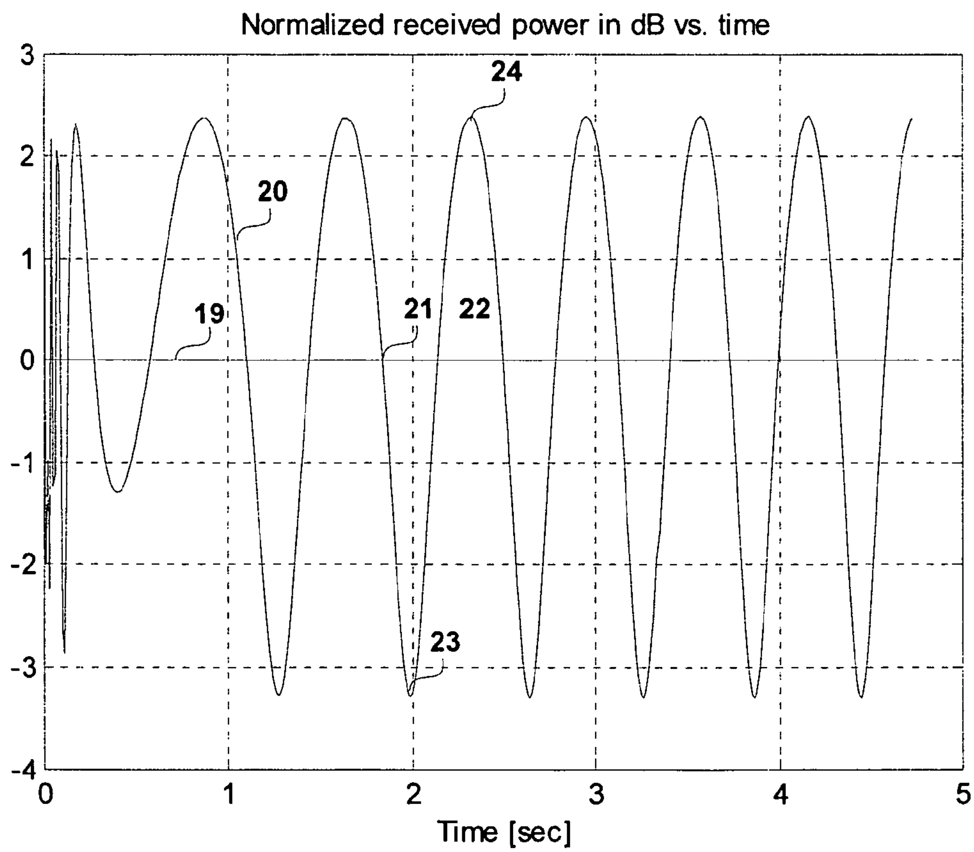
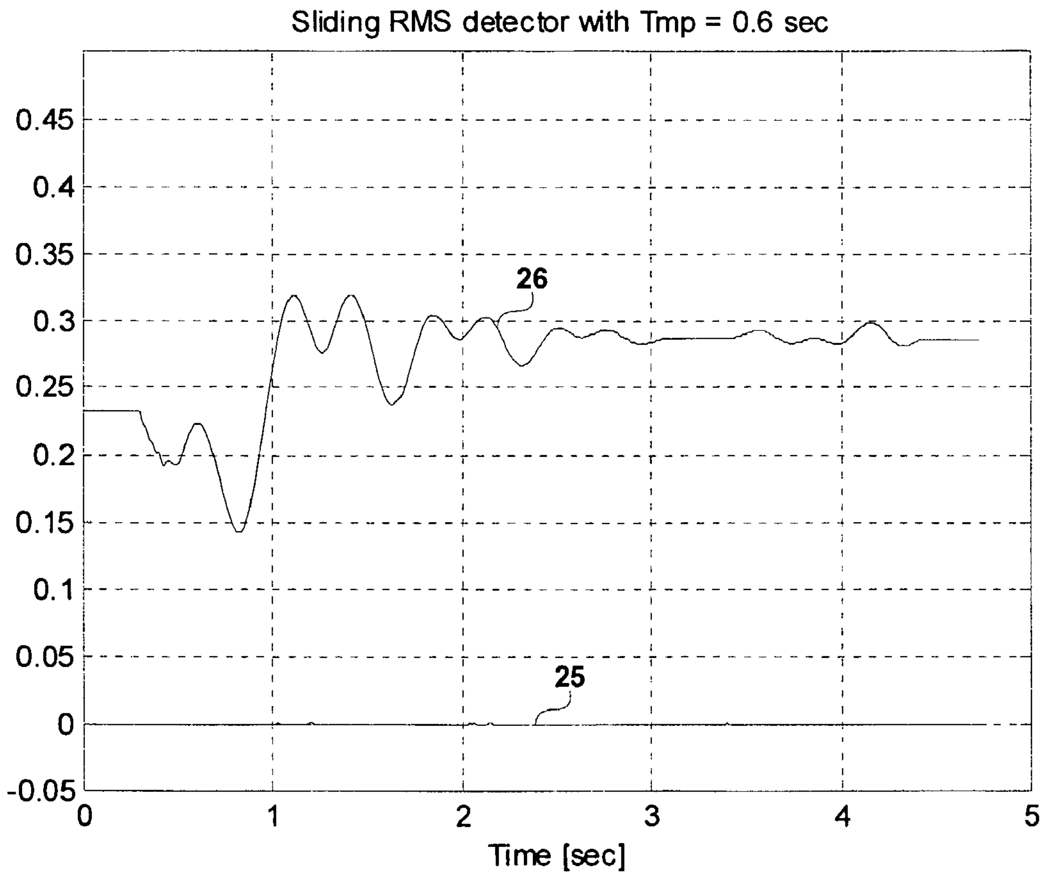

Normalized received power in dB vs. time
3
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5
Time [sec]
19
20
21
22
23
24

Fig. 7



Sliding RMS detector with Tmp = 0.6 sec
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
1
2
3
4
5
Time [sec]
26
25

Fig. 8

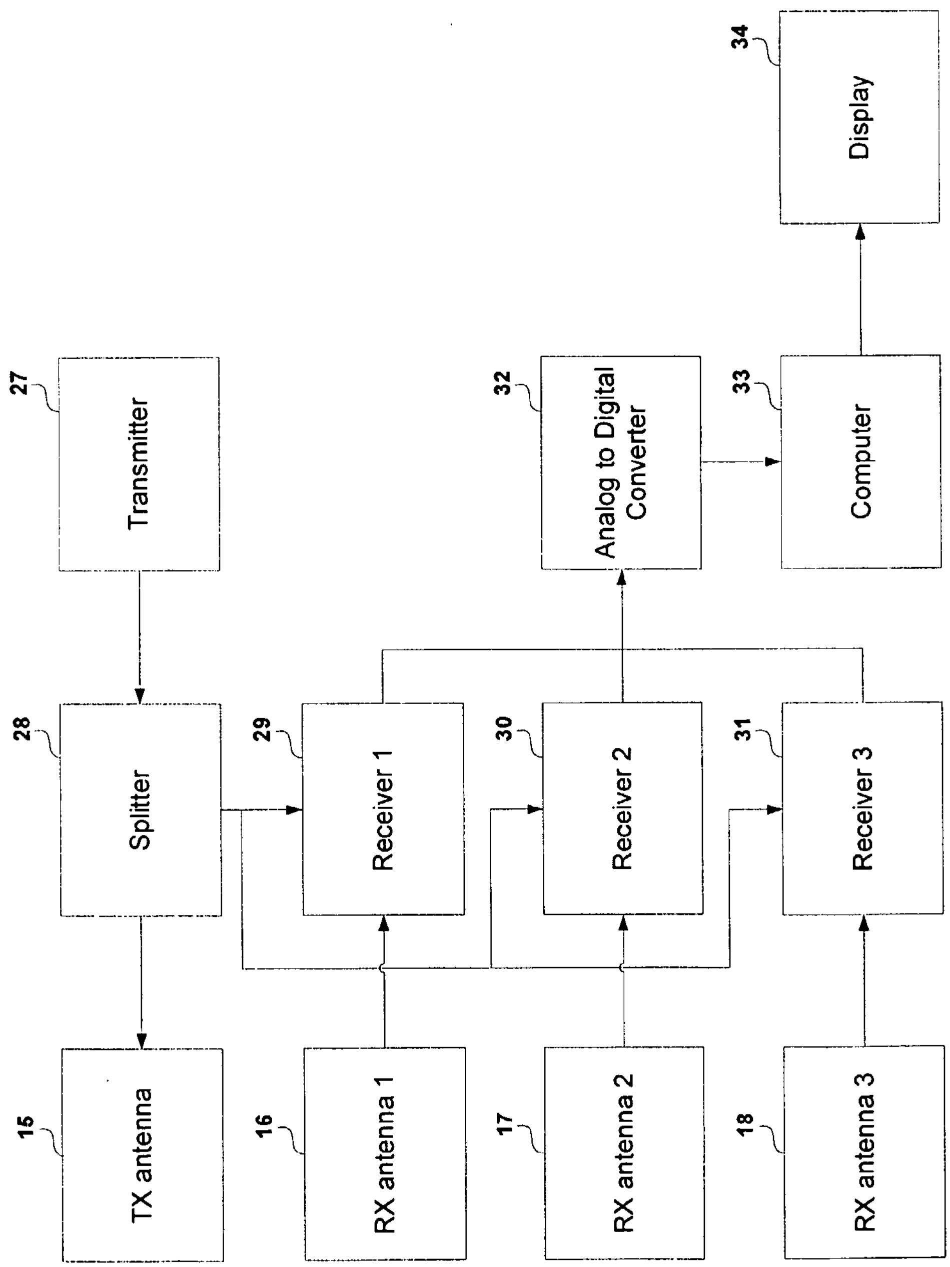

27
Transmitter
28
Splitter
15
TX antenna
29
Receiver 1
16
RX antenna 1
30
Receiver 2
17
RX antenna 2
31
Receiver 3
18
RX antenna 3
32
Analog to Digital Converter
33
Computer
34
Display

