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(54) METHOD AND AN APPARATUS FOR DETERMINING A PARAMETER OF A PATH OF A SPORTS BALL ON THE BASIS OF A LAUNCH POSITION THEREOF

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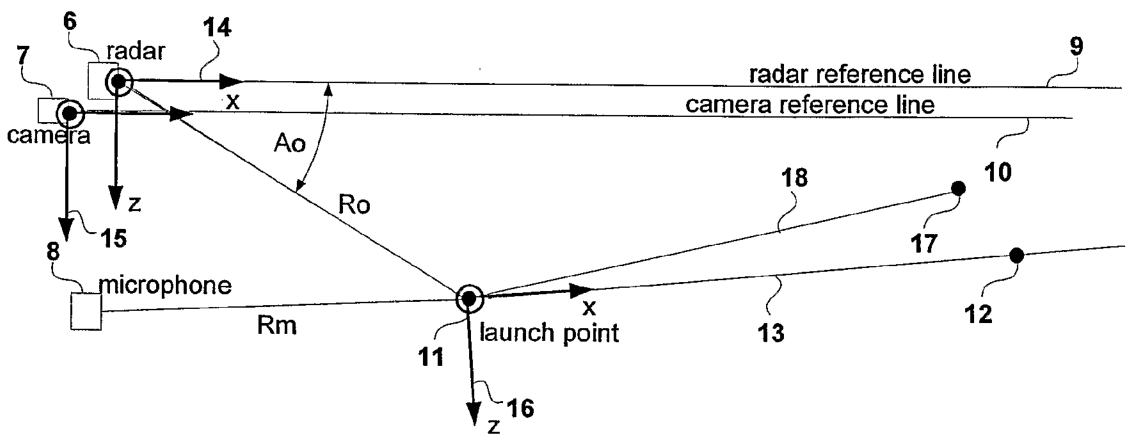
(57) **ABSTRACT**

A method of estimating a parameter of a sports ball in flight which parameter is estimated on the basis of a determined or measured position of launch thereof. The launch position may be determined using path information relating to the flight path of the ball or an element used for launching the ball. Optionally, optical data, such as image data, and/or sound may be used for determining the launch position.



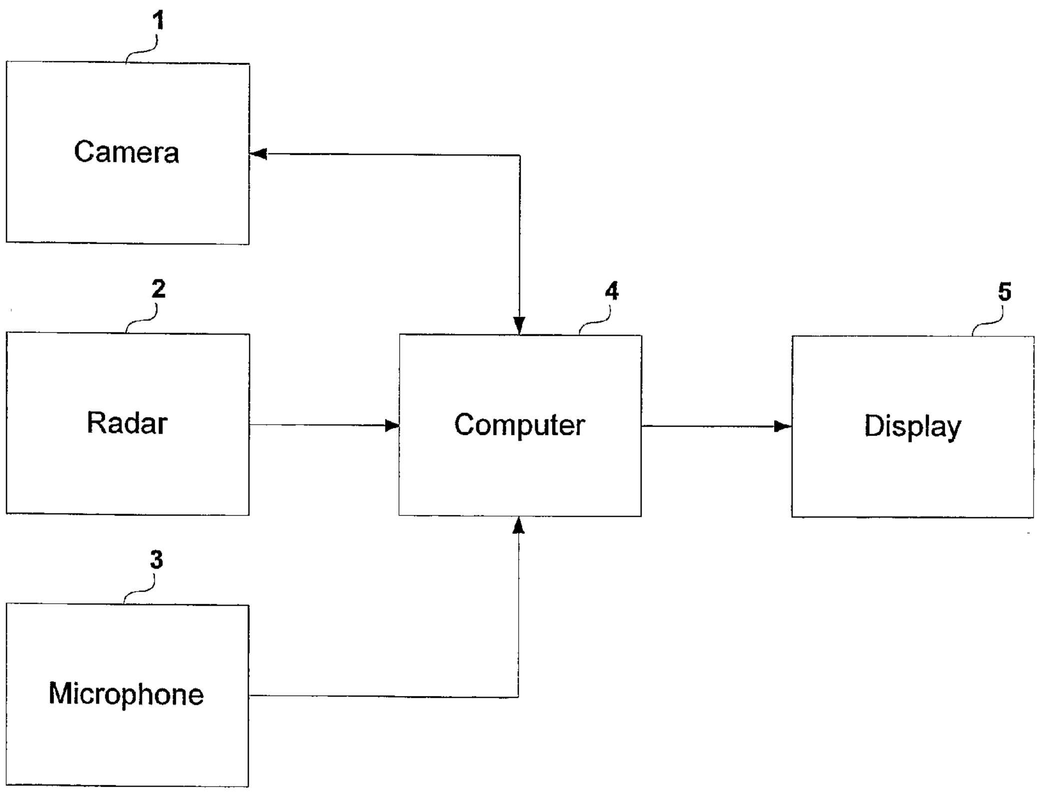
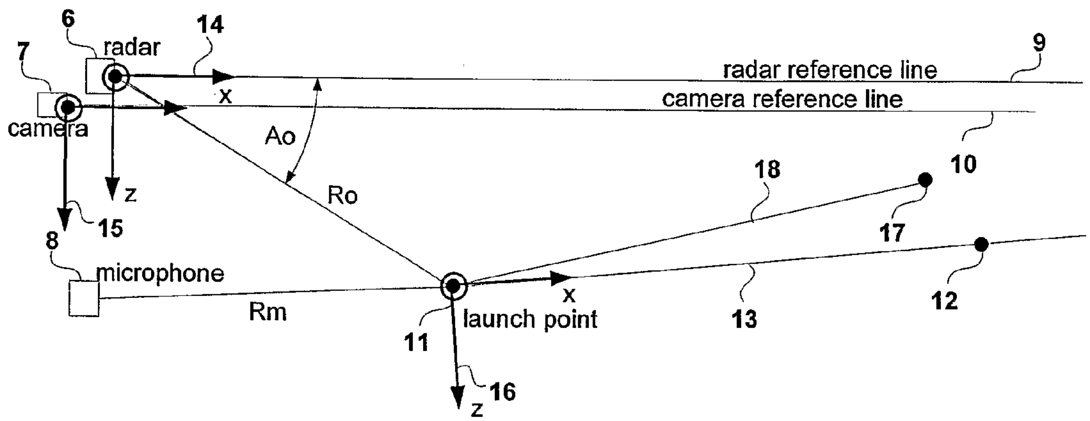


Fig. 1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radar
14
9
radar reference line
7
x
camera reference line
camera
Ao
10
z
Ro
18
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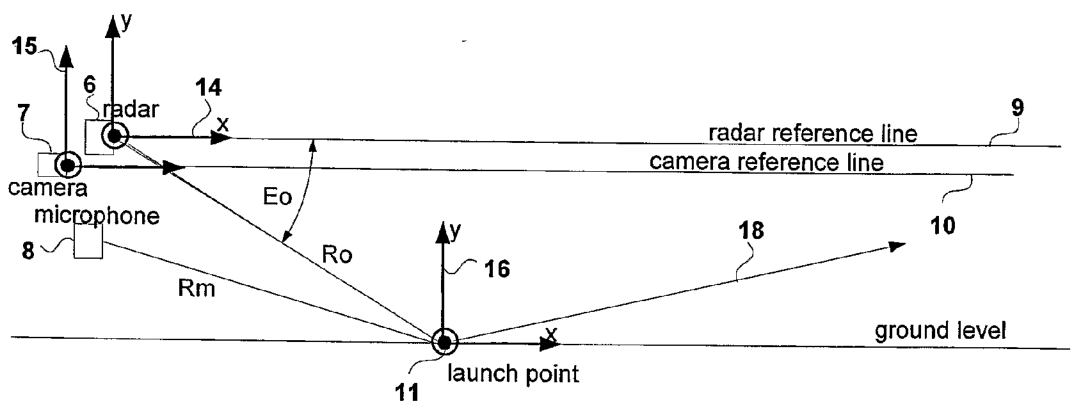
17
8
microphone
x
Rm
13
12
11
launch point
16
z

