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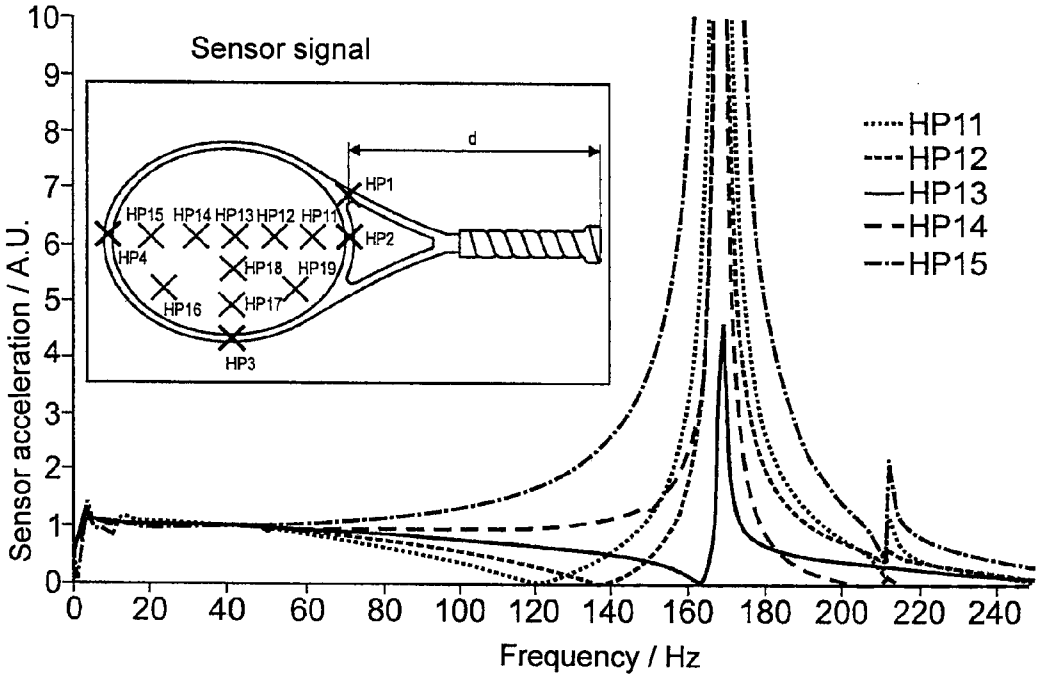
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(57) **ABSTRACT**

The present invention is directed to a process for determining at least one first coordinate of the point of contact of a ball on the strings of a ball game racquet, as well as a ball game racquet suitable for carrying out such a process.