Fig. 9

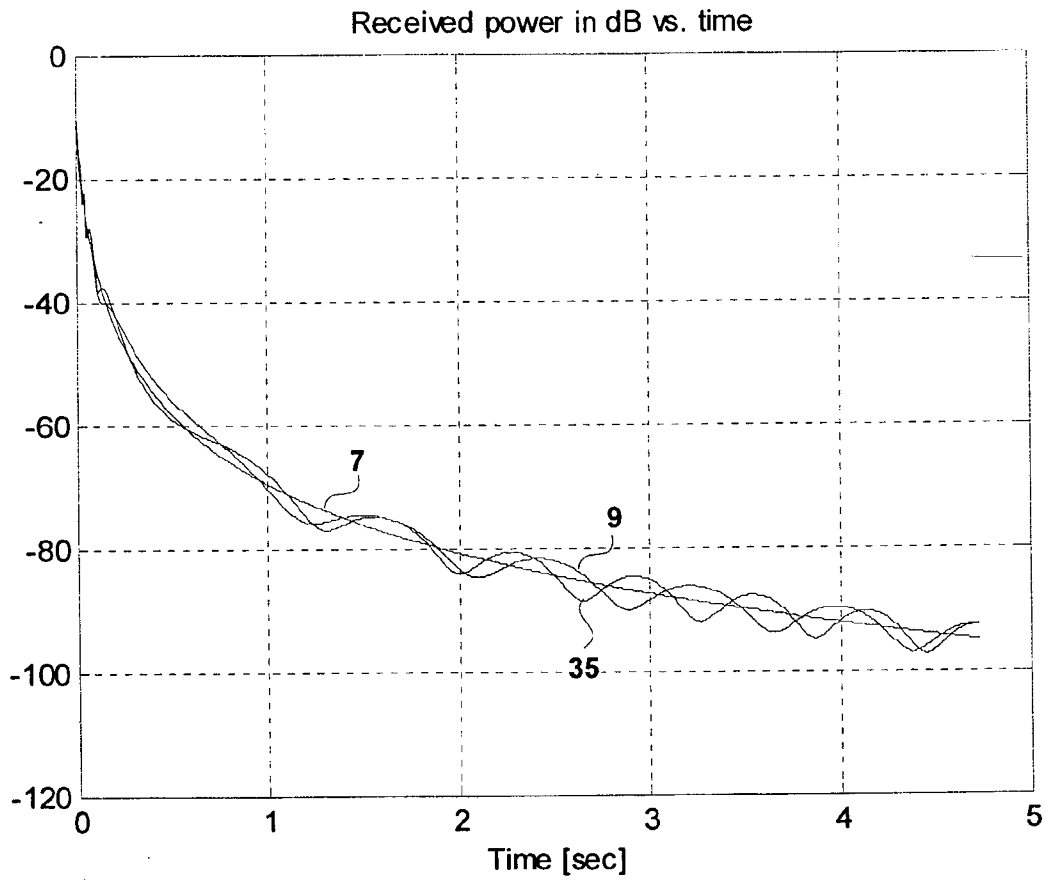

Received power in dB vs. time
0
-20
-40
-60
-80
-100
-120
0
1
2
3
4
5
Time [sec]
7
9
35

Fig. 10

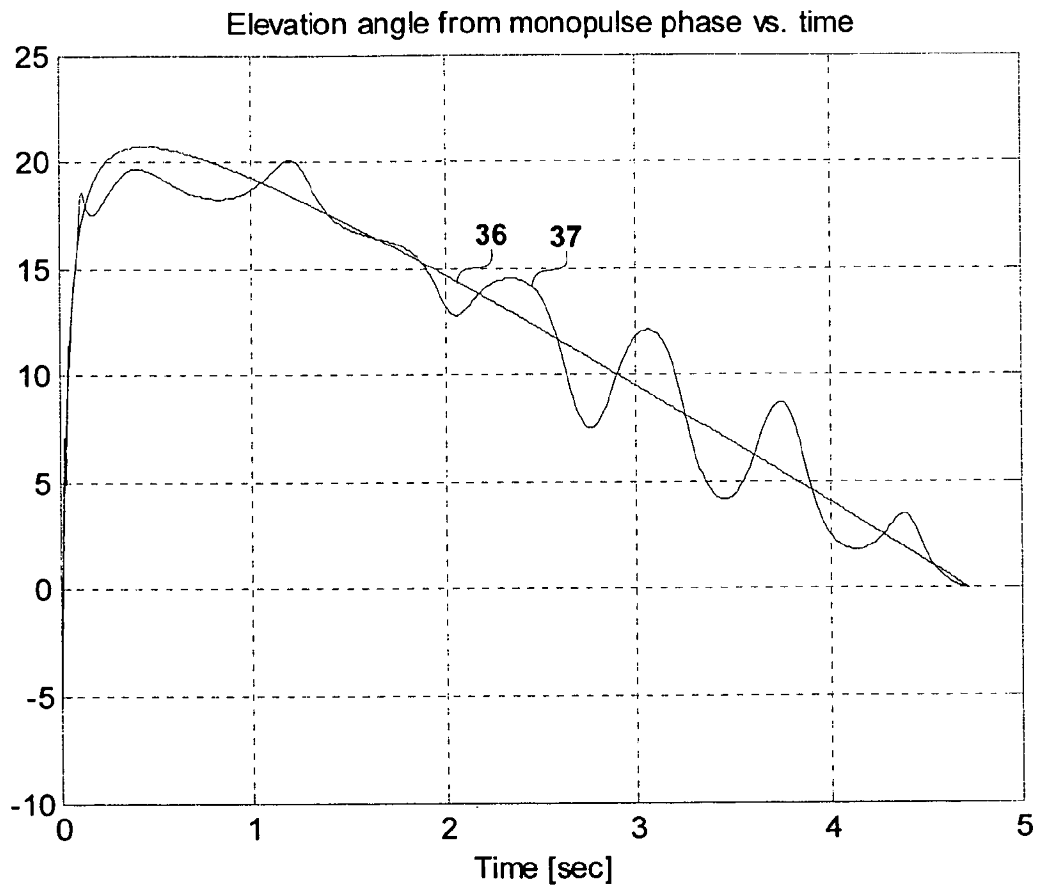

Elevation angle from monopulse phase vs. time
25
20
15
10
5
0
-5
-10
0
1
2
3
4
5
Time [sec]
36
37

Fig. 11

METHOD OF AND AN APPARATUS FOR DETERMINING INFORMATION RELATING TO A PROJECTILE, SUCH AS A GOLF BALL

[0001] The present invention relates to a method and an apparatus for determining information relating to a projectile, such as a rifle projectile, a missile or, a sports ball, such as a golf ball, or another object adapted to be launched. The information relates to the projectile at least partly while the projectile is in flight. In a number of embodiments, the information sought may be the actual path taken by the projectile, the deviation thereby from a predetermined path, the landing point, or the like.

[0002] A number of apparatus and methods are known for determining information from flying projectiles. Such apparatus may comprise the providing of transmitting equipment inside the projectile or e.g. a bat used for hitting a sports ball. Other equipment uses a radar for receiving radiation from the projectile, such as from a golf ball, and for determining information from the projectile. However, such apparatus is not able to determine the actual landing point of the ball in that, normally, the radar is turned off, lacks sensitivity, or the measurement stopped before the ball lands.

[0003] Golf radars are described in: WO03/032006, WO 91/06348, U.S. Pat. Nos. 5,700,204, 6,547,671, 5,092,602, 4,509,052, 3,798,644, 6,133,946, 5,489,099, 6,244,971, 6,456,232, and 5,495,249 as well as in JP-A-6126015 and 8266701.

[0004] A problem encountered using radar or the like on a flying projectile is that of the radiation transmitted from the projectile to the receiver may take multiple paths. Such multiple paths will have different path lengths, whereby the signals from the individual paths will interfere with each other. This interference will influence rather drastically on the final result, such as a determination of a velocity or position of the projectile.

[0005] Especially the determination of a landing point of the projectile is difficult in that the radiation from the projectile will experience also the ground especially when close to the ground, where the detection is critical. At this point, the interference of the signals will be large, whereby the signal will vary and actually reaches zero even though the projectile is still in flight. In this respect, it should be noted that the signal needs not actually reach zero, but it will be smaller than a detection threshold, whereby it will "formally" be zero in the sense that it is not detectable within the detection limit.

[0006] This multi-path problem may be solved by preventing radiation from all but one such path from reaching the detector. This, however, may be difficult to obtain especially when the projectile is close to the ground and is far away from the detector.

[0007] This problem is seen both in golf, cricket and baseball, where balls are hit large distances and where, such as for training purposes or entertainment purposes, it is desired to know where the ball landed or other characteristics of the ball flight path.

[0008] One aspect of the invention relates to another manner of handling the multi-path situation. This aspect relates to a method of determining information relating to a projectile, the method comprising:

[0009] receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

[0010] generating an altered signal by removing, from the provided signal, an oscillating signal, and

[0011] determining the information relating to the projectile from the altered signal.

[0012] In the present context, normally, the radiation emitted/reflected from the projectile takes more than one path toward the receiver, whereby the radiation received has the same frequency/wavelength or is within a predetermined wavelength interval. In this manner, wavelength filtering may be provided in order to filter away noise caused by radiation outside this frequency or this interval.

[0013] The oscillating signal may be caused (at least partly) by the radiation taking more than one path, where the radiation from the multiple paths interfere and cause the oscillating signal.

[0014] Also, that the radiation is received at least partly while the projectile is in flight relates to the fact that radiation received and information derived from the projectile before flying or after having landed may be very valuable in combination with the radiation received (and information derived) during the flight.

[0015] This oscillation is caused by the projectile moving, whereby the path lengths in the different paths vary and cause, together with the wavelength of the radiation, an oscillation of the resulting signal received.