Fig. 2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6
radar
14
x
7
9
radar reference line
camera reference line
camera
10
microphone
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8
Ro
y
18
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Rm
x
ground level
launch point
11

Fig. 3

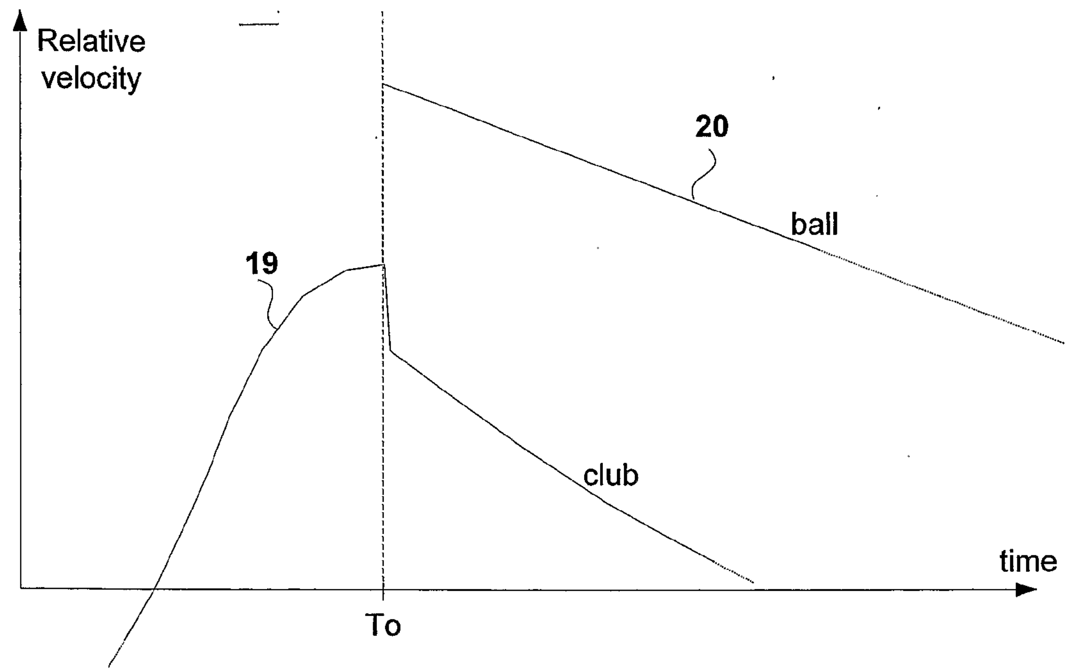

Fig. 4

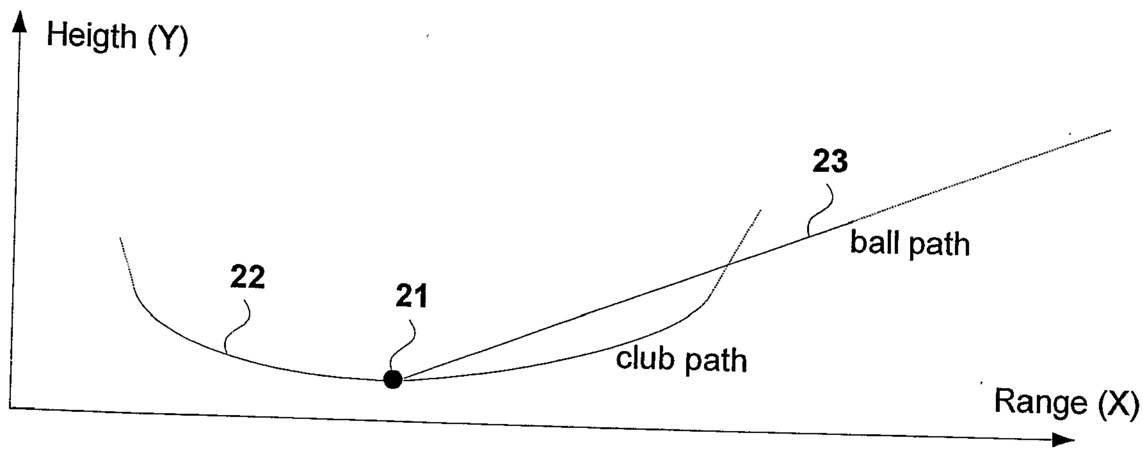

Fig. 5

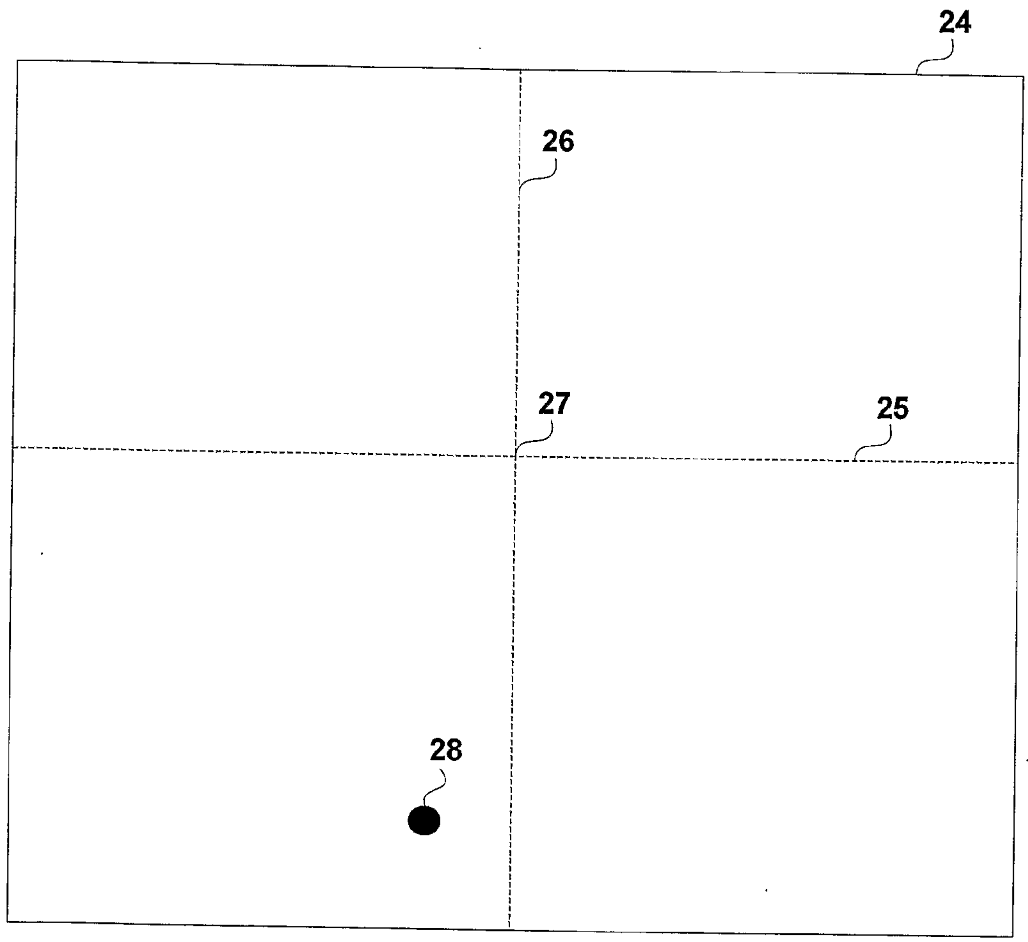

Fig. 6

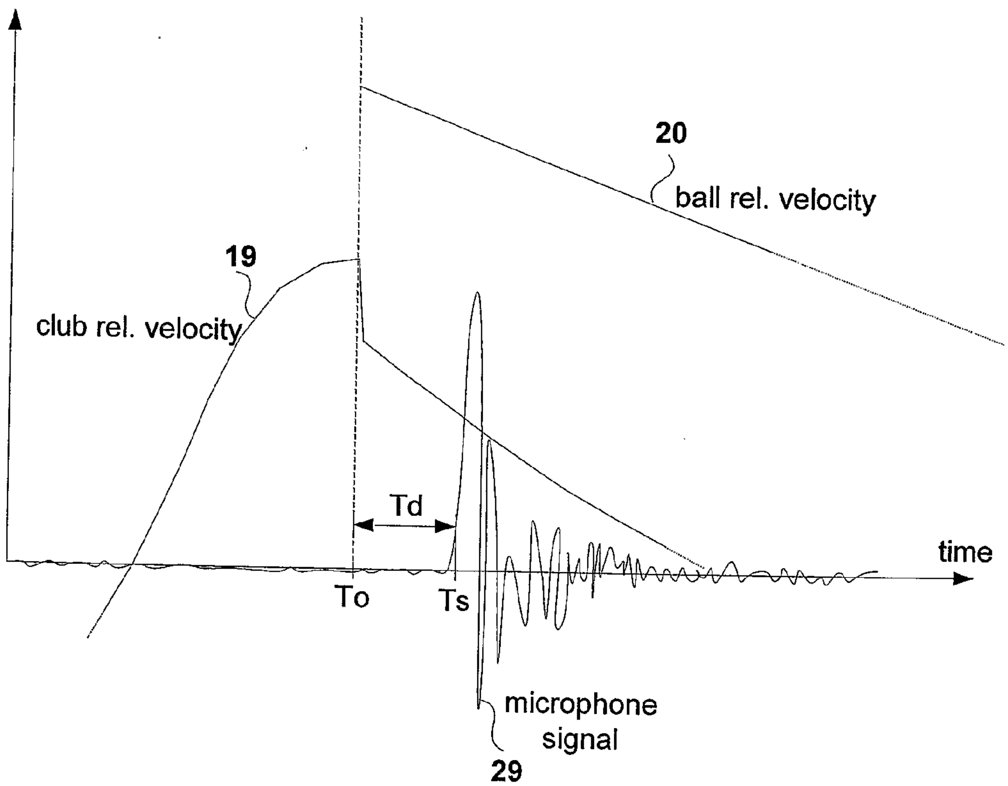
20
ball rel. velocity
19
club rel. velocity
Td
time
To
Ts
microphone
signal
29

Fig. 7

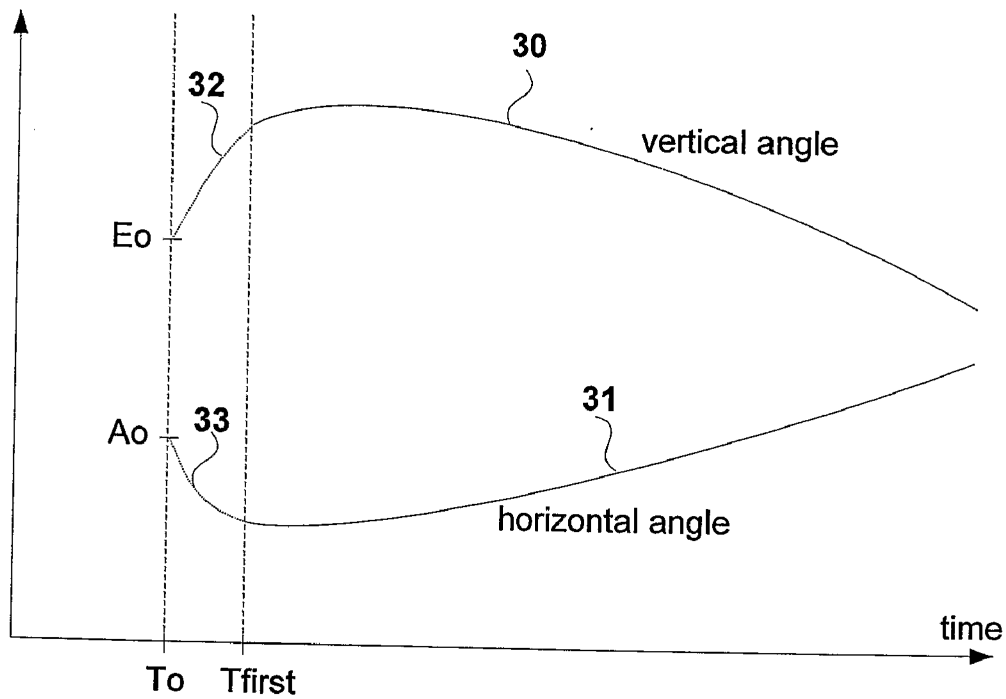
30
32
vertical angle
Eo
Ao
33
31
horizontal angle
time
To
Tfirst

Fig. 8

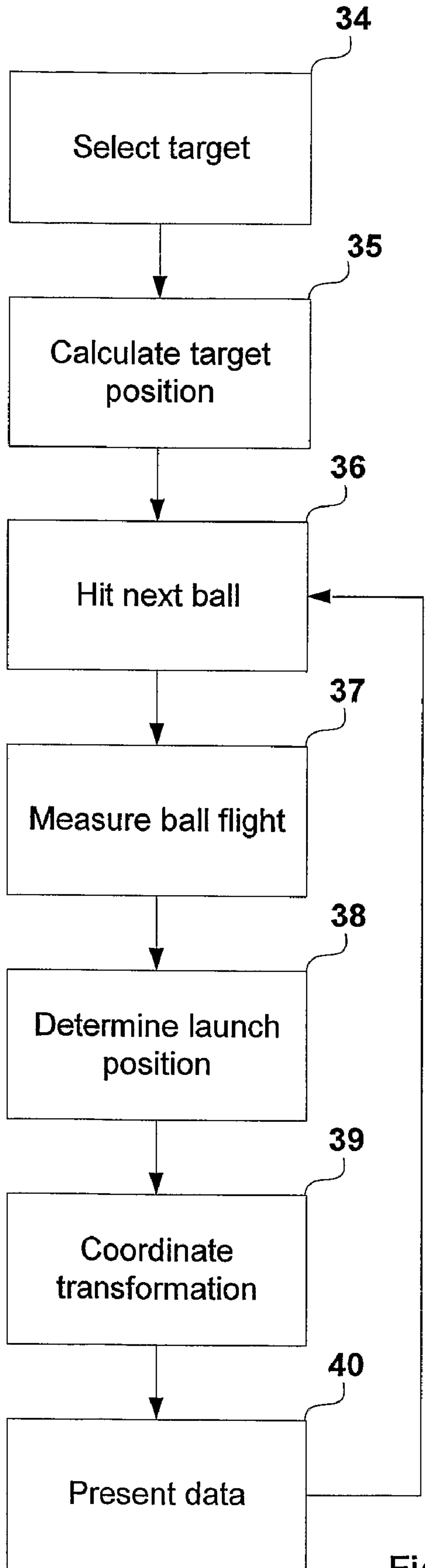
34
Select target
35
Calculate target position
36
Hit next ball
37
Measure ball flight
38
Determine launch position
39
Coordinate transformation
40
Present data

Fig. 9

METHOD AND AN APPARATUS FOR DETERMINING A PARAMETER OF A PATH OF A SPORTS BALL ON THE BASIS OF A LAUNCH POSITION THEREOF

[0001] The present invention relates to a method and an apparatus for determining a parameter of a sports ball and in particular to determining the parameter on the basis of a determined launch position thereof.

[0002] In a number of sports disciplines, different parameters of sports balls are desired. In a number of these disciplines, information is desired relating to the launch thereof. In golf, e.g. a number of apparatus have been described which determine parameter of the golf ball. However, these parameters have been determined solely on the basis of the golf ball when in flight, and none of these references describe the determination of the launch position and the determination of the parameters on the basis of this position. Normally, a launch position is assumed or dictated, and if this position is not used, a wrongly determined parameter is determined.