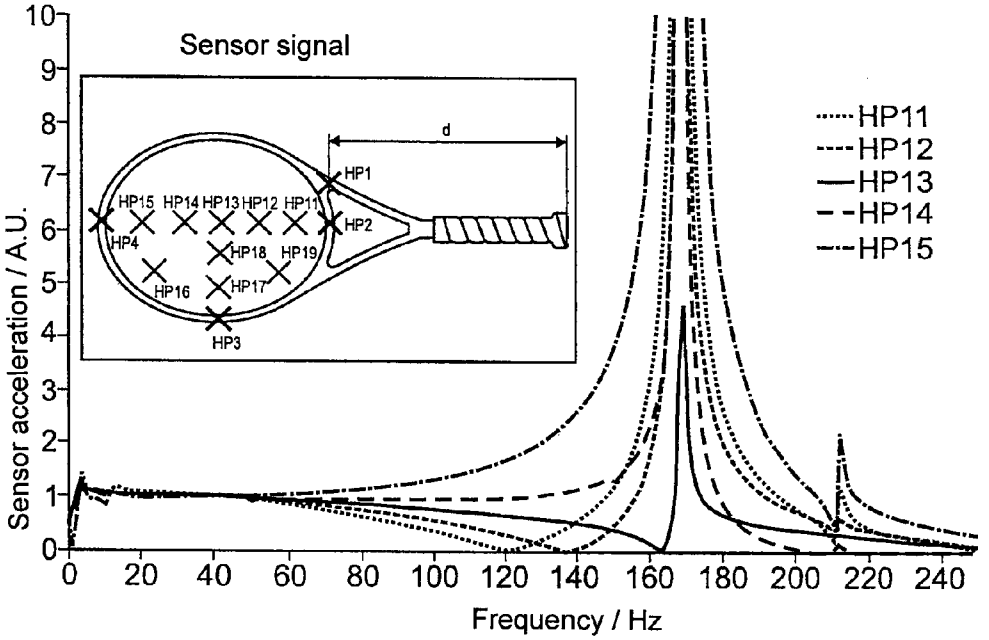

Sensor signal
Sensor acceleration / A.U.
Frequency / Hz
HP11
HP12
HP13
HP14
HP15
d
HP1
HP2
HP3
HP4
HP11
HP12
HP13
HP14
HP15
HP16
HP17
HP18
HP19

Fig. 1a

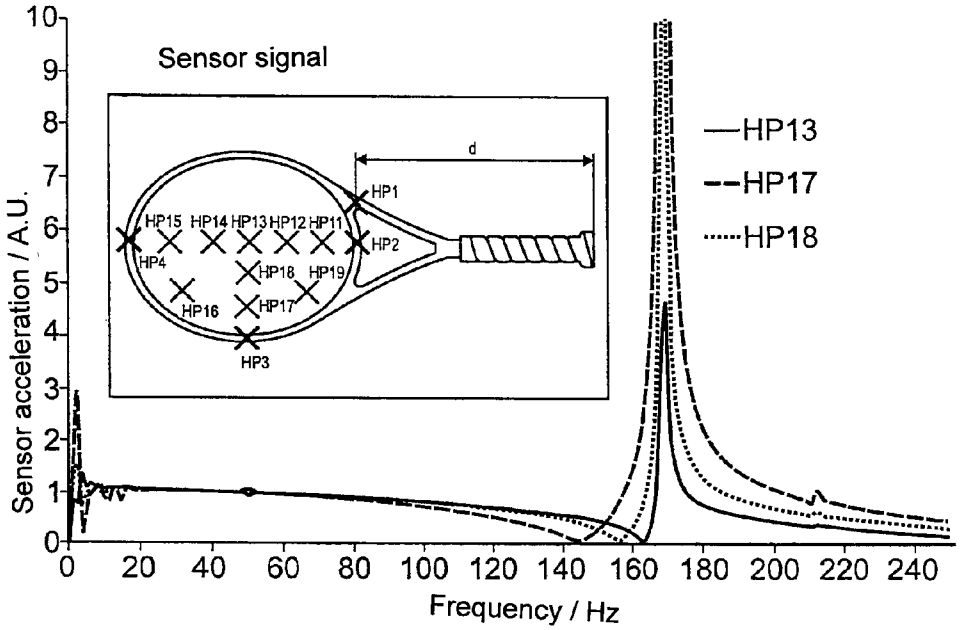

Sensor signal
Sensor acceleration / A.U.
Frequency / Hz
HP13
HP17
HP18
d
HP1
HP2
HP3
HP4
HP11
HP12
HP13
HP14
HP15
HP16
HP17
HP18
HP19