[0016] The oscillating signal is continuous and may, but need not, be sinusoidal. In fact, the oscillation would, if caused by this multi-path effect, increase in amplitude over time and it will also change in frequency. The amplitude will depend on the reflection of the surroundings, normally the ground. The oscillation will depend on the shape of the surroundings (path length difference) as well as the projectile trajectory and relative position of the receiver. For a golf ball trajectory, the frequency of the oscillating signal is, for a receiver placed a couple of meters behind the launch point, normally in the interval of 0.5-10 Hz. For riffle projectiles, missiles or artillery projectiles the frequency of the oscillating signal is slightly lower, normally in the interval of 0.1-2 Hz.

[0017] Naturally, any type of radiation may be used, such as visible light, IR, NIR, UV, Microwaves or radio waves may be used. Also sound, such as ultrasound may be used.

[0018] The corresponding signal may be a signal representing signal strength, a frequency, a wavelength, intensity, a phase or any other characteristic of the radiation received. Normally, the corresponding signal represents this characteristic over a period of time.

[0019] The information derived relating to the projectile may be the position thereof, the velocity, spin, rotation, height, acceleration, path, or the like.

[0020] In the present context, the removal of the oscillating signal from the corresponding signal may be a coherent adding of the unwanted signal shifted 180 degrees in phase or any other manner of taking away the oscillating signal from the other signal.

[0021] The resulting, altered signal will be a smooth signal, representing the actual position and movement of the projectile.

[0022] In one embodiment, the generating step comprises performing an averaging operation comprising averaging the provided signal over a predetermined time period. Averaging over a period of time larger than a full period or variation (of a non-periodical signal) of the oscillating signal will average out the oscillating signal and provide an altered signal with components having a frequency lower than a signal having a period of the averaging time period. This is one manner of removing the oscillating signal.

[0023] Another manner is one wherein the generating step comprises tracking the oscillating signal and subtracting the oscillating signal from the provided signal. This tracking may be obtained on the basis of a knowledge of the frequency (or frequency interval) of the oscillating signal. In this manner, the signal may be identified and tracked, whereby subtraction is easy.

[0024] As mentioned above, the provided signal may, due to interference, reach zero even though the actual signal desired—the altered signal—has not reached zero. Thus, one embodiment relates to a method where the generating step comprises generating the altered signal for a predetermined period of time after, that the provided signal reaches zero. If the provided signal subsequently rises above zero, the providing of the altered signal may continue, until the provided signal has not increased over zero for the predetermined point in time. In this manner, any interference will not untimely stop the determination.

[0025] As mentioned above, the oscillating signal may be caused by interference from multiple paths. Thus, the receiving step may comprise receiving the radiation from at least two different directions or paths.

[0026] In one embodiment, the determining step comprises determining a parameter of the projectile at a first point in time and estimating, from the determined parameter, the parameter at a second, later, point in time. One manner of performing this estimation is to perform it using a predetermined relation between the parameter and time. In that situation, the parameter will have a predetermined course or development over time. One such parameter is a distance between a means receiving the radiation and the projectile. When monitoring the parameter, such as the distance, at a first point in time or during a first period of time, it is possible to predict the parameter/distance at a later point in time.

[0027] When the corresponding signal provided is a signal representing an intensity of the radiation received, the determining step may comprise determining a distance between a means receiving the radiation and the projectile. This is due to the fact that the intensity emitted or reflected by the projectile may be independent of an orientation of the projectile or it is a priori known, whereby the intensity/signal strength received will relate to the distance between the projectile and the receiver. Naturally, if a radiation/sound emitter is used, the distance between the projectile and the emitter should also be taken into account.

[0028] A particularly interesting embodiment is one which is able to determine the landing point or landing spot of the projectile. Hitherto, landing point determination has been performed on the basis of knowledge of only part of the path or the projectile during flight. This, however, has presented uncertainties in the determination. One reason for the prior art techniques not putting emphasis on the signals from a projectile close to the ground may be the above-mentioned oscillating multiple-path signals.

[0029] In this embodiment, the generating step comprises generating the altered signal, until the altered signal fulfils a predetermined criterion, the determining step further comprising providing, as the information, an estimate of a landing point of the projectile.

[0030] Thus, now that it is possible to actually remove the oscillating signal, which in multiple-path situations is the strongest, when the projectile is close to the ground, it is possible to keep providing a reliable altered signal. Then, the certain criterion is preferably related to a situation where it is probable that the projectile has, in fact, landed.

[0031] In this situation, the landing point of the projectile will normally be the spot of impact between the projectile and the ground. In the situation where the projectile subsequently bounces back up and again hits the ground, the landing point is the first point of impact.

[0032] The predetermined criterion will relate to what the provided and actual signals represent. When these signals represent a signal strength or amplitude, the predetermined criteria may be an absolute or a relative signal strength/intensity/amplitude, a predetermined absolute or relative drop/increase of the strength/intensity/amplitude, a predetermined course or development over time.

[0033] One particular manner is to have the determining step comprise performing a filtering using a time constant larger than a period of the oscillating signal, and to determine a landing point as a point where the signal level has decreased a predetermined amount, such as 3 dB.

[0034] The frequency or period of the oscillating signal depends on both the trajectory of the projectile as well as the height thereof above the ground (or the distance to the reflecting surface) and the velocity of the projectile. Thus, a golf ball may give rise to a period in the interval of 0.5-10 Hz, whereas a projectile launched by a rifle or a handgun may give rise to longer periods, such as 0.1-2 Hz, again depending on the actual trajectory.

[0035] One manner of using this landing point is one where the determining step comprises providing as the information an estimate of a distance between the landing point of the projectile and a predetermined target. This may be useful for practising hitting a target, such as a flag on a golf course, where it may then be desirable to also know the distance, and often also the direction and height difference, from the target to the receiver. Thus, using this set-up, it is possible to determine the actual distance between the target and the landing point without having to travel to the target area.

[0036] Another manner of using the landing point information is to have the determining step comprise providing as the information an estimate of a deviation from a predetermined direction and a determined direction of the projectile. This determined direction may e.g. be determined from the landing point.

[0037] This deviation may be an angular deviation between the two directions, but the deviation may also be determined as a 3 dimensional distance between the intended and the actual directions at the distance of the landing point of the projectile.

[0038] In order to determine the actual path/direction of the projectile, it is desired that the determining step further comprises determining a launch position of the projectile, the determined direction of the projectile being a direction between the launch position and the landing point. A number of manners exist of determining the launch position of the projectile. One method is to simply dictate this position in relation to the receiver.

[0039] The launch position may be a position where the projectile leaves the ground plane, as would be the case for a golf ball, it might be a position from where the projectile leaves a launch pad, such as a rifle, or it may be a position where the projectile is impacted in order to initiate its path, such as where it is hit by a hand, a bat, or the like.

[0040] A second aspect relates to e.g. the use of the provided signal even though the oscillating signal forms part thereof. This aspect relates to a method of determining information relating to a projectile, the method comprising:

[0041] receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

[0042] identifying whether an amplitude of the provided signal varies more than a predetermined threshold,

[0043] determining the information from the corresponding signal, and

[0044] quantifying an uncertainty of the determination of the information from the variation of the amplitude.

[0045] Thus, the oscillating signal is accepted, and an uncertainty of the information is quantified on the basis of the strength/intensity/amplitude of the oscillating signal. This quantification is a standard technique in statistical analysis.

[0046] Naturally, the oscillating signal could also be removed by the method further having a step of generating the altered signal by removing from the provided signal an oscillating signal, the method further comprising the step of determining further information from the altered signal. The information determined from the altered signal may be that described in relation to the first aspect. Thus, his generating step could comprise performing an averaging operation comprising averaging the provided signal over a time period larger than a predetermined time period or tracking the oscillating signal and subtracting the oscillating signal from the provided signal.

[0047] As mentioned above, the generating step could generate the altered signal for a predetermined period of time after, that the provided signal reaches zero, in order to more precisely determine e.g. a landing point.

[0048] The oscillating signal may be caused by multiple-path problems caused when the receiving step comprises receiving the radiation from at least two different directions or paths.

[0049] Also, the determining step could comprise determining a parameter of the projectile at a first point in time and estimating, from the determined parameter, the parameter at a second, later, point in time. This estimation may be performed using a predetermined relation between the parameter and time, and the parameter determined may be a distance between a means receiving the radiation and the projectile.

[0050] The corresponding signal provided may be a signal representing an intensity of the radiation received. Then, the determining step could comprise determining a distance between a means receiving the radiation and the projectile.

[0051] A third aspect of the invention relates to the use of the oscillating signal for providing information. This aspect relates to a method of determining information relating to the surroundings of a projectile, the method comprising:

[0052] receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

[0053] generating an altered signal by isolating, from the provided signal, an oscillating signal, and

[0054] determining, as the information and from the altered signal, In one situation, an angle to vertical of, and/or a distance to, a surface over which the projectile flies and/or a reflection coefficient of the radiation of a surface over which the projectile flies.

[0055] When the oscillating signal relates to a multiple-path situation, it should be remembered that one path may be that directly between the projectile and the receiver, but that the others must have experienced at least one reflection from or by the surroundings. This reflection provides information about the reflecting coefficient and the angle of, and/or a distance to, the point of reflection. During flight of the projectile, this point will also move in the surroundings.

[0056] This may be combined with knowledge, such as provided using the first or second aspects, of the position of the projectile.

[0057] A fourth aspect relates to a method of determining a distance between a projectile and a radiation receiver, the method comprising the steps of:

[0058] receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight,

[0059] determining an intensity of the radiation received and a distance between the receiver and the projectile at a first point in time,

[0060] determining, at a second, later point in time, a second intensity of the radiation received, and

[0061] determining from a mathematical relation between the first and second intensities determined, a distance, at the second point in time, between the receiver and the projectile.

[0062] This is especially interesting, if it may be assumed that the emission or reflection from the projectile toward the receiver is constant, in that the difference between the intensities may then simply only relate to the difference in distance. In that situation, the mathematical relation is simple.