[0003] Assuming a certain launch position forces the athlete/golfer to launch from that position. If that position is disadvantageous to the athlete and he wishes to launch from another position, either a wrongly determined parameter is determined, or the apparatus must be displaced in order to facilitate a better launch position and still obtain the correct value for the parameter. This is highly unwanted in that the apparatus should be as maintenance free and adjustment free as possible.

[0004] The present invention relates to a solution to that problem.

[0005] In a first aspect, the invention relates to a method of determining a parameter of a path of a sports ball, the method comprising:

- **[0006]** receiving electromagnetic radiation emitted from or reflected by the sports ball when in flight,
- **[0007]** determining a position from which the sports ball was launched, and
- **[0008]** determining the parameter on the basis of the determined launch position of the sports ball.

[0009] In the present context, the sports ball may be any type of ball used in any type of sports, such as a golf ball, a basket ball, a foot ball, a soccer ball, a volley ball, a base ball, or the like.

[0010] The parameter to be determined may relate to any part of the path of the ball, such as the launch position, launch angle or velocity, the flight, the maximum height obtained, a deviation from a desired or assumed direction, a spin, a landing position, a flight distance, or the like.

[0011] The parameter and/or (as will be described further below) the launch position may be determined from the received electromagnetic radiation.

[0012] Also, in the present context, the radiation used may be any type of radiation, such as visible, X-ray, UV, IR, NIR, microwave, radio wave radiation. In fact, also sound could be used for this purpose.

[0013] In one embodiment, the ball emits the radiation and the receiving means receive emitted radiation. In another embodiment, a radiating means emits radiation toward the ball which reflects the radiation toward the receiving means.

[0014] The presently preferred radiation and reception is the use of a CW Doppler RADAR, which normally is able to determine an angle from the radar to the object (ball), but not directly the distance, and a velocity of the object toward or away from the radar.

[0015] The launch position may be represented in a number of manners and in a number of coordinate systems, such as a polar coordinate system or a Cartesian coordinate system. The origin of the coordinate system may be selected at any position, such as at the receiving means. The coordinates of the launch position may be relative or absolute and may be provided in any unit desired.

[0016] Preferably, the position is represented in polar coordinates being two angles (vertical and horizontal) and a distance—from the radiation receiver.

[0017] In a first preferred embodiment, the determination of the launch position comprises determining information relating to an angle between a predetermined coordinate system and the launch position.

[0018] This angle may be represented as an angle or as a number of distances describing the angle. For example, a downward angle may be represented by a height and a horizontal distance. Naturally, such simple shifts of coordinate systems are well known and within the grasp of the skilled person.

[0019] The predetermined coordinate system may be any desired coordinate system, such as one having its origin at the receiving position.

[0020] In one situation, the angle information determination comprises:

- **[0021]** providing image data relating to the coordinate system and the launch position and
- **[0022]** determining the angle information on the basis of the image data.

[0023] Preferably, the image data may be related to the desired coordinate system such that any position in the image data is related to a direction in the coordinate system. In that situation, the position of the launch position in the image data may be described as an angle.

[0024] The launch position may be determinable in the image data in a number of manners. In one manner, the position of the ball in the image may be taken as the launch position. In another manner, a number of images are taken, and a position where, in an earlier image, the ball is present and where it, in a later image, is not, may be taken as the launch position. In fact, the launch position may be taken as a position in which the ball was present in a number of the earlier images indicating that the ball was stationary at that position.

[0025] In another situation, the angle information determination comprises providing, from the received radiation, information relating to a path of the ball at launch and determining the angle information from the path information. Thus, when receiving radiation also at the point in time where the ball was launched, information may be derived as to the path taken at or just after launch. From this path, different parameters, such as a maximum velocity, maximum acceleration or the like may be derived, and the launch position may be taken as a position in which that parameter was present.

[0026] In a different situation, the angle information determination comprises providing, from the received radiation, information relating to a path of an element used for launching the ball and determining the angle information from the path information. Elements used for launching sports balls may be bats, golf clubs, rackets, hands, feet, heads, or the like. Monitoring or receiving the radiation from the launch position would normally also provide radiation from any launching element, whereby this radiation will also comprise information relating to the launch.

[0027] Interesting parameters of the path of the launching element may be a position where a velocity of the element changes abruptly, indicating that energy is transferred to the ball. Another parameter may be a certain extreme position of the element (minimum height for golf clubs, maximum height of a hand in volley ball, left/rightmost position of a baseball bat). These parameters are derivable from the path of that element.

[0028] In yet another situation, the angle information determination comprises providing, from the received radiation, information relating to a path of the ball while in flight and determining the angle information from the path information and an estimate of the path at a point in time of launch. In this situation, path parameters or a shape of the path is assumed, so that the path may be estimated by determining a part thereof from the radiation while the ball is in flight. From that path information, the path may be "back-tracked" toward and to the point in time of launch. Further below, a number of manners of estimating the point in time of launch are described.

[0029] Naturally, the above situations relating to the providing of angle information may be combined in order to e.g. obtain a better certainty or precision of the angle information.

[0030] Depending on the reception strategy of the radiation, the angle information may be combined with distance information in order to determine the launch position.

[0031] In other systems, the distance may be the only information desired.

[0032] Thus, in a second embodiment, the determination of the launch position comprises determining information relating to a distance from a radiation receiver to the launch position.

[0033] In a first situation, the determination of the distance information comprises:

- [0034] determining, from the received electromagnetic radiation, a velocity at a number of consecutive points in time,
- [0035] estimating a point in time of launch as a first point in time of non-zero velocity,
- [0036] determining launch using audio detection, and
- [0037] determining the distance from a difference in the determined points in time of non-zero velocity and audio detection.

[0038] The consecutive points of velocity information may be provided using e.g. a radar in that some radar set-ups are useful only for detecting moving objects. Thus, this type of detection set-up automatically provides this type of information.

[0039] In a second situation, the distance information determination comprises optically viewing the ball and determining the launch using audio detection, the distance information determination determining the distance information from a difference in points in time of detection of the launch by the optical system and the sound detection system.

[0040] Thus, when monitoring or viewing the ball, using e.g. a video camera or a camera providing a plurality of images one after the other, the launch may be determined by the ball having one position in one image and another position (or not being present there at all) in another image. Thus, this will provide a point in time of optically detecting the launch.

[0041] Also, the launch may be detected by sound in that a launch of a ball may provide a recognizable sound or a recognizable change in sound. Thus, simultaneously "listening" will provide another point in time of launch, but this point in time will be delayed due to the velocity of sound being lower than the velocity of light. Naturally, other delays relating to detection delays etc. may also occur, but these may be taken into account.

[0042] In another situation, the distance information determination comprises providing an image of the ball at the launch position and determining the distance information by an extent of the ball in the image.

[0043] Knowing the size of the ball will provide a distance determination merely from the extent of the ball in the image. Whether the image is digital or analogue (standard image film) is not critical, even though a measurement of a linear dimension in a digital image may provide a lower precision due to the resolution of the image.

[0044] In yet another situation, the distance information determination comprises determining angle information according to the first embodiment, and wherein the distance information is determined on the basis of the angle information determined and a predetermined height difference between a means for receiving the radiation and the launch position.

[0045] The angle information from the first embodiment preferably represents at least a vertical angle from e.g. the radiation receiver to the launch position. In that situation, the distance from the radiation receiver, such as the horizontal distance, may be determined, when the vertical distance, the height, of the radiation receiver over the launch position is known. This height may e.g. be defined by e.g. a tripod or the like on which the receiver is positioned.

[0046] In another situation, the distance information determination comprises providing a stereo image pair of the ball at the launch position and determining the launch position from an angular displacement of the ball in the two images. Stereo imaging is a known technology well adapted to determine distances.

[0047] In an alternative situation, the distance information determination comprises determining an intensity of emitted/reflected radiation at least substantially at the point in time of launch and determining the distance information from the determined intensity. The emission or reflection of the ball may be known so that by simply determining the intensity of the radiation received may provide an estimate of the distance to the ball. If the ball then is at the launch position, the distance to the launch position may be determined.