Fig. 1b

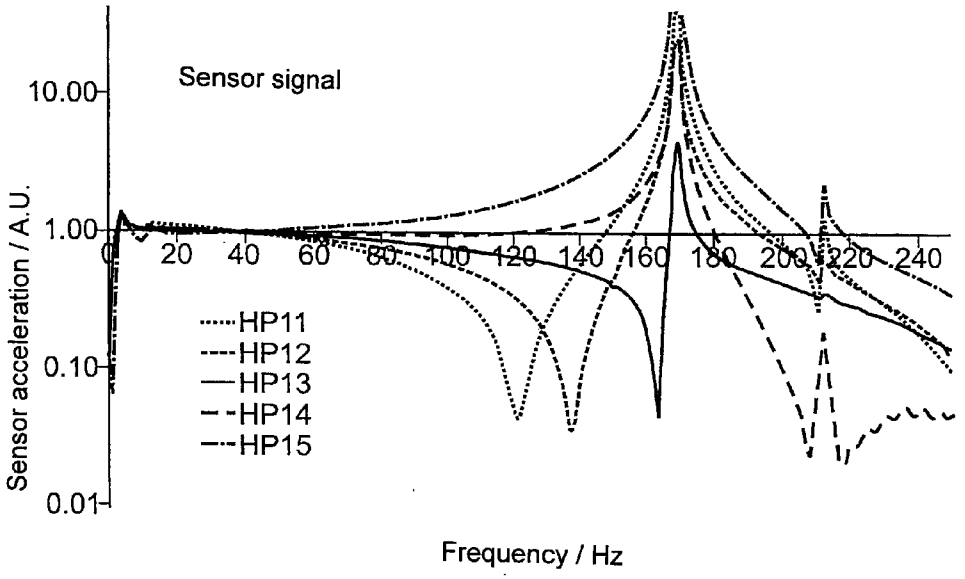

Sensor signal
10.00
1.00
0.10
0.01
Sensor acceleration / A.U.
0
20
40
60
80
100
120
140
160
180
200
220
240
HP11
HP12
HP13
HP14
HP15
Frequency / Hz