[0063] A situation which may complicate the matter slightly is that where the receiver(s), or any transmitter providing the radiation, have an angle dependent emission or sensitivity/gain, in which the angle or position of the projectile also has to be taken into account. This, however, is a known procedure e.g. in radar technology.

[0064] Naturally, if a transmitter is used for providing the radiation/sound toward the projectile, the distance between the transmitter and the projectile also has to be taken into account.

[0065] The first point in time may be a point in time before, at, or after launch of the projectile where the position of the projectile is known.

[0066] The present distance determination may be used for determining the actual distance to the projectile or it may be used for checking another distance measurement.

[0067] In any of the above aspects, the step of providing the corresponding signal could comprise providing a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval. In that manner, a filtering of unrelated radiation/sound may be performed.

[0068] Also, the method according to any of the above aspects may further comprise the initial step of providing electromagnetic radiation toward the projectile while in flight. In that manner, the wavelength/frequency of the radiation/sound as well as the intensity/signal strength thereof may be controlled.

[0069] A fifth aspect relates to, as the first aspect, the removal of the oscillating. In particular, the fifth aspect relates to an apparatus for determining information relating to a projectile, the apparatus comprising:

[0070] means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

[0071] means for generating an altered signal by removing, from the provided signal, an oscillating signal, and

[0072] means for determining the information relating to the projectile from the altered signal.

[0073] The present receiving means may be a single receiving means or be multiple receiving means positioned in predetermined positions in relation to each other in order for the receiving means to be able to e.g. determine from where the radiation is received.

[0074] The receiving means may be adapted to receive the radiation/sound at multiple positions and thereby be adapted to provide an altered signal for each receiving means. This may provide additional information, such as three-dimensional or two-dimensional information relating to the projectile.

[0075] Again, radiation of any wavelength and e.g. sound may be used for the present determination.

[0076] In one embodiment, the generating means are adapted to perform an averaging operation comprising averaging the provided signal over a predetermined time period. In this manner, when the predetermined time period exceeds a period of the oscillating signal, this signal may be averaged out.

[0077] Also, the generating means may be adapted to track the oscillating signal and subtract the oscillating signal from the provided signal. This also makes it possible to remove the oscillating signal. In fact, it makes it possible to also derive the oscillating signal and derive information there from—see below.

[0078] Preferably, the generating means are adapted to generate the altered signal for a predetermined period of time after, that the provided signal reaches zero. In this manner, when the oscillating signal has a large amplitude compared to that of the altered signal, the determination of the altered signal may be continued even though the oscillating signal extinguishes it for a period of time.

[0079] As mentioned above, the receiving means are preferably adapted to receive the radiation from at least two different directions. The receiving means need not be angle sensitive in that the interference is removed by the present generating means. However, if the oscillating signal is caused by multiple paths of the radiation, its detection requires detection of the radiation from these paths.

[0080] In one embodiment, the determining means are adapted to determine a parameter of the projectile at a first point in time and to estimate, from the determined parameter, the parameter at a second, later, point in time. In one situation, the determining means are adapted to perform the estimation using a predetermined relation between the parameter and time. This relation may be provided empirically or may be determined on the basis of a theory. One parameter to determine is a distance between the receiving means and the projectile.

[0081] The receiving means may be adapted to provide the corresponding signal representing an intensity/signal strength/amplitude of the radiation received. Then, the determining means may be adapted to determine a distance between the receiving means and the projectile. This is especially so, if the reflection/emission characteristics of the projectile are known or even constant, which makes the distance determination easier.

[0082] In a particularly interesting embodiment, the generating means are adapted to generate the altered signal, until the altered signal fulfils a predetermined criterion, the determining means being adapted to provide, as the information, an estimate of a landing point of the projectile. As mentioned above, this enables the method and apparatus to make a better estimation of the landing point. Also, the criteria may be determined within a wide variety of possibilities depending on the situation.

[0083] Then, the determining means could be adapted to provide, as the information, an estimate of a distance between the landing point of the projectile and a predetermined target. In this manner, it may be desired to know the positional relation between the receiver and the target. This relation may also comprise a height difference between the receiver and the target.

[0084] Alternatively or in addition, the determining means could be adapted to provide as the information an estimate of a deviation from a predetermined direction and a determined direction of the projectile. Different types of deviations are described above. This provides another type of coordinate system in which the projectile path is analyzed. This type of analysis may be desired in order to evaluate the difference between an aiming direction and the actual direction of the projectile.

[0085] Especially in the last situation, the determining means could further comprise means for determining a launch position of the projectile, the determining means being adapted to provide the determined direction of the projectile as a direction between the launch position and the landing point. Determining the launch position instead of dictating it provides a better user-friendliness and facilitates use of the apparatus in field operations where fixed positions are not usual.

[0086] As mentioned above, one manner of removing the oscillating signal is to perform a suitable averaging. One manner of averaging is to have the generating means comprise means for filtering the provided signal using a time constant larger than a period of the oscillating signal, the determining means being adapted to determine a landing point as a point where the signal level has decreased a predetermined amount, such as 3 dB.

[0087] A sixth aspect relates to an apparatus of determining information relating to a projectile, the apparatus comprising:

[0088] means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

[0089] means for identifying whether an amplitude of the provided signal varies more than a predetermined threshold,

[0090] means for determining the information from the corresponding signal, and

[0091] means for quantifying an uncertainty of the determination of the information from the variation of the amplitude.

[0092] As is the case in the second aspect, this means that the oscillating signal need not be removed but that the results (the information) take this "error" signal into account.

[0093] Then, the generating means may be adapted to perform an averaging operation comprising averaging the provided signal over a time period larger than a predetermined time period. This may then be used for quantifying the oscillating signal and the uncertainty.

[0094] Naturally, the fifth and sixth aspects may be combined, whereby the sixth aspect may also comprise generating means for generating an altered signal by removing an oscillating signal from the provided signal, the determining means being adapted to provide additional information relating to the projectile from the altered signal.

[0095] Then, the generating means may be adapted to track the oscillating signal and subtract the oscillating signal from the provided signal. Also, the generating means could be adapted to generate the altered signal for a predetermined period of time after, that the provided signal reaches zero.

[0096] In general, the receiving means are preferably adapted to receive the radiation from at least two different directions.

[0097] In one embodiment, the determining means are adapted to determine a parameter of the projectile at a first point in time and estimate, from the determined parameter, the parameter at a second, later, point in time. Then, the determining means may be adapted to perform an estimation using a predetermined relation between the parameter and time. Also, the determining means are preferably adapted to determine a parameter being a distance between a means receiving the radiation and the projectile.

[0098] In a preferred embodiment, the receiving means are adapted to provide a corresponding signal representing an intensity of the radiation received and wherein the determining means are adapted to determine a distance between the receiving means receiving the radiation and the projectile.

[0099] As the third aspect, a seventh aspect relates to the use of the oscillating signal. This embodiment relates to an apparatus of determining information relating to the surroundings of a projectile, the apparatus comprising:

[0100] means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

[0101] means for generating an altered signal by isolating, from the provided signal, an oscillating signal, and

[0102] means for determining, as the information and from the altered signal, an angle to vertical of, and/or a distance to, a surface over which the projectile flies and/or a reflection coefficient of the radiation of a surface over which the projectile flies.

[0103] Naturally, this may be combined with a means for providing information relating to a position of the projectile. This means may be one according to any of the first, second, fifth, and sixth aspects.

[0104] In any of the fifth-seventh aspects, as well as the eighth aspect mentioned below, the receiving means are preferably adapted to provide the corresponding signal as a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval and/or the apparatus preferably further comprises means for providing electromagnetic radiation toward the projectile while in flight,

[0105] An eighth aspect of the invention relates to an apparatus of determining a distance between a projectile and a radiation receiver, the apparatus comprising:

[0106] means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight,

[0107] means for determining an intensity of the radiation received and a distance between the receiver and the projectile at a first point in time,

[0108] means for determining, at a second, later point in time, a second intensity of the radiation received, and

[0109] means for determining from a mathematical relation between the first and second intensities determined, a distance, at the second point in time, between the receiver and the projectile.

[0110] This aspect relates to the fourth aspect mentioned above.

[0111] A ninth aspect relates to a method of determining information relating to a projectile, the method comprising:

[0112] receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

[0113] determining an expected oscillation of the corresponding signal, and

[0114] determining the information from a deviation between the corresponding signal and the expected oscillation.

[0115] When the oscillation relates to the multipath problem stated above, the oscillation may be estimated from e.g. knowledge of the path of the projectile. This deviation may be calculated from parameters relating to the projectile, its path and/or surroundings of the projectile. Then, both the signal strength and the amplitude oscillation may be determined and compared to the provided signal. Deviations there from may be caused by deviations in the path of the projectile compared to that used in the estimation. Such a deviation in the path of the projectile may be that the projectile has, in fact, actually landed.

[0116] In that manner, the information may be derived from a deviation, such as a deviation between the corresponding signal and the estimated oscillation.

[0117] The estimated oscillation may be an estimate of the amplitude or period/frequency of the provided signal as a function of time.

[0118] The deviation may be a deviation in intensity/signal strength or in the phase of the estimated signal compared to the estimated oscillation. Other types of deviations or other criteria which the deviation should fulfil are described further above.

[0119] In addition, a step of identifying whether the amplitude of the provided signal varies more than a predetermined threshold may be added in order to determine whether an oscillation large enough is present for it to be taken into account. Also, the presence of this variation may be an indication of that the projectile is close to the ground.

[0120] An interesting piece of information to derive is the landing point of the projectile. This may be estimated (as the information) from the deviation in that the provided signal will drop, when the projectile has landed. Then, the provided signal will deviate from the estimated oscillation which does not foresee the drop. Then, e.g. a drop of the signal of a predetermined amount may be used for determining the landing point. The actual landing point may be determined on the basis of knowledge of the trajectory of the projectile while flying.

[0121] It should be remembered that the provided signal may, when the oscillation is large, actually become lower than the detection threshold (become zero). However, the estimation of the variation may take this into account, whereby this will not interfere with the correct determination of the information, such as the landing point.