[0048] Depending on the receiver set-up, the ball may not be determinable if it is not moving, whereby the first detection thereof by the receiver may be at or shortly after launch, whereby the initially received intensity may be used for determining the distance information.

[0049] If a set-up is used where radiation is emitted toward the ball and reflected by the ball, the intensity will relate differently to the distance, but this is mere mathematics, which the skilled person will master.

[0050] In another situation, the distance information determination comprises emitting radiation of at least two wavelengths toward the ball, and determining the distance information from the received radiation. One manner of performing this is to use two radiation providers which are phase locked. If this technique is used with a Radar, it is termed a Multi Frequency CW Radar (MF-CW Radar). In this situation, where the phases or frequencies of the two providers is known, the distance to the ball or launch point may be determined from the phase of the received, interfering radiation. The phase shift will relate to the distance which the radiation has travelled.

[0051] Alternatively, the distance information may be determined using a single frequency or phase-modulated carrier of signal. In this case, the distance information may be determined by correlation analysis. A Radar using this technique may be called a Phase-modulated or Frequency-modulated CW Radar (PM- or FM-CW Radar). Thus, the distance information determination could comprise emitting radiation comprising a phase and/or frequency modulated signal and determining the distance information from the received radiation.

[0052] Naturally, the individual situations or embodiments of the second embodiment may be combined in order to achieve an increased precision of the information. Also, the distance information and the angle information may be combined in order to determine the launch position.

[0053] In certain of the above methods, it is desired or required that the launch position determination comprises estimating a point in time of launch. This may be in situations, where it is desired to back-track e.g. a path to the point in time of the launch. Normally, the path is determined as a plurality of points along which the ball flies. This path is extended or tracked toward the launch position/time, but it may not be determinable that a certain point of the path actually is at the launch position. Also, no points may be available as early as at the launch position, whereby this point in time is required in order to determine the position of the path at that point in time: the launch position.

[0054] In one situation, the launch time estimation comprises providing a plurality of images of the launch position and determining the launch time by a difference being present between two images, such as on either side of the launch time.

[0055] This is also described above. A video sequence or a sequence of images may be used, and the launch may be determined as a point in time between two images where the ball is present in the earlier image but not in the next image. Naturally, the launch position may be a position where the ball is present in a number of the earlier images (making sure that it is stationary, e.g.).

[0056] In another situation, the launch time estimation comprises providing, from the received radiation, information relating to a path of the ball at launch and determining the launch time from the path information. As mentioned above, the path of the ball may illustrate specific parameters or behaviours at the position—and time—of launch. Thus, as well as the launch position may e.g. be determined at the position of largest velocity, the point in time may be determined also at the time of largest velocity. Naturally, also other parameters may be used for indicating launch: extreme positions (lowest, highest etc), highest acceleration or the like. Also, the path may be determined from a number of determinations of the ball, such as velocity and/or position date. Thus, the launch time may be determined as a first detection of the ball where it has a non-zero velocity.

[0057] In yet another situation, the launch time estimation comprises providing, from the received radiation, information relating to a path of an element used for launching the ball and determining the launch time from the path information. This is also indicated above, where the element is also tracked and the launch position is determined from specific characteristics of the path thereof. The same characteristics may be used for indicating the launch time.

[0058] Also, the launch time estimation may comprise providing, from the received radiation, information relating to a path of the ball while in flight and determining the launch time from the path information and an estimate of the path at a point in time of launch. In this manner, parameters of the path (such as the shape, velocity, height, e.g.) are assumed, and the point in time may be determined by back-tracking the path until a given parameter is obtained. This parameter may be that the ball reaches a certain height, at which launch takes place (such as ground level in golf).

[0059] Finally, the launch time estimation could comprise estimating the point in time of launch on the basis of a predetermined audio parameter determined from sound detected at launch. Thus, a microphone may be used for the determination. The parameter may be a characteristic sound, frequency, intensity level, intensity increase, or the like.

[0060] If the above-mentioned delay caused by the velocity of sound is a problem, the microphone may be moved closer to the launch position or the delay may be estimated on the basis of a distance measurement as described above.

[0061] Again, the individual situations in the third embodiment may be combined in order to obtain a higher precision of the determined point in time.

[0062] In a second aspect, the invention relates to an apparatus of determining a parameter of a path of a sports ball, the apparatus comprising:

- **[0063]** means for receiving electromagnetic radiation emitted from or reflected by the sports ball when in flight,
- **[0064]** means for determining a position from which the sports ball was launched and
- **[0065]** means for determining the parameter on the basis of the determined launch position of the sports ball.

[0066] As mentioned above, the apparatus may also comprise means for emitting radiation toward the ball, which then reflects radiation toward the receiver.

[0067] The launch position and/or the parameter may be determined from the received electromagnetic radiation.

[0068] The receiving means may be adapted to receive any wavelength or wavelength interval of a wide variety of types of radiation, such as microwaves, visible light, X-rays, IR, NIR, ultrasound or the like—or sound.

[0069] In one embodiment, the means for determining the launch position comprise means for determining information relating to an angle between a predetermined axis of the receiving means and the launch position.

[0070] In one situation, the angle information determining means comprise means for providing image data relating to the axis and the launch position., the angle information determining means being adapted to determine the angle information on the basis of the image data. The image data providing means may be a camera, such as a still camera or a video camera. If the camera is fixed at a given position, the position of the launch position in the image may directly describe one or more angles in which this position is in a predetermined coordinate system, such as a coordinate system having origin at the image providing means.

[0071] Naturally, the position may be translated into any other coordinate system.

[0072] In another situation, the angle information determining means comprise means for providing, from the received radiation, information relating to a path of the ball at launch, the information determining means being adapted to determine the angle information from the path information. The path of the ball at launch may be determined using e.g. a radar or the like. From this path, an extrapolation may be performed, if required, in order to determine the position of the launch.

[0073] In a third situation, the angle information determining means comprise means for providing, from the received radiation, information relating to a path of an element used for launching the ball, the information determining means being adapted to determine the angle information from the path information. This is described above.

[0074] In yet another situation, the angle information determining means comprise means for providing, from the received radiation, information relating to a path of the ball while in flight, the angle information determining means being adapted to provide estimate of the path at a point in time of launch and to determine the angle information from the estimate and the path information.

[0075] In another embodiment, the means for determining the launch position comprise means for determining information relating to a distance from the radiation receiver to the launch position.

[0076] In a first situation, the distance information determining means comprise:

- **[0077]** means for determining, from the received electromagnetic radiation, a velocity of the ball at a number of consecutive points in time,
- **[0078]** means for estimating a point in time of launch as a first point in time of non-zero velocity,
- **[0079]** means for determining launch using audio detection, and
- **[0080]** means for determining the distance from a difference in the determined points in time of non-zero velocity and audio detection.

[0081] This is a simple manner of determining the distance information.

[0082] In another situation, the distance information determining means comprise means for optically viewing the ball and means for detecting the launch on the basis of received audio information, the distance information determining means being adapted to determine the distance information from a difference in points in time of detection of the launch by the optical system and the sound detection system. Thus, a camera for viewing the ball by providing a series of images and determining the launch as a difference in two consecutive images.

[0083] Thus, in these two situations, a microphone may be used for detecting the launch by a characteristic sound or change in sound, and the distance may be determined from a difference in launch times caused by the difference in the velocity of sound and light/radiation.

[0084] Alternatively or in addition, the distance information determining means may comprise means for providing an image of the ball at the launch position, the distance information determining means being adapted to determine the distance information by an extent of the ball in the image. This image providing means may be any type of camera. Alternatively, the image may be a hard copy which is subsequently used for the determination.

[0085] In another situation, the distance information determining means comprise means for determining angle information according to the first embodiment, and wherein the distance information determining means are adapted to determine the distance information on the basis of the angle information determined and a predetermined height difference between the receiving means and the launch position. As described above, the angle and distance information may be represented also as distances, angles and the like. Determining the distance when the height (vertical distance) and the angle are known is trivial.