Fig. 1c

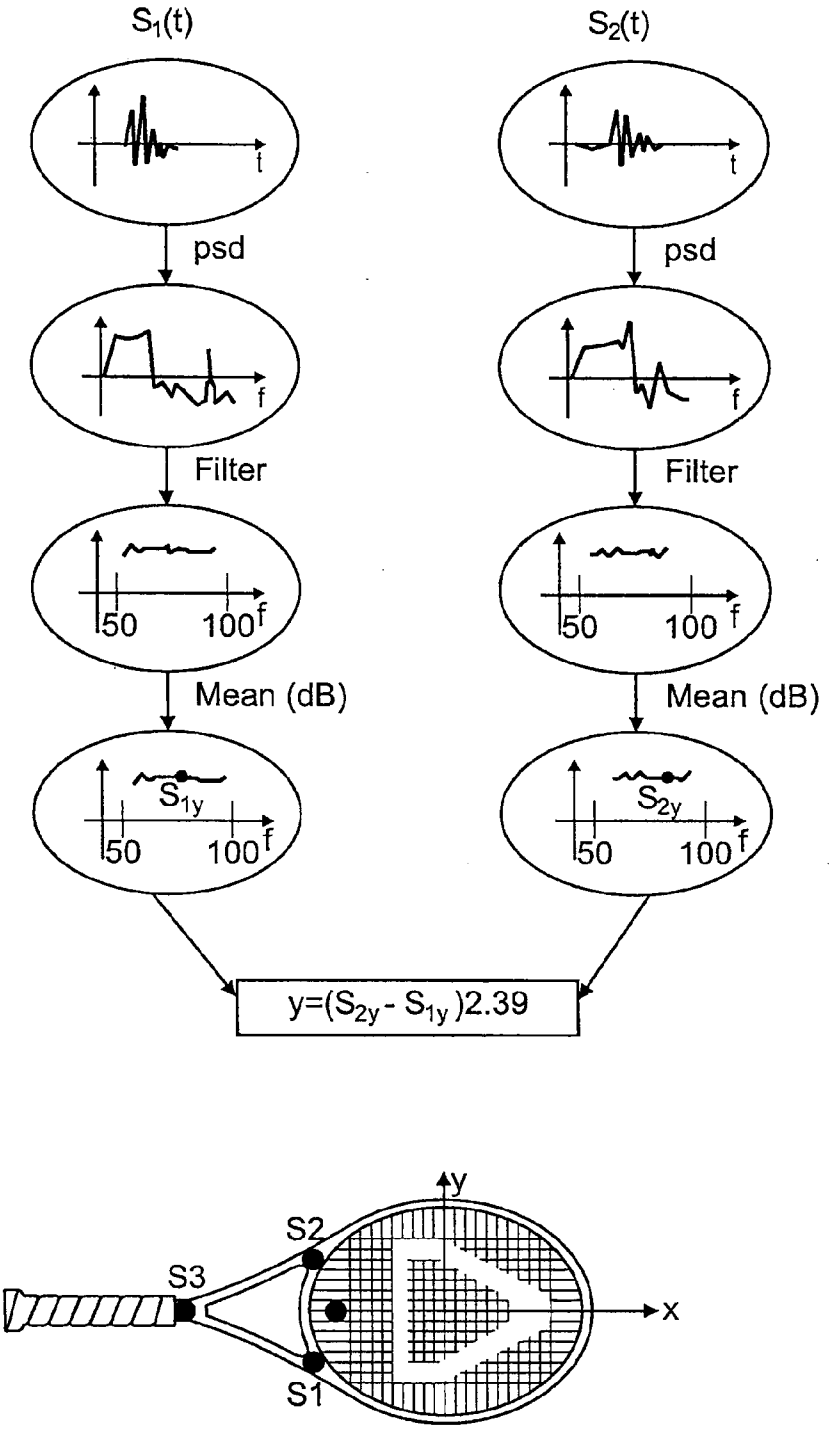

S1(t)
S2(t)
t
psd
f
Filter
50
100
Mean (dB)
S1y
S2y
y=(S2y - S1y)2.39
y
x
S2
S3
S1