[0122] A tenth aspect relates to an apparatus of determining information relating to a projectile, the apparatus comprising:

[0123] means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

[0124] means for determining an expected oscillation of the provided signal, and

[0125] means for determining the information from a deviation between the corresponding signal and the expected oscillation.

[0126] The advantages described in relation to the ninth aspect relate equally to this aspect.

[0127] An especially interesting embodiment or group of embodiments is one where a plurality of receiving means are used or the radiation is determined at a plurality of displaced positions. In this manner, the different detections may be used for deriving additional information.

[0128] This additional information may relate to the position of the projectile in that the angle(s) of incident radiation may now be determined, such as by measuring an amplitude or phase difference between the radiation determined at a plurality of positions. Preferably, the positional relationship between the positions is known.

[0129] In addition, the plurality of determinations of the radiation may also, or optionally, be used for providing further statistics in the measurement in that a mathematical operation may be performed (e.g. on information that may be provided from e.g. a single determination) in order to increase the certainty of the determination.

[0130] The above-mentioned oscillating signal may, in addition to vary the amplitude of the signal received, cause a determination of the angle detected (using the radiation received at a plurality of positions) to be uncertain. Thus, the removal or tracking of the oscillating signal will also improve the certainty on an angle determination—and thereby on the position determination. This is important in a number of situations, such as when wishing to determine the landing point of the projectile.

[0131] Preferably, in the method of the first aspect:

[0132] the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

[0133] the generating step comprises generating an altered signal for each provided signal, and

[0134] the determining step comprises determining the information on the basis of all provided signals.

[0135] Naturally, the filtering, averaging etc. described above may be performed on each individual signal or after combining the signals.

[0136] The altered signals may, for a number of the provided signals, be identical. However, there may also be differences between the provided signals in that e.g. phase shifts may be caused by the different positions for the detection.

[0137] In this context, a spatial displacement simply means that the radiation is received at a plurality of different positions. These positions may have differing heights over a ground plane and may have different angles to the trajectory of the projectile. Naturally, different displacements give different advantages depending on the directions or angles preferably determined.

[0138] The determination may then be the determination of a position, angle, velocity, or any other of the above-mentioned types of information relevant to a flying or landing projectile. The information may also be a combination of this information, such a trajectory and a landing point in time so that the landing point position may be determined.

[0139] In the second aspect, preferably:

[0140] the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

[0141] the identifying step is performed for each provided signal,

[0142] the determining step comprises determining the information on the basis of all provided signals, and

[0143] the quantifying step is performed on the basis of the variation of the amplitudes of all provided signals.

[0144] Naturally, the quantifying step may be a quantification based on each individual position, which quantifications are then subsequently assembled into a single, overall uncertainty. Alternatively, it may be determined initially as the overall uncertainty.

[0145] In the third aspect, preferably:

[0146] the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

[0147] the generating step is performed for at least two of the provided signals, and

[0148] the determining step comprises determining the information on the basis of all generated, altered signals.

[0149] As mentioned above, the oscillating signals need not be different at all positions, whereby it may not be required to actually determine or track (derive or remove) the oscillating signal individually for each position.

[0150] In the fourth aspect, preferably:

[0151] the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

[0152] the steps of determining intensities comprises determining the intensities at each position, and

[0153] the step of determining the distance comprises determining the distance on the basis of all intensities determined.

[0154] In this embodiment, a distance estimate may be derived for each position, which estimates are then subsequently merged (such as averaged). Alternatively, a single distance is determined from the intensities (which may then alternatively be merged prior to the determination of the distance).

[0155] In the fifth aspect, preferably:

[0156] the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

[0157] the step of determining the expected oscillation comprises determining an expected oscillation for at least one of the positions, and

[0158] the step of determining the information comprises determining the information on the basis of the deviation between at least one pair of an expected oscillation and the corresponding provided signal.

[0159] As mentioned above, an expected oscillation may be relevant to a plurality of the positions, whereby it is not required to determine an expected oscillation individually for each position.

[0160] From the deviation of the oscillation of one pair of an expected oscillation and the corresponding provided signal, certain information, such as a landing time, may be derived. However, it is preferred that an expected oscillation is actually determined for a plurality of the positions. Then, the deviation will be performed on a number of such pairs. In that manner, a better estimation of e.g. the angle and thereby position of the projectile may be obtained, whereby a better estimation of the landing spot position is obtained.

[0161] In the sixth aspect, preferably:

[0162] the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

[0163] the generating means area adapted to generate an altered signal for each receiving means, and

[0164] the determining means are adapted to determine the information on the basis of all provided signals.

[0165] This is parallel to the above-mentioned preferred embodiment of the first aspect.

[0166] In the seventh aspect, preferably:

[0167] the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

[0168] the identifying means performed for each provided signal,

[0169] the determining means are adapted to determine the information on the basis of all provided signals, and

[0170] the quantifying means is adapted to perform the quantification on the basis of the variation of the amplitudes of all provided signals.

[0171] This is parallel to the above-mentioned preferred embodiment of the second aspect.

[0172] In the eight aspect, preferably:

[0173] the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

[0174] the generating means is adapted to generate an altered signal for each of at least two of the provided signals, and

[0175] the determining means is adapted to determine the information on the basis of all generated, altered signals.

[0176] This is parallel to the above-mentioned preferred embodiment of the third aspect.

[0177] In the ninth aspect, preferably:

[0178] the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

[0179] the means for determining intensities are adapted to determine the intensities at each receiving means, and

[0180] the means for determining the distance is adapted to determine the distance on the basis of all intensities determined.

[0181] This is parallel to the above-mentioned preferred embodiment of the fourth aspect.

[0182] In the tenth aspect, preferably:

[0183] the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

[0184] the means for determining the expected oscillation is adapted to determine an expected oscillation for at least one of the receiving means, and

[0185] the means for determining the information is adapted to determine the information on the basis of a deviation between at least one pair of an expected oscillation and the corresponding provided signal.

[0186] This is parallel to the above-mentioned preferred embodiment of the fifth aspect.

[0187] It is clear that the above aspects relate to overlapping effects and technologies, whereby any two or more thereof may be combined in order to obtain even better products.

[0188] In the following, a preferred embodiment will be described with reference to the drawing, wherein:

[0189] FIG. **1** shows the positioning of the radar relative to the tracking object trajectory as well as a reflective surface,

[0190] FIG. **2** shows an example of a ball trajectory with reference to the radar position,

[0191] FIG. **3** shows the received signal intensity of the different received signals,

[0192] FIG. **4** is a vector diagram showing the multipath signal adding with the direct reflected signal,

[0193] FIG. **5** shows the process flow to isolate and quantify the multipath signal,

[0194] FIG. **6** shows schematically the position of the transmitter and receivers of the system,

[0195] FIG. **7** shows the normalized received signal intensity in both presence and absence of multipath signals,

[0196] FIG. **8** shows the output of the sliding RMS detector in both presence and absence of multipath signals,

[0197] FIG. **9** shows an electronic functional block diagram of the system,

[0198] FIG. **10** shows the received signal intensity of two different receivers, and

[0199] FIG. **11** shows elevation angle measurement derived from the monopulse phase.

[0200] In the preferred embodiment of the present invention, the transmitter **27** is a continuous wave (CW) signal being emitted from an antenna **15** co-located with at least one receiving antenna, i.e. a CW Doppler radar. In the preferred embodiment, the receiver consists of at least three separate receiving antennas **16-18**, enabling use of the well known monopulse measuring principle to measure the angle to the projectile, see “Introduction to Radar Systems” Third Edition, Merril I. Skolnik, which is incorporated herein as reference. An electrical functional block diagram of the system is shown in FIG. **9**.

[0201] In the preferred embodiment, the projectile is a sports ball, a special interest is related to the case of a golf ball, where there is high commercial interest of being able to measure the exact trajectory, including precise determination of the landing point. In the following description the measuring object in flight will be referred to as a ball, but can be any type of a solid object traveling through the air, such as projectiles, missiles, airplanes and other sports balls.

[0202] The antennas can be arranged as shown in FIG. **6**, but many other combinations are possible. The receiving antennas **16** and **17** are vertically spaced a distance DV, where as the receiving antennas **17** and **18** are horizontally spaced a distance DH. In this way the phase difference ΔV between the signal from a ball recorded by receiving antennas **16** and **17** will be directly related to the vertical angle E from the radar to the ball through [eq. 1]. The phase difference ΔH between receiving antennas **17** and **18** will consequently be directly related to the horizontal angle A from the radar to the ball through [eq. 2].

$$\Delta V = 2\pi * DV/\lambda * \sin(E) \quad \text{[eq. 1]}$$

[0203] , where λ is the radar wavelength

$$\Delta H = 2\pi * DV/\lambda * \sin(A) \quad \text{[eq. 2]}$$

[0204] In the preferred embodiment of the present invention, the phase differences between receiving antennas **16-18** are measured by using the phase-phase monopulse principle on the recorded signals. However, many other standard techniques can be used for this, like the amplitude-amplitude monopulse principle, as outlined in the publication “Introduction to Radar Systems” Third Edition, Merril I. Skolnik, which is incorporated herein as reference again.