[0086] In yet another situation, the distance information determining means comprise means providing a stereo image pair of the ball at the launch, position, the distance information determining means being adapted to determine the launch position from an angular displacement of the ball in the two images. Stereo imaging is a known technology also for distance determination.

[0087] Alternatively or in addition, the distance information determining means may comprise means for determining an intensity of emitted/reflected radiation at least substantially at the point in time of launch, the distance information determining means being adapted to determine the distance information from the determined intensity. Knowing the intensity emitted from the ball or a reflection coefficient thereof (and an intensity transmitted toward the ball) will enable this feature.

[0088] In another situation, the distance information determining means comprise means for emitting radiation of at least two wavelengths toward the ball, the distance information determining means being adapted to determine the distance information from the received radiation. One manner of obtaining this is to have two radiation providers which are phase-locked. The received radiation interferes and consequently has a phase which is modulated depending on the distance from the ball to the receiver.

[0089] Also, the distance information determining means may comprise means for emitting radiation comprising a phase and/or frequency modulated signal, the distance information determining means being adapted to determine the distance information from the received radiation.

[0090] In a third embodiment, as described above, the launch position determination means comprise means for estimating a point in time of launch.

[0091] In one situation, the launch time estimating means comprise means for providing a plurality of images of the launch position, the launch time estimating means being adapted to determine the launch time by a difference being present between two images. Again a camera such as a video camera or a still camera may be used.

[0092] In another situation, the launch time estimating means comprise means for providing, from the received radiation, information relating to a path of the ball at launch, the launch time estimating means being adapted to determine the launch time from the path information.

[0093] Alternatively or in addition, the launch time estimating means may comprise means for providing, from the received radiation, information relating to a path of an element used for launching the ball, the launch time estimating means being adapted to determine the launch time from the path information.

[0094] Also, the launch time estimating means may comprise means for providing, from the received radiation, information relating to a path of the ball while in flight, the launch time estimating means being adapted to determine the launch time from the path information and an estimate of the path at a point in time of launch.

[0095] Finally, the launch time estimating means may comprise means for detecting sound and means for determining the point in time of launch by identifying a predetermined parameter in the detected sound.

[0096] It is clear that the situations of the individual embodiments of the second aspect may be combined in any manner desired in order to provide the information required or even increase a precision in the determination of the information.

[0097] Also, it is dear that the tracking of the paths, the back-tracking and other calculations or determinations as well as the geometrical conversions desired are standard operations of persons working with tracking using e.g. radars.

[0098] In the following, a preferred embodiment of the invention will be described with reference to the drawing, wherein:

[0099] FIG. **1** is a block diagram of the main components in the present invention.

[0100] FIG. **2** shows the positions of the different coordinate systems in a top view.

[0101] FIG. **3** shows the positions of the different coordinate systems in a side view.

[0102] FIG. **4** shows the relative velocity measured by the radar during launch of a ball with a club.

[0103] FIG. **5** shows the path of club and ball during launch.

[0104] FIG. **6** shows the image of a camera looking in the launching area.

[0105] FIG. **7** shows the relative velocity measured by the radar during launch of a ball with a club as well as the audio signal captured by a microphone.

[0106] FIG. **8** shows the vertical and horizontal angle of the ball just after launch measured by the radar.

[0107] FIG. **9** shows the process flow of the present invention.

[0108] In the present embodiment, the projectile is a golf ball being launched towards a target. The image capturing device is a camera **1**, and the measurement equipment to determine the actual projectile path is a radar **2**, as shown in FIG. **1**. Preferably, the radar **2** is a velocity and angle measuring type, e.g. a monopulse Doppler radar. The radar **2** might optionally be equipped with a range measuring capability, such as frequency- or phase-modulated (FM or PM) Doppler radar, or be a multi-frequency (MF) type of Doppler radar.

[0109] Optionally, the system may also include a microphone **3** to detect the launch time. The radar, image and microphone data are captured by a computer **4**, which displays the ball flight data in the proper coordinate system.

[0110] Independently of the position and physical orientation of the radar, the golf ball flight path **18** data, and specifically the landing point **17**, is desired in a coordinate system **16** which has origin at the launch point **11** and with a horizontal reference line **13** that goes through the desired target **12**. The hereby defined coordinate system is called the golfer coordinate system **16**, as seen in FIG. **2**.

[0111] The trajectory data of the ball flight path **18** is measured by the radar **6** in the radar coordinate system **14**. The image captured by the camera **7** is obtained in the camera coordinate system **15**.

[0112] Every golf shot will typically be launched from slightly different positions, and also the target will often change during a golf session. This means that the position and orientation of the golfer coordinate system **16** is in general different for every golf shot. This illustrates the need for an efficient way to automatically transfer measurement data from the radar coordinate system **14** into the golfer coordinate system **16**.

[0113] Previous techniques require that the golf ball is launched from within a very limited area (20 cm diameter circle) to operate correctly. When using such a system for golf shots from the grass, it will be required to move the radar unit very often, since the preferred tee-off position of the golfer changes all the time—the golfer wants to have fresh grass under the ball.

[0114] The present invention has a much less stringent requirement on where to tee-off, since the system actually measures the launch position. This makes system using the present invention much more user-friendly.

[0115] The process flow of the current invention is shown in FIG. **9**. The user selects a target to aim for in step **34**. Then, in step **35** the system calculates the target position **12** in the radar coordinate system **14**. The ball is launched in step **36**, and the radar **6** measures the ball flight. The ball flight path **18** is measured in step **37** by the radar **8**. After completion of tracking the system determines, in step **38**, the actual launch position from the recorded data from the radar **6**, the camera **7**, and/or the optional microphone **8**, see further below. Having the launch position **11** and the target position **12**, the golfer coordinate system **16** is determined relative to the radar coordinate system **14**. All the measured ball flight data are then transformed **39** from the radar coordinate system **14** to the golfer coordinate system **16**. Finally, the data is presented **40** on the display **5** for the user.

[0116] Most of the steps in the process flow in FIG. **9** are well known from prior art. However the determination of the launch point in this context is novel, as is the determination of parameters of the ball path on the basis of a measured launch point. The determination of the launch point will be outlined in details below.

[0117] In the preferred embodiment, the radar **6** is a continuous wave (CW) type Doppler radar. These types of radars are very well suited for measuring on golf balls. However, a CW Doppler radar is in general not able to directly measure the distance from the radar to the object being tracked. The Doppler radar measures the relative velocity of the object relative to the radar. To obtain the distance to a tracking object from a CW based radar system, it is necessary to integrate the relative velocity from a known reference point—normally the launch point. Any biases or offsets in the reference point will be directly added to the 3D position. This is why previous techniques require the golf ball to be launched from a very limited area.

[0118] The launch position relative to the radar can be expressed in many ways, but are typically either in Cartesian or polar coordinates, see FIGS. **2** and **3**.

$$[Xo, Yo, Zo] = Ro*[\cos(Eo)*\cos(Ao), \sin(Eo), \cos(Eo)*\sin(Ao)] \qquad \text{[eqn. 1]}$$

[0119] Ro, distance from launch point to radar

[0120] Eo, vertical angle to launch point from radar

[0121] Ao, measured horizontal angle to launch point from radar

[0122] [Xo,Yo,Zo], Cartesian coordinates of launch point in radar coordinate system **14**

[0123] The determination of the launch point consists of two steps.

[0124] The first step is determination of the angles Eo and Ao from the radar to the launch point. Several different methods for doing this are outlined below.

[0125] The second step is determination of the distance Ro from the radar to the launch point. Several different methods for doing this are outlined below.

1. Determination of Angles to Launch Point Eo, Ao

[0126] In the following, several different methods will be outlined.