Fig. 2

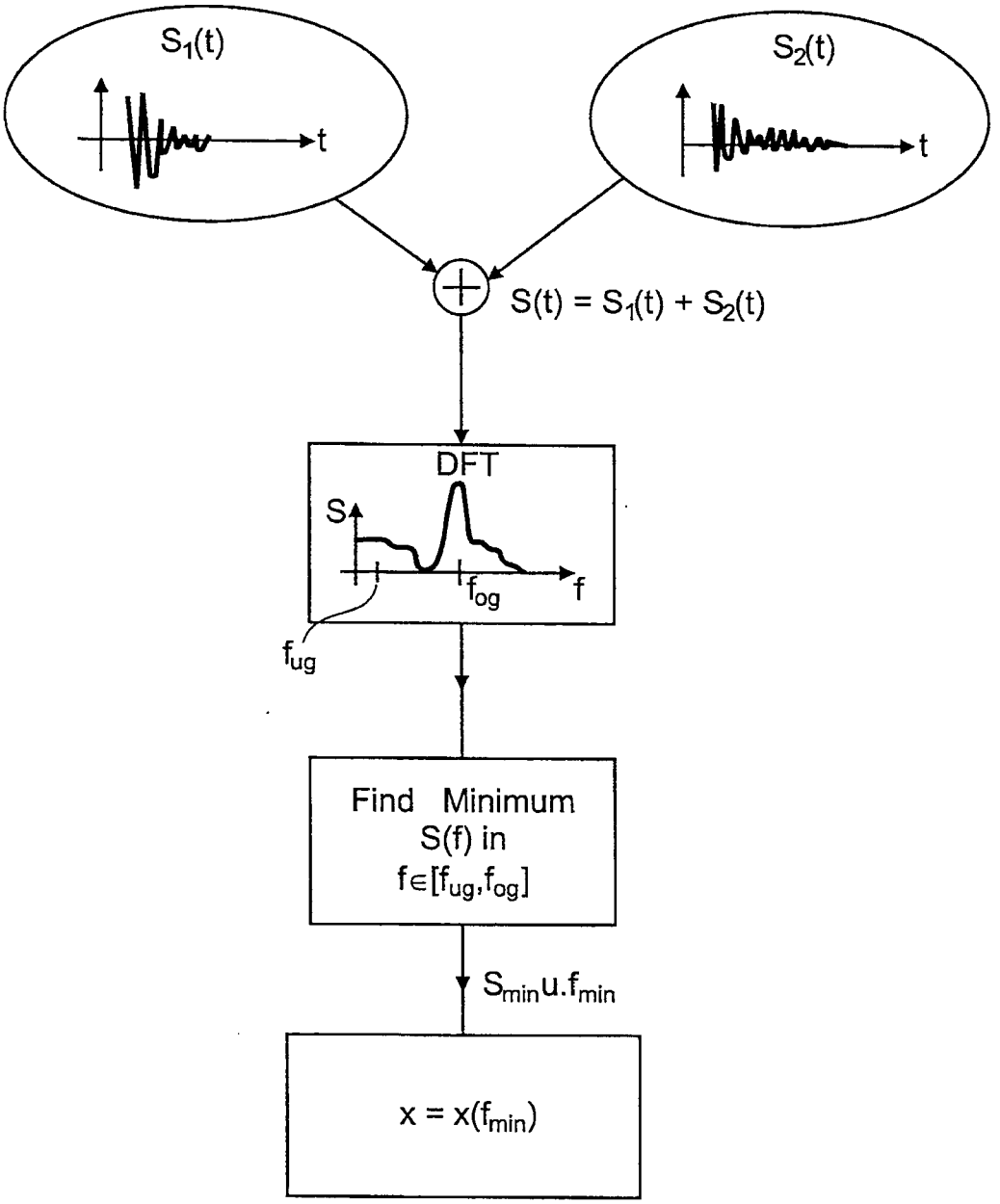

S1(t)
t
S2(t)
t
S(t) = S1(t) + S2(t)
DFT
S
fog
f
fug
Find Minimum
S(f) in
f∈[fug,fog]
Sminu.fmin
x = x(fmin)

Fig. 3

POINT OF CONTACT DETECTION

[0001] This application claims priority under 35 U.S.C. §119 to German Patent Application No. DE 10 2014 003 353.8, filed Mar. 7, 2014, the entirety of which is incorporated herein by reference.

[0002] The present invention is directed to a process for determining at least one coordinate of the point of contact or impact of a ball on the strings of a ball game racquet, as well as a ball game racquet suitable for carrying out such a process.

[0003] It has been known for a long time that the point of contact of a ball on the strings of a ball game racquet significantly influences the performance and efficiency of a player. If the so-called "sweet spot" of the racquet is hit, both the transmission of force from the racquet, or its strings, to the ball and the control of the flight direction of the ball are optimal. Therefore, attempts were made quite a while ago to provide practice racquets by means of which it was possible to determine or monitor whether the ball has hit that sweet spot. For example, DE 198 16 389 A1 describes a tennis racquet for practicing accuracy and improving the efficiency of the hit, which has an integrated sensor in its strings. This sensor emits a signal if, and only if, it is hit by the ball. If the ball makes contact next to the sensor, no signal is generated. DE 29 425 33 A1 also describes a tennis racquet with a hit signal generator which generates a hit signal if the tennis ball hits the central area of the strings. However, these tennis racquets have the disadvantage that the player merely receives a qualitative signal (hit the sweet spot or did not hit the sweet spot), without getting any information regarding the actual point of contact of the ball on the strings. U.S. Pat. No. 4,101,132 and U.S. Pat. No. 4,257,594 provide an improved tennis racquet in that several zones can be defined on the racquet and it can be determined by means of several sensors which of these zones were hit by the ball. However, this type of tennis racquet also only generates a discrete signal. Furthermore, due to the large number of sensors needed for the increasing number of zones, this tennis racquet becomes technically complex and thus expensive. Finally, EP 0 377 614 B1 describes a tennis racquet with a plurality of sensing means located at the periphery of its playing surface to detect shock waves traversing along the surface when the ball hits the strings. Then, a distinction is made between the points in time when the shock waves are initially detected by the individual sensing means. If the points in time fall within a predetermined reference time frame which corresponds to the sweet spot, a signal is emitted indicating that the sweet spot of the tennis racquet has been hit. However, as is immediately apparent, such a tennis racquet requires an extremely high time resolution if the point of contact of the ball is to be determined with high accuracy. Consequently, necessary sensor technology is technically sophisticated and therefore expensive.