[0205] The radar return signal from a CW Doppler radar consists of a number of continuous signals x(t) corresponding each to the relative position and movement of the reflective objects in front of the radar. In the following the situation only one reflective object, the ball, is considered, but the description holds as well for multiple reflective objects. In this case the received signal $z_{rx}(t)$ of one of the receivers **16-18** only consist of the direct reflected signal x(t) from the ball, see [eq. 3].

$$z_{rx}(t) = x(t) \quad \text{[eq. 3]}$$

[0206] The amplitude of the x(t), a(t) is determined by the radar cross section of the ball as well as the distance from the radar and radar gain in the specific direction of the ball, see [eq. 4].

$$|x(t)|^2 = a(t)^2 = Ptx * Gtx * Grx * RCS * \lambda^2 / ((4*\pi)^3 * R^4) \quad \text{[eq. 4]}$$

[0207] , where:

[0208] Ptx is the transmitted power

[0209] Gtx is the transmitting antenna gain in direction of ball

[0210] Grx is the receiving antenna gain in direction of ball

[0211] RCS is the radar cross section of ball

[0212] λ is the the radar wavelength

[0213] R is the distance from radar to ball

[0214] In most practical situations not only the direct reflected signal, R, **5** is received from the ball **1**, flying along a trajectory **40** between a launch position **38** and a landing point **39**, also a multipath reflected signal, Rmp, **6** is received, see FIG. **1**. The resulting received signal $z_{rx}(t)$ can be described by [eq. 5].

$$z_{rx}(t)=x(t)+x_{mp}(t)=x(t)*(1+e_{mp}(t)) \quad \text{[eq. 5]}$$

[0215] , where:

[0216] x(t) is the received signal of the direct reflected ray **5** from the ball **1**

[0217] $x_{mp}(t)=x(t)*e_{mp}(t)$ received signal of the multipath reflected ray **6** from the ball **1**.

[0218] $e_{mp}(t)$ is the modulation of the multipath reflected signal **6** relative to the direct reflected signal **5**.

[0219] In the following only one multipath signal will be considered, but the general principles are also applicable on multiple multipath signals.

[0220] The multipath reflected signal **6** will be highly correlated with the direct reflected signal **5**, but will include a modulation, described by $e_{mp}(t)$. $e_{mp}(t)$ will depend on the geometry and reflection characteristics of the ball and the reflecting point **4**. $e_{mp}(t)$, where the reflecting point is on a reflecting surface (illustrated by a horizontal line) can be described by [eq. 6].

$$e_{mp}(t)=\sqrt{(\delta RCS*\rho_g*dG)}*(R/Rmp)^2*\exp(-j*2n*dR/\lambda)=a_{mp}(t)*\exp((\phi_{mp}(t)) \quad \text{[eq. 6]}$$

[0221] , where:

[0222] δRCS is the reflection difference in multipath geometry compared to direct reflection

[0223] ρ_g is the reflection coefficient of the ground

[0224] dG is the radar gain difference for the incoming multipath reflected ray

[0225] dR is the path length difference between multipath ray **6** and direct reflected ray **5**.

[0226] λ is the wavelength of the radio wave

[0227] For an object propagating in a stationary environment, i.e. multipath reflection point **4** does not jump around, the modulation signal $e_{mp}(t)$ will be a slowly varying oscillating signal dictated by the variation of the path length difference dR.

[0228] The path length difference dR can be mathematically expressed from the geometry in FIG. **1** by [eq. 7].

$$dR=Rmp-R=R(\sqrt{(1+4*y*hr/R^2)}-1) \quad \text{[eq. 7]}$$

[0229] , where:

[0230] hr is the height of the receiving antenna above the reflecting surface

[0231] y is the height of the ball above the reflecting surface

[0232] Assuming a ball trajectory (see FIG. **2**), observed by a radar **2**, the received power over time will be as shown in FIG. **3**. In FIG. **3**, **7** is the received power $|x(t)|^2$ from the direct reflected ray **5** alone, graph **8** is the received power $|x^{mp}(t)|^2$ from the multipath reflected ray **6** alone. The resulting received power $|z_{rx}(t)|^2$ (graph **9**) shows an oscillating signal around the power received from the direct reflected ray, graph **7**. It is realized that the oscillation of **9** is directly related to the variation of $e_{mp}(t)$ coherently adding with a unity vector representing the normalized direct reflected signal x(t), as can be seen in the vector diagram in FIG. **4**.

[0233] The period, Tmp, of the oscillation of **9** is given by when dR changes λ. Tmp is typically in the interval of 0.1-2 seconds for sports ball trajectories with radar **2** placed close to some part of the trajectory.

[0234] If more receivers are present like in FIG. **9**, the heights hr of the individual receiving antennas are in general not the same. This means that dR is slightly different at a given point in time for the different receivers, this introduces a phase difference of the oscillating signal power between the different receivers in the multipath scenario. In FIG. **10** the received power $|z_{rx}(t)|^2$ for receiving antenna **17** is plotted as **9** together with the received power $|z_{rx}(t)|^2$ for receiving antenna **16** which also plotted as **35**. In FIG. **10** the received power $|x(t)|^2$ from the direct reflected ray **5** alone is shown as **7** for comparison.

[0235] Due to the phase difference of the oscillating signals of the different receivers, the monopulse phase difference will be distorted in a multipath scenario. In FIG. **11** the vertical angle **36** derived from [eq. 1] is shown for the case of only the direct reflected ray **5**, and also the vertical angle **37** in the case of presence of multipath signals is shown.

[0236] Determination of Presence of Multipath Signals

[0237] The process of detecting the presence of multipath signals in the received signal $z_{rx}(t)$ is shown in FIG. **5**.

[0238] First the tracking is established **10** as normally done with Doppler radars, i.e. tracking the Doppler frequency generated by the moving ball over time. From the recorded data of the at least three receivers, the three dimensional position is calculated **11** without knowing whether a multipath signal is present or not. The range R to the ball is calculated as an integration of the tracked Doppler frequency from launch time and adding the assumed distance between the radar and the launch position **38**. The vertical and horizontal angles are calculated from [eq. 1] and [eq. 2]. If a multipath signal is present this will introduce an error in the three dimensional position through distortion on the vertical (and horizontal) angle as illustrated in FIG. **11**. Heavy filtering (averaging) is done on the angles to reduce the negative influence on the three dimensional position, the time constant on the angle filtering should be higher than the period of the oscillation Tmp.

[0239] All the three received signals are then normalized **12** for the known time variation of the direct reflected signal power as can be derived from [eq. 4].

[0240] The normalization equation is:

$$z_{n,rx}(t)=z_{rx}(t)*R^2/\sqrt{(Gtx*Grx*RCS)} \quad \text{[eq. 8]}$$

[0241] , where:

[0242] Gtx is the transmitting antenna gain in direction of ball **1**

[0243] Grx is the receiving antenna gain in direction of ball **1**

[0244] RCS is the radar cross section of ball **1**

[0245] In the case of a spherical symmetrical ball, like golf balls, tennis balls, baseballs, cricket balls and similar, the radar cross section RCS of the ball is to a very high degree constant independent of orientation of the ball relative to the radar. In this case RCS in [eq. 8] can be omitted.

[0246] In FIG. **7** the normalized signal power $|z_{n,rx}(t)|^2$ is shown. The trace **19** corresponds to the normalized signal power without multipath **7**, and the trace **20** corresponds to the normalized signal power with multipath **9**. The oscillation of **20** is clearly an indication of multipath.

[0247] It is noted that the detection of oscillation of power of the normalized signal $z_{n,rx}(t)$ can be done in number of different ways. In the following only one of the preferred methods are outlined, but many other standard methods may be applied.

[0248] To isolate the multipath signal **13** a sliding root-mean-square (RMS) detector on the normalized signal $z_{n,rx}(t)$ is used. The RMS detector is performed over a time corresponding to the expected period of the oscillation Tmp, and is calculated according to [eq. 9].

$$RMS_{Tmp}(t)=(E\{/z_{n,rx}(t)|^2\}_{t\pm Tmp/2}-E\{/z_{n,rx}(t)|\}^2{}_{t\pm Tmp/2})/(\sqrt{2}*E\{/z_{n,rx}(t)|\}_{t\pm Tmp/2}) \quad \text{[eq. 9]}$$

[0249] In FIG. **8** the sliding RMS detector $RMS_{Tmp}(t)$ is shown. The trace **25** corresponds to the normalized signal power without multipath **7**, and the trace **26** corresponds to the normalized signal power with multipath **9**.

[0250] To quantify the magnitude of the multipath signal, the output of the sliding RMS detector can be used directly. In fact the value of $RMS_{Tmp}(t)$ is directly an estimation of $a_{mp}(t)$ in [eq. 6]. To quantify whether multipath signals is present or not, the output of the RMS detector is compared with a predetermined threshold **14**.

[0251] The sliding RMS detector as outlined above must in general be applied separately on all the three received signals, since the amplitude of the oscillation need not be the same for all the receiving signals.

[0252] Once the magnitude of the multipath signal $a_{mp}(t)$ is known, the tracking and smoothing filters can be adjusted to tolerate the errors caused by the multipath signals. The worst case error in the phase differences in [eq. 1] and [eq. 2] are given by:

$$\Delta V_{err,W.C.}\approx 2*A\tan(a_{mp}(t))$$

$$\Delta H_{err,W.C.}\approx 2*A\tan(a_{mp}(t))$$

[0253] Using these error margins in the tracking and smoothing filters will enable the ball to be tracked more robust and provide more accurate flight path data.

[0254] To detect when the ball has actually landed **39**, the knowledge of the multipath level is used.

[0255] When the ball is about to land, the signal level of the direct reflected ray **5** is normally at a minimum, due to maximum distance between ball **1** and radar **2**. Further more, the power of the received multipath signal **6** will be only slightly smaller than the direct reflected signal **5**, since the ground reflection coefficient ρ_g is close to 1.0 for parallel incident rays. Consequently the total received signal $z_{rx}(t)$ can reach a minimum that might be under the detection limit, even though the ball has not landed. The minimum signal level in the landing scenario happens exactly when the phase of the multipath signal is 180 degrees out of phase with the direct reflected signal, i.e. when $\phi_{mp}(t)=-n$. This happens exactly the time Tmp/2 before the ball actually lands. Consequently the tracking is always continued at least Tmp/2 after the signal level has dropped below the detection limit when multipath is detected as explained above. If the signal reappears after this dropout, it will only reappear for Tmp/2 seconds. These reappearing data are merged with the previous track.