[0127] 1.1. By frequency analysing the received radar signal during launch of a golf ball, a diagram like that illustrated in FIG. **4** can be constructed. The radar **6** is positioned behind the launch point **11**; thereby the radar signal in FIG. **4** will monitor both the relative velocity of the dub **19** as well as the relative velocity of the ball **20**. The first data point of the ball velocity **20** corresponds to the launch of the ball. This first ball data point is then evaluated for the vertical angle Eo and horizontal angle Ao directly, e.g. by using the monopulse principle as outlined in the publication "Introduction to Radar Systems", Third Edition, Merril I. Skolnik, which is incorporated herein as reference.

[0128] 1.2. In cases where the ball velocity and/or angles can not be detected exactly at launch time, another approach may be used. In FIG. **8** the first data point of the ball happens at time Tfirst, which is after the launch time To. The measured vertical angle **30** and horizontal angle **31** of the ball will look like those illustrated in FIG. **8**. By other means adapted to determine the launch time To, see later, the vertical and horizontal angle can be back-extrapolated in time until To. Then Eo and Ao can directly be determined.

[0129] The back-extrapolation is preferably done assuming a linear motion of the ball, which can take into account known forces acting on the ball, like gravity, drag and lift.

[0130] 1.3. The third method to determine Eo and Ao uses images from the camera **7** taken both before and after ball launch. The image **24** could look like that illustrated in FIG. **6**, where **25** is the horizontal reference line of the camera coordinate system **15**, and **26** is the vertical reference line of the camera coordinate system **15**. By analyzing the difference of a sequence of images **24** taken before and after launch, the launched ball **28** can be identified in the image **24**. Hereby the vertical and horizontal angle to the launch position from the camera **7** can be determined.

[0131] The vertical and horizontal angle from the camera is then converted to Eo and Ao, which are the same angles seen from the radar **6**, by taking into account the known geometric relation between the radar **6** and camera **7**. This step requires knowledge of the distance Ro from the radar to the launch point. See below how Ro may be determined.

2. Determination of Distance to Launch Point Ro

[0132] In the following, several different methods will be outlined.

[0133] 2.1. By analysing the change in received power level of the radar signal versus time for a sports ball, the distance to the ball can in fact be determined. This method is outlined in applicants co-pending PCT/DK2005/000336 and which is incorporated herein by reference.

[0134] The determination of Ro can preferably be done using the first range data point of the ball flight, similar to what is described in paragraph 1.1. above. Alternatively, back-extrapolation of the measured range to the ball until launch time To may be used; this is similar to what is described in paragraph 1.2 above.

[0135] 2.2. If the radar incorporates frequency- or phase-modulation on the carrier (FM or PM based radar systems), the range to both the sports ball and the launching element can be measured directly. The range can also be directly measured by using a multi-frequency Doppler radar, sometimes used in telerometers as explained in the publication "Introduction to Radar Systems", Second Edition, Merril I. Skolnik, which is incorporated herein as reference.

[0136] Identical to 2.1. above, the determination of Ro can preferably be done using the first range data point of the ball flight, similar to 1.1. above. Alternatively, back-extrapolation of the measured range to the ball until launch time To may be used; this is similar to 1.2 above.

[0137] 2.3. In many cases the height of the launch point above the ground is actually well known within some minor limits. This is the case for golf balls, where the ball is launched if not on the ground, then only elevated up to 5 cm. By knowing the height of the radar **6** above the ground, the distance Ro can be calculated from the measured vertical angle Eo by [eqn. 2].

$$Ro=H/\cos(Eo) \qquad \text{[eqn. 2]}$$

[0138] where H is the predetermined height of the radar above the ground

[0139] Obviously, the same method can be applied to the vertical angle determined from the camera **7**, as in 1.3 above. In this case, H should be replaced by the height of the camera **7** above the ground, and the hereby determined 'Ro' from [eqn. 2] must be converted to Ro, seen from the radar, by taking into account the known geometric relation between the radar **6** and camera **7**.

[0140] It is clear that the precision of this method is proportional to the degree of flatness from the radar/camera position to the launch point.

[0141] 2.4. If the system includes the optional microphone **3**, another method exits. The sound signal captured by the microphone **8** will change dramatically when the impact between the launching element and the sports ball takes place. This is illustrated in FIG. **7**, where the relative velocity of the club **19** and relative velocity of the ball **20** captured by the radar **6** is shown in relation to the recorded audio signal **29** recorded by the microphone **8**. Because of the speed of sound being around 1.000.000 times less than the speed of light, the impact detection time Ts of the audio signal will be delayed Td relative to the launch time To measured by the radar and/or camera.

[0142] By arranging the microphone in the same distance as the radar from the launch point Rm will equal Ro. In this case Ro can be determined from [eqn. 3].

$$Ro=Td/(1/Vs-1/c)\approx Td*Vs \qquad \text{[eqn. 3]}$$

[0143] ,where

[0144] Td is the delay of the audio launch time and the radar/camera launch time

[0145] Vs is the speed of sound

[0146] c is the speed of light

[0147] 2.5. This method uses images from the camera **7** taken both before and after ball launch. By analyzing the difference of a sequence of images **24** taken before and after launch, the launched ball **28** can be identified in the image **24**. From the image **24**, the angular extent of the launched ball **28** can be determined by well known vision methods.

[0148] In most cases, the diameter of the sport ball is well defined. By relating the determined angular extent of the ball to the physical, predetermined diameter, the distance to the launch point 'Ro' from the camera can be determined.

[0149] As for method 2.3, the distance 'Ro' from the camera must be converted to Ro seen from the radar by taking into account the known geometric relation between the radar **6** and the camera **7**.

[0150] 2.6. If the camera **7** is a stereo camera, the distance to the launch point can be determined directly from the angular displacement in the two corresponding pictures. This technique will not be explained further here, but it is a well known technique within vision technology.

[0151] Again, simple geometric correction is required on the determined distance to account for the displacement of the stereo camera **7** relative to the radar **6**.

3. Determination of Launch Time To

[0152] In some of the above methods for determining the launch position parameters Eo, Ao and Ro, it is required to know the launch time To. Below, several different methods to determine To will be outlined.

[0153] 3.1. In FIG. **4**, the relative velocity of the club **19** and the ball **20** is shown. In FIG. **5**, the corresponding measured club path **22** and ball path **23** are shown. The launch point **21** and the launch time To may be determined where the club and the ball are present at the same point at the same time. The launch time To can be found from FIG. **4** and/or FIG. **6** in a number of different ways, to name a few:

[0154] Maximum club velocity

[0155] Minimum club height

[0156] First ball velocity higher than 0

[0157] 3.2. Another method uses the measured ball flight data from the radar. The trajectory data can then be back-extrapolated until a predetermined launch height is reached.

[0158] The precision of this method as for method 2.3 is proportional with the degree of flatness from radar position to launch point.

[0159] 3.3. If the system includes the optional microphone **3**, one further method exits. The sound signal captured the microphone **8** will change dramatically, as explained above in method 2.4, when impact between launching element and sports ball takes place. By knowing the distance Rm from the microphone to the launch point, the launch time To can be calculated using [eqn. 4].

$$To=Ts=Td\approx Rm/Vs \qquad \text{[eqn. 4]}$$

[0160] ,where

[0161] Ts is the detected beginning of the abrupt change in the audio signal

[0162] 3.4 Another method again uses a rapid sequence of pictures taken by the camera **7** during launch. By vision techniques, detecting the picture frame of ball impact and correlating this picture timewise with the recorded radar signal, the ball launch time To can be determined in the radar signal. This may be a single frame or a point in time between two frames: one where the ball is present and another where the ball is in movement or is gone.

[0163] All the methods may be combined and used in conjunction to increase the accuracy of the determination of the launch point **11**.

1-42. (canceled)

43. A method of determining a parameter of a path of a sports ball, the method comprising:

receiving, using a CW Doppler Radar, electromagnetic radiation emitted from or reflected by the sports ball when in flight, and

determining the parameter on the basis of information received from the Radar, the method being characterized by determining, on the basis of received electromagnetic radiation emitted from or reflected by the sports ball, a position from which the sports ball was launched,

wherein the determining step comprises determining the parameter also on the basis of the determined launch position of the sports ball.