[0004] It is therefore an object of the present invention to provide an improved process for determining at least one coordinate of the point of contact or impact of a ball on the strings of a ball game racquet which takes into account the disadvantages of the processes known in the prior art discussed above. It is furthermore an object of the present invention to provide a ball game racquet suitable for carrying out such a process. These objects are achieved by the process according to claims **1** and **2** and by a ball game racquet according to claims **15** and **18**. Preferred embodiments of the present invention are described in the dependent claims.

[0005] The present invention is directed, inter alia, to a process for determining at least one first coordinate of the point of contact or impact of a ball on the strings of a ball game racquet. The ball game racquet comprises a racquet head and a handle section, wherein the longitudinal axis defines an x-coordinate, the transverse axis defines a y-coordinate and the line perpendicular to the strings defines a z-coordinate. According to the present invention, at least one kinematic basic parameter or kinematic variable is measured in a first direction as a function of time at a first point or location of the ball game racquet, wherein the measurement rate is preferably at least 200 Hz. The at least first measured kinematic basic parameter or kinematic variable is then transformed into the frequency domain. The first coordinate of the point of contact of the ball on the strings of the ball game racquet is calculated on the basis of the transformed kinematic basic parameter in the frequency domain.

[0006] Furthermore, the present invention is directed to a process for determining a first and a second coordinate of the point of contact or impact of a ball on the strings of a ball game racquet. The ball game racquet comprises a racquet head and a handle section, wherein the longitudinal axis defines an x-coordinate, the transverse axis defines a y-coordinate and the line perpendicular to the strings defines a z-coordinate. According to this alternative preferred embodiment of the present invention, a first kinematic basic parameter or kinematic variable is measured in a first direction as a function of time at a first point or location of the ball game racquet and a second kinematic basic parameter or kinematic variable is measured in a second direction as a function of time at a second point or location of the ball game racquet. The measurement rate during measuring the first and/or second kinematic basic parameter is preferably at least 200 Hz. The measured first kinematic basic parameter and the measured second kinematic basic parameter are then transformed into the frequency domain. Alternatively or additionally, a linear combination of the measured first kinematic basic parameter and the measured second kinematic basic parameter can be transformed into the frequency domain. The first and/or second coordinate of the point of contact is calculated on the basis of the transformed kinematic basic parameter(s) in the frequency domain.

[0007] The transformation into the frequency domain can be carried out using known methods such as for example DFT, preferably FFT. The kinematic basic parameter or kinematic variable can be the speed, the acceleration, or another kinematic basic parameter or kinematic variable. Measurement is preferably carried out with an acceleration sensor and/or a gyrometer. Instead of the actually measured kinematic basis parameter, a value derived therefrom can also be transformed. For example, the speed can be measured, the acceleration can be derived from that value and then the acceleration can be transformed into the frequency domain and vice versa. The first and second coordinate of the point of contact refer to the coordinates within the plane of the strings. Preferably, the first and second coordinates are perpendicular to each other. It is especially preferred that the first and second coordinates be oriented towards the x- and the y-coordinate, respectively.

[0008] Preferably, the first direction is essentially identical to the second direction. It is especially preferred that the first and second directions be essentially parallel to the z-coordi-

nate. In other words, the speed or acceleration is preferably measured perpendicularly to the strings or stringing plane of the ball game racquet.

[0009] The first point of the ball game racquet can be identical to the second point of the ball game racquet. For example, the first kinematic basic parameter and the second kinematic basic parameter can be measured with one and the same sensor. However, preferably, the first point is different from the second point. It is especially preferred that at least one of the two points be located off to the side in relation to the longitudinal axis of the ball game racquet.