[0256] The landing point is determined as being the last measurement point including any merging of reappearing signals. If the detection of the measurement point is done by frequency analysis, which extend over some data points, the time for landing is being determined as being when the signal level has dropped 3 dB relative to the expected power variation taking into account the multipath influence. By adding the three received signals before detecting the measurement points an increase in signal-to-noise ratio is gained, which will give a more accurate determination of the landing time. The final three dimensional landing point is calculated by evaluating the smoothed trajectory data at the landing time determined above. The relative phase of the multipath signal $\phi_{mp}(t)$ can be estimated in a number of different ways. One method is to detect the zero-crossings **21** and **22** (in dB) and minimum **23** and maximum **24** of the normalized signal power $|z_{n,rx}(t)|^2$ like **20** in FIG. **7**. The minimum represent $\phi_{mp}(t)$ equal to ±n, the maximum $\phi_{mp}(t)$ equal to 0 and finally the zero crossings close to ±n/2. This gives two solutions for the slope of the phase $\phi_{mp}(t)$, an upwards and a downwards slope. The slope is determined from the sign of the derivative of dR with respect to time, which is calculated from the measured trajectory during step **11**. The final estimation of $\phi_{mp}(t)$ is done by fitting a smooth curve to the found phase points above.

[0257] The estimation of the phase of the multipath signal must be carried out separately for each of the receiving signals

[0258] Removal of Multipath Signal

[0259] Once the presence of the multipath signal has been detected and the relative multipath signal $e_{mp}(t)$ has been estimated, it is possible to remove the multipath signal from the received signals by altering the receiver signal according to [eq. 10].

$$x_{est}(t)=z_{rx}(t)/(1+\hat{e}_{mp}(t)) \quad \text{[eq. 10]}$$

[0260] Then the three dimensional position can be re-calculated from the altered receiver signals $x_{est}(t)$. The trajectory data derived from the altered receiver signals will to a high degree be cleaned for multipath distortion on the vertical and horizontal angles. Further the altered signal will not experience the oscillation, and possible dropouts just before landing, thus given a much better accuracy on the estimation of landing time and thereby more accurate landing position.

[0261] Range and RCS Measurement from Signal Power Level

[0262] In the following all the receiver signals are either cleaned for oscillating signals as explained above [eq. 10], or averaged out the oscillation in the normalized $z_{n,rx}(t)$ similar to [eq. 8] and then inverse normalization of [eq. 6] to get $z_{rx}(t)$, or the level of the multipath signal is below a certain limit not to affect the received power level according to [eq. 3].

[0263] In relation to range measurement of Doppler radar signals, all previous inventions have analyzed the radar return from a single fixed frequency Doppler radar only for the frequency shift generated by the apparent velocity Vr of the ball moving in front of the radar, or more precisely the change in range over time (sometimes denoted range rate), mathematically dR/dt.

[0264] To calculate the distance R to the ball, all previous Doppler radar inventions have integrated the range rate Vr from a known reference point. Consequently the distance R is a derived measurement from the directly measured range rate Vr and it requires a fix point.

[0265] The present invention presents a novel method to actually measure the distance R to the ball by proper analyzing of the radar return signal from a Doppler radar. The distance R is measured independently from the measured range rate.

[0266] The direct measured distance R in a Doppler radar system can be used in many different applications and scenarios. More generally speaking the direct measured range adds a new independent measured parameter for a Doppler radar.

[0267] The present invention measures the distance R to the ball by measuring the signal level Prx corresponding to the tracking object. The preferred method to measure the signal level of a given tracking object is by frequency analyzing methods, but other methods may also be applied.

[0268] The distance R to the ball is calculated from the received signal level Prx by using the radar equation inversely:

$$R=((Ptx/Prx*Gtx*Grx*\lambda^2)/(4\pi)^3*RCS)^{0.25} \quad \text{[eq. 11]}$$

[0269] All the parameters on the right hand side above, are system parameters that are known except for the radar cross section RCS of the ball.

[0270] The antenna gain of the Doppler radar in the transmitter Gtx and receiver Grx can vary inside the coverage volume of the radar. However, if the sighting angle to the target is known, this inaccuracy can be removed by using the known radiation pattern of the transmitting and receiving antennas.

[0271] In a monopulse Doppler radar system, the sighting angle to the target can be measured independently of the range rate Vr and the distance R. This means that in such a system the only unknown on the right hand side of [eq. 11] is the RCS.

[0272] Equation [eq. 11] can be simplified to [eq. 12], where M is the measured signal level adjusted for system parameters.

$$R=M*RCS^{0.25}$$
$$, M=((Ptx/Prx*Gtx*Grx*L*\lambda^2)/(4\pi)^3)^{0.25} \quad \text{[eq. 12]}$$

[0273] In some cases the RCS of the ball is known a priori. In this case [eq. 12] can be used directly to measure the distance R.

[0274] In other cases only the relative level of RCS is known when viewing the ball from different aspect angles, i.e. RCS=RCSo*func((ϕ,θ) where RCSo is unknown. In this case [eq. 12] can be rewritten to [eq. 13], where M' includes the known func((ϕ,θ)$^{0.25}$ variation of the RCS.

$$R=M'*RCSo^{0.25}$$
$$, M'=M*func((\phi,\theta)^{0.25} \quad \text{[eq. 13]}$$

[0275] In this case the ball is observed at minimum two different distances, see [eq. 14-15] where the relative change in distance is measured by integration of the measured range rate Vr.

$$R(n)=M'(n)*RCSo^{0.25} \quad \text{[eq. 14]}$$
$$R(n+1)=R(n)+\Delta R=M'(n+1)*RCSo^{0.25}$$
$$, \Delta R=int(n,n+1,Vr) \quad \text{[eq. 15]}$$

[0276] RCSo can now be calculated from [eq. 16]:

$$RCSo=(\Delta R/(M'(n+1)-M'(n)))^4 \quad \text{[eq. 16]}$$

[0277] After having found RCSo, [eq. 13] is used directly to measure the distance R.

[0278] Spherically shaped targets are a special interesting group of targets. This type of targets includes also targets that are nearly spherical. Examples include small projectiles, calibration spheres and most sporting balls (golf ball, base ball, foot/soccer ball, tennis ball, cricket ball etc.). The spherically shaped targets has the advantage that the RCS is constant independent of orientation of target (func((ϕ,θ)=1), and that it is relatively simple to theoretically predict the RCS from given dimensions and material characteristics.

[0279] Reflection Coefficient and Position of Reflection Point

[0280] When the relative phase $\phi_{mp}(t)$ of the multipath signal has been estimated as outlined above, the variation of dR over time is also known through [eq. 6]. When dR is known, [eq. 7] can be used to estimate the height hr of the radar **2** above the reflection point, where R and y are taken from the measured three dimensional position of the ball. The only assumption is that the reflecting surface is horizontal.

[0281] When the height hr is known, also the angle Emp in FIG. **1** can be found, this means that the reflection point can be positioned three dimensionally.

[0282] By also having the estimation of the relative amplitude $a_{mp}(t)$ of the multipath signal, the reflection coefficient ρ_g of the reflecting surface can be estimated using [eq. 6] inversely.

1-68. (canceled)

69. A method of determining information relating to a projectile, the method comprising:

receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

generating an altered signal by removing, from the provided signal, an oscillating signal, and

determining the information relating to the projectile from the altered signal.

70. A method according to claim 69, wherein the generating step comprises performing an averaging operation comprising averaging the provided signal over a predetermined time period.

71. A method according to claim 69, wherein the generating step comprises tracking the oscillating signal and subtracting the oscillating signal from the provided signal.

72. A method according to claim 69, wherein the generating step comprises generating the altered signal for a predetermined period of time after, that the provided signal reaches zero.

73. A method according to claim 69, wherein the receiving step comprises receiving the radiation from at least two different directions.

74. A method according to claim 69, wherein the determining step comprises determining a parameter of the projectile at a first point in time and estimating, from the determined parameter, the parameter at a second, later, point in time.

75. A method according to claim 74, wherein the estimation is performed using a predetermined relation between the parameter and time.

76. A method according to claim 74, wherein the parameter determined is a distance between a means receiving the radiation and the projectile.

77. A method according to claim 69, wherein the corresponding signal provided is a signal representing an intensity of the radiation received and wherein the determining step comprises determining a distance between a means receiving the radiation and the projectile.

78. A method according to claim 69, wherein the generating step comprises generating the altered signal, until the altered signal fulfils a predetermined criterion, the determining step comprising providing, as the information, an estimate of a landing point of the projectile.

79. A method according to claim 78, wherein the determining step comprises providing as the information an estimate of a distance between the landing point of the projectile and a predetermined target.

80. A method according to claim 78, wherein the determining step comprises providing as the information an estimate of a deviation from a predetermined direction and a determined direction of the projectile.

81. A method according to claim 80, wherein the determining step further comprises determining a launch position of the projectile, the determined direction of the projectile being a direction between the launch position and the landing point.

82. A method according to claim 78, wherein the generating step comprises performing a filtering using a time constant larger than a period of the oscillating signal and wherein the determining step comprises determining the landing point as a point where the signal level has decreased a predetermined amount.

83. A method of determining information relating to a projectile, the method comprising:

receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

identifying whether an amplitude of the provided signal varies more than a predetermined threshold,

determining the information from the corresponding signal, and

quantifying an uncertainty of the determination of the information from the variation of the amplitude.

84. A method according to claim 83, wherein the generating step comprises performing an averaging operation comprising averaging the provided signal over a time period larger than a predetermined time period.

85. A method according to claim 83, further comprising a step of generating an altered signal by removing an oscillating signal from the provided signal, the method further comprising the step of determining further information from the altered signal.

86. A method according to claim 85, wherein the generating step comprises tracking the oscillating signal and subtracting the oscillating signal from the provided signal.

87. A method according to claim 85, wherein the generating step comprises generating the altered signal for a predetermined period of time after, that the provided signal reaches zero.

88. A method according to claim 83, wherein the receiving step comprises receiving the radiation from at least two different directions.

89. A method according to claim 83, wherein the determining step comprises determining a parameter of the projectile at a first point in time and estimating, from the determined parameter, the parameter at a second, later, point in time.