44. A method according to claim **43**, wherein the determination of the launch position comprises determining information relating to an angle between a predetermined coordinate system and the launch position.

45. A method according to claim **44**, wherein the angle information determination comprising providing image data relating to the coordinate system and the launch position and determining the angle information on the basis of the image data.

46. A method according to claim **44**, wherein the angle information determination comprises providing, from the received radiation, information relating to a path of the ball at launch and determining the angle information from the path information.

47. A method according to claim **44**, wherein the angle information determination comprises providing, form the received radiation, information relating to a path of an element used for launching the ball and determining the angle information from the path information.

48. A method according to claim **44**, wherein the angle information determination comprises providing, from the received radiation, information relating to a path of the ball while in flight and determining the angle information from the path information and an estimate of the path at a point in time of launch.

49. A method according to claim **43**, wherein the determination of the launch position comprises determining a information relating to a distance from a radiation receiver to the launch position.

50. A method according to claim **49**, wherein the determination of the distance information comprises:

determining, from the received electromagnetic radiation, a velocity at a number of consecutive points in time,

estimating a point in time of launch as a first point in time of non-zero velocity,

determining launch using audio detection, and

determining the distance from a difference in the determined points in time of non-zero velocity and audio detection.

51. A method according to claim **49**, wherein the distance information determination comprises optically viewing the ball and determining the launch using audio detection, the distance information determination determining the distance information from a difference in points in time of detection of the launch by the optical system and the sound detection system.

52. A method according to claim **49**, wherein the distance information determination comprises providing an image of the ball at the launch position and determining the distance information by an extent of the ball in the image.

53. A method according to claim **49**, wherein the distance information determination comprises determining angle information according to any of claims **3-6**, and wherein the distance information is determined on the basis of the angle information determined and a predetermined height difference between a means for receiving the radiation and the launch position.

54. A method according to claim **49**, wherein the distance information determination comprises providing a stereo image pair of the ball at the launch position and determining the launch position from an angular displacement of the ball in the two images.

55. A method according to claim **49**, wherein the distance information determination comprises determining an intensity of emitted/reflected radiation at least substantially at the point in time of launch and determining the distance information from the determined intensity.

56. A method according to claim **49**, wherein the distance information determination comprises emitting radiation of at least two wavelengths toward the ball and determining the distance information from the received radiation.

57. A method according to claim **49**, wherein the distance information determination comprises emitting radiation comprising a phase and/or frequency modulated signal and determining the distance information from the received radiation.

58. A method according to claim **43**, wherein the launch position determination comprises estimating a point in time of launch.

59. A method according to claim **48**, wherein the launch time estimation comprises providing a plurality of images of the launch position and determining the launch time by a difference being present between two images.

60. A method according to claim **48**, wherein the launch time estimation comprises providing, from the received radiation, information relating to a path of the ball at launch and determining the launch time from the path information.

61. A method according to claim **48**, wherein the launch time estimation comprises providing, form the received radiation, information relating to a path of an element used for launching the ball and determining the launch time from the path information.

62. A method according to claim **48**, wherein the launch time estimation comprises providing, from the received radiation, information relating to a path of the ball while in flight and determining the launch time from the path information and an estimate of the path at a point in time of launch.

63. A method according to claim **48**, wherein the launch time estimation comprises estimating the point in time of launch on the basis of a predetermined audio parameter determined from sound detected at launch.

64. An apparatus of determining a parameter of a path of a sports ball, the apparatus comprising:

a CW Doppler radar for receiving electromagnetic radiation emitted from or reflected by the sports ball when in flight, and

means for determining the parameter on the basis of information received from the radar,

the apparatus being characterized by means for receiving electromagnetic radiation emitted from or reflected by the sports ball and, from the received radiation, determining a position from which the sports ball was launched,

wherein the means for determining the parameter are adapted to determine the parameter also on the basis of the determined launch position of the sports ball.

65. An apparatus according to claim **64**, wherein the means for determining the launch position comprise means for determining information relating to an angle between a predetermined axis of the receiving means and the launch position.

66. An apparatus according to claim **65**, wherein the angle information determining means comprise means for providing image data relating to the axis and the launch position, the angle information determining means being adapted to determine the angle information on the basis of the image data.

67. An apparatus according to claim **65**, wherein the angle information determining means comprise means for providing, from the received radiation, information relating to a path of the ball at launch, the information determining means being adapted to determine the angle information from the path information.

68. An apparatus according to claim **65**, wherein the angle information determining means comprise means for providing, from the received radiation, information relating to a path of an element used for launching the ball, the information determining means being adapted to determine the angle information from the path information.

69. An apparatus according to claim **65**, wherein the angle information determining means comprise means for providing, from the received radiation, information relating to a path of the ball while in flight, the angle information determining means being adapted to provide estimate of the path at a point in time of launch and to determine the angle information from the estimate and the path information.

70. An apparatus according to claim **64**, wherein the means for determining the launch position comprise means for determining information relating to a distance from the radiation receiver to the launch position.

71. An apparatus according to claim **70**, wherein the distance information determining means comprise:

means for determining, from the received electromagnetic radiation, a velocity at a number of consecutive points in time,

means for estimating a point in time of launch as a first point in time of non-zero velocity,

means for determining launch using audio detection, and

means for determining the distance from a difference in the determined points in time of non-zero velocity and audio detection.

72. An apparatus according to claim **70**, wherein the distance information determining means comprise means for optically viewing the ball and means for detecting the launch on the basis of received audio information, the distance information determining means being adapted to determine the distance information from a difference in points in time of detection of the launch by the optical system and the sound detection system.

73. An apparatus according to claim **70**, wherein the distance information determining means comprise means for providing an image of the ball at the launch position, the distance information determining means being adapted to determine the distance information by an extent of the ball in the image.

74. An apparatus according to claim **70**, wherein the distance information determining means comprise means for determining angle information according to any of claims **3-6**, and wherein the distance information determining means are adapted to determine the distance information on the basis of the angle information determined and a predetermined height difference between the receiving means and the launch position.

75. An apparatus according to claim **70**, wherein the distance information determining means comprise means providing a stereo image pair of the ball at the launch position, the distance information determining means being adapted to determine the launch position from an angular displacement of the ball in the two images.

76. An apparatus according to claim **70**, wherein the distance information determining means comprise means for determining an intensity of emitted/reflected radiation at least substantially at the point in time of launch, the distance information determining means being adapted to determine the distance information from the determined intensity.

77. An apparatus according to claim **70**, wherein the distance information determining means comprise means for emitting radiation of at least two wavelengths toward the ball, the distance information determining means being adapted to determine the distance information from the received radiation.

78. An apparatus according to claim **70**, wherein the distance information determining means comprise means for emitting radiation comprising a phase and/or frequency modulated signal, the distance information determining means being adapted to determine the distance information from the received radiation.

79. An apparatus according to claim **70**, wherein the launch position determination means comprise means for estimating a point in time of launch.

80. An apparatus according to claim **79**, wherein the launch time estimating means comprise means for providing a plurality of images of the launch position, the launch time estimating means being adapted to determine the launch time by a difference being present between two images.

81. An apparatus according to claim **79**, wherein the launch time estimating means comprise means for providing, from the received radiation, information relating to a path of the ball at launch, the launch time estimating means being adapted to determine the launch time from the path information.

82. An apparatus according to claim **79**, wherein the launch time estimating means comprise means for providing, from the received radiation, information relating to a path of an element used for launching the ball, the launch time estimating means being adapted to determine the launch time from the path information.

83. An apparatus according to claim **79**, wherein the launch time estimating means comprise means for providing, from the received radiation, information relating to a path of the ball while in flight, the launch time estimating means being adapted to determine the launch time from the path information and an estimate of the path at a point in time of launch.

84. An apparatus according to claim **79**, wherein the launch time estimating means comprise means for detecting sound and means for determining the point in time of launch by identifying a predetermined parameter in the detected sound.

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