90. A method according to claim 89, wherein the estimation is performed using a predetermined relation between the parameter and time.

91. A method according to claim 89, wherein the parameter determined is a distance between a means receiving the radiation and the projectile.

92. A method according to claim 83, wherein the corresponding signal provided is a signal representing an intensity of the radiation received and wherein the determining step comprises determining a distance between a means receiving the radiation and the projectile.

93. A method of determining information relating to the surroundings of a projectile, the method comprising:

receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

generating an altered signal by isolating, from the provided signal, an oscillating signal, and

determining, as the information and from the altered signal, an angle to vertical of, and/or a distance to, a surface over which the projectile flies and/or a reflection coefficient of the radiation of a surface over which the projectile flies.

94. A method according to claim 69, wherein the step of providing the corresponding signal comprises providing a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval.

95. A method according to claim 69, the method further comprising the initial step of providing electromagnetic radiation toward the projectile while in flight.

96. A method of determining a distance between a projectile and a radiation receiver, the method comprising the steps of:

receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight,

determining an intensity of the radiation received and a distance between the receiver and the projectile at a first point in time,

determining, at a second, later point in time, a second intensity of the radiation received, and

determining from a mathematical relation between the first and second intensities determined, a distance, at the second point in time, between the receiver and the projectile.

97. An apparatus for determining information relating to a projectile, the apparatus comprising:

means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

means for generating an altered signal by removing, from the provided signal, an oscillating signal, and

means for determining the information relating to the projectile from the altered signal.

98. An apparatus according to claim 97, wherein the generating means are adapted to perform an averaging operation comprising averaging the provided signal over a predetermined time period.

99. An apparatus according to claim 97, wherein the generating means are adapted to track the oscillating signal and subtract the oscillating signal from the provided signal.

100. An apparatus according to claim 97, wherein the generating means are adapted to generate the altered signal for a predetermined period of time after, that the provided signal reaches zero.

101. An apparatus according to claim 97, wherein the receiving means are adapted to receive the radiation from at least two different directions.

102. An apparatus according to claim 97, wherein the determining means are adapted to determine a parameter of the projectile at a first point in time and estimate, from the determined parameter, the parameter at a second, later, point in time.

103. An apparatus according to claim 102, wherein the determining means are adapted to perform the estimation using a predetermined relation between the parameter and time.

104. An apparatus according to claim 102, wherein the determining means are adapted to determine a parameter being a distance between the receiving means and the projectile.

105. An apparatus according to claim 97, wherein the receiving means are adapted to provide the corresponding signal representing an intensity of the radiation received and wherein the determining means are adapted to determine a distance between the receiving means and the projectile.

106. An apparatus according to claim 97, wherein the generating means are adapted to generate the altered signal, until the altered signal fulfils a predetermined criterion, the determining means being adapted to provide, as the information, an estimate of a landing point of the projectile.

107. An apparatus according to claim 106, wherein the determining means are adapted to provide as the information an estimate of a distance between the landing point of the projectile and a predetermined target.

108. An apparatus according to claim 106, wherein the determining means are adapted to provide as the information an estimate of a deviation from a predetermined direction and a determined direction of the projectile.

109. An apparatus according to claim 108, wherein the determining means further comprise means for determining a launch position of the projectile, the determining means being adapted to provide the determined direction of the projectile as a direction between the launch position and the landing point.

110. An apparatus according to claim 105, wherein the generating means comprise means for filtering the provided signal using a time constant larger than a period of the oscillating signal, the determining means being adapted to determine a landing point as a point where the signal level has decreased a predetermined amount.

111. An apparatus of determining information relating to a projectile, the apparatus comprising:

means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

means for identifying whether an amplitude of the provided signal varies more than a predetermined threshold,

means for determining the information from the corresponding signal, and

means for quantifying an uncertainty of the determination of the information from the variation of the amplitude.

112. An apparatus according to claim 111, wherein the generating means are adapted to perform an averaging operation comprising averaging the provided signal over a time period larger than a predetermined time period.

113. An apparatus according to claim 111, further comprising means for generating an altered signal by removing an oscillating signal from the provided signal, the determining means being adapted to provide additional information relating to the projectile from the altered signal.

114. An apparatus according to claim 111, wherein the generating means are adapted to track the oscillating signal and subtract the oscillating signal from the provided signal.

115. An apparatus according to claim 113, wherein the generating means are adapted to generate the altered signal for a predetermined period of time after, that the provided signal reaches zero.

116. An apparatus according to claim 111, wherein the receiving means are adapted to receive the radiation from at least two different directions.

117. An apparatus according to claim 111, wherein the determining means are adapted to determine a parameter of the projectile at a first point in time and estimate, from the determined parameter, the parameter at a second, later, point in time.

118. An apparatus according to claim 117, wherein the determining means are adapted to perform an estimation using a predetermined relation between the parameter and time.

119. An apparatus according to claim 117, wherein the determining means are adapted to determine a parameter being a distance between a means receiving the radiation and the projectile.

120. An apparatus according to claim 111, wherein the receiving means are adapted to provide a corresponding signal representing an intensity of the radiation received and wherein the determining means are adapted to determine a distance between the receiving means receiving the radiation and the projectile.

121. An apparatus of determining information relating to the surroundings of a projectile, the apparatus comprising:

means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

means for generating an altered signal by isolating, from the provided signal, an oscillating signal, and

means for determining, as the information and from the altered signal, an angle to vertical of, and/or a distance to, a surface over which the projectile flies and/or a reflection coefficient of the radiation of a surface over which the projectile flies.

122. An apparatus according to claim 97, wherein the receiving means are adapted to provide the corresponding signal as a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval.

123. An apparatus according to claim 97, the apparatus further comprising means for providing electromagnetic radiation toward the projectile while in flight.

124. An apparatus of determining a distance between a projectile and a radiation receiver, the apparatus comprising:

means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight,

means for determining an intensity of the radiation received and a distance between the receiver and the projectile at a first point in time,

means for determining, at a second, later point in time, a second intensity of the radiation received, and

means for determining from a mathematical relation between the first and second intensities determined, a distance, at the second point in time, between the receiver and the projectile.

125. A method of determining information relating to a projectile, the method comprising:

receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and providing a corresponding signal,

determining an expected oscillation of the provided signal, and

determining the information from a deviation between the corresponding signal and the expected oscillation.

126. An apparatus of determining information relating to a projectile, the apparatus comprising:

means for receiving electromagnetic radiation emitted from or reflected by the projectile at least partly while it is in flight, and for providing a corresponding signal,

means for determining an expected oscillation of the provided signal, and

means for determining the information from a deviation between the corresponding signal and the expected oscillation.

127. A method according to claim 69, wherein:

the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

the generating step comprises generating an altered signal for each provided signal, and

the determining step comprises determining the information on the basis of all provided signals.

128. A method according to claim 83, wherein:

the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

the identifying step is performed for each provided signal,

the determining step comprises determining the information on the basis of all provided signals, and

the quantifying step is performed on the basis of the variation of the amplitudes of all provided signals.

129. A method according to claim 91, wherein:

the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

the generating step is performed for at least two of the provided signals, and

the determining step comprises determining the information on the basis of all generated, altered signals.

130. A method according to claim 96, wherein:

the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

the steps of determining intensities comprises determining the intensities at each position, and

the step of determining the distance comprises determining the distance on the basis of all intensities determined.

131. A method according to claim 125, wherein:

the receiving step comprises receiving radiation at a plurality of spatially displaced positions and providing a provided signal for each position,

the step of determining the expected oscillation comprises determining an expected oscillation for at least one of the positions, and

the step of determining the information comprises determining the information on the basis of the deviation between at least one pair of an expected oscillation and the corresponding provided signal.

132. An apparatus according to claim 97, wherein:

the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal, the generating means area adapted to generate an altered signal for each receiving means, and

the determining means are adapted to determine the information on the basis of all provided signals.

133. An apparatus according to claim 111, wherein:

the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

the identifying means performed for each provided signal,

the determining means are adapted to determine the information on the basis of all provided signals, and

the quantifying means is adapted to perform the quantification on the basis of the variation of the amplitudes of all provided signals.

134. An apparatus according to claim 119, wherein:

the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

the generating means is adapted to generate an altered signal for each of at least two of the provided signals, and

the determining means is adapted to determine the information on the basis of all generated, altered signals.

135. An apparatus according to claim 124, wherein:

the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

the means for determining intensities are adapted to determine the intensities at each receiving means, and

the means for determining the distance is adapted to determine the distance on the basis of all intensities determined.

136. An apparatus according to claim 126, wherein:

the receiving means comprise a plurality of spatially displaced receiving means each adapted to provide a provided signal,

the means for determining the expected oscillation is adapted to determine an expected oscillation for at least one of the receiving means, and

the means for determining the information is adapted to determine the information on the basis of a deviation between at least one pair of an expected oscillation and the corresponding provided signal.

137. A method according to claim 83, wherein the step of providing the corresponding signal comprises providing a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval.

138. A method according to claim 93, wherein the step of providing the corresponding signal comprises providing a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval.

139. A method according to claim 83, the method further comprising the initial step of providing electromagnetic radiation toward the projectile while in flight.

140. A method according to claim 93, the method further comprising the initial step of providing electromagnetic radiation toward the projectile while in flight.

141. An apparatus according to claim 106, wherein the generating means comprise means for filtering the provided signal using a time constant larger than a period of the oscillating signal, the determining means being adapted to determine a landing point as a point where the signal level has decreased a predetermined amount.

142. An apparatus according to claim 111, wherein the receiving means are adapted to provide the corresponding signal as a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval.

143. An apparatus according to claim 121, wherein the receiving means are adapted to provide the corresponding signal as a signal representing an intensity or power of the received radiation within a predetermined frequency/wavelength interval.

144. An apparatus according to claim 111, the apparatus further comprising means for providing electromagnetic radiation toward the projectile while in flight.

145. An apparatus according to claim 121, the apparatus further comprising means for providing electromagnetic radiation toward the projectile while in flight.

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