[0010] Preferably, the calculation of the first and/or second coordinate of the point of contact on the basis of the transformed kinematic basic parameter(s) in the frequency domain comprises the following steps: Determining a characteristic frequency interval, determining at least one characteristic value of the first and/or second kinematic basic parameter with respect to the characteristic frequency interval and calculating the first and/or second coordinate of the point of contact on the basis of the at least one characteristic value. The characteristic frequency interval is preferably determined or specified in advance. The lower limit of the characteristic frequency interval is preferably between 0 Hz and 100 Hz, more preferred between 10 Hz and 80 Hz and especially preferred between 25 Hz and 75 Hz. The upper limit of the characteristic frequency interval is preferably between 50 Hz and 500 Hz, more preferred between 75 Hz and 400 Hz and especially preferred between 100 Hz and 300 Hz. According to this preferred embodiment of the process according to the invention, the point of contact is determined on the basis of relatively small frequencies. Consequently, the process of the present invention does not require a high-resolution measurement in terms of time of the kinematic basic parameters. This allows the use of relatively simple standard sensors which are therefore reasonably priced.

[0011] The characteristic value can preferably be one or a combination of the following values: local or absolute minimum of the first and/or second kinematic basic parameter in the characteristic frequency interval, local or absolute maximum of the first and/or second kinematic basic parameter in the characteristic frequency interval, mean value of the first and/or second kinematic basic parameter in the characteristic frequency interval, mean value of the first and/or second kinematic basic parameter in a subinterval of the characteristic frequency interval. According to the present invention, it has been found that the point of contact of the ball on the strings of the ball game racquet leaves a characteristic signature in the frequency domain of the respective kinematic basic parameter. Since this signature can have different effects, the present invention is not limited to certain characteristic values. Rather, depending on the arrangement of the sensors and the vibration properties of the ball game racquet, different characteristic values can be defined which directly correlate with the point of contact of the ball. Essentially, the present invention is based, inter alia, on the basic idea that the frequency spectrum correlates with the point of contact of the ball on the strings of the ball game racquet in different but specific ways. This correlation can be found for every ball game racquet by means of corresponding experiments. Once such a correlation is known, the first and/or second coordinate of the point of contact can be calculated by means of an analysis of the spectrum in the frequency domain or a determination of a certain characteristic value of the kinematic basic parameter in the frequency domain. This can for example be done by means of a table wherein certain points of contact of the ball are assigned to certain characteristic values. However, the first and/or second coordinate is preferably a function of one or more characteristic values.

[0012] According to a preferred embodiment, the first coordinate is the x-coordinate, the first direction is essentially parallel to the z-coordinate and the first point or location is provided at the handle section. According to another preferred embodiment, the first coordinate is the y-coordinate, the first direction is essentially parallel to the z-coordinate and the first point is provided at the racquet head. According to another preferred embodiment, the first coordinate is the x-coordinate, the second coordinate is the y-coordinate and the first and second directions are essentially parallel to the z-coordinate. Preferably, the first point is provided at the racquet head or the handle section and the second point is provided at the racquet head.

[0013] The present invention is furthermore directed to a ball game racquet with at least one first sensor for measuring at least one first kinematic basic parameter or kinematic variable and a processing unit, wherein the first sensor and the processing unit are suitable for carrying out the process as described above. Preferably, the ball game racquet furthermore comprises a second sensor for measuring at least one second kinematic basic parameter. It is especially preferred that the first sensor be provided in or at the racquet head or handle section and that the second sensor be provided in or at the racquet head.

[0014] The present invention is furthermore directed to a ball game racquet comprising a racquet head accommodating strings, a handle section, an acceleration sensor and a processing unit suitable for calculating a coordinate of the point of contact of a ball on the strings based on the acceleration in a first direction measured by the acceleration sensor. Preferably, the acceleration sensor is provided in or at the handle section. Preferably, the first direction runs along the longitudinal axis of the racquet. Preferably, the ball game racquet comprises a second acceleration sensor, wherein the processing unit is suitable for calculating two coordinates of the point of contact of a ball on the strings of the racquet based on the acceleration in the directions measured by the two acceleration sensors, respectively.

[0015] Preferably, the processing unit is suitable for calculating two coordinates of the point of contact of a ball on the strings of the racquet based on the acceleration in a first direction measured by the acceleration sensor.

[0016] Preferably, the ball game racquet furthermore comprises a gyrometer wherein the processing unit is suitable for calculating a second coordinate of the point of contact of a ball on the strings of the racquet based on the acceleration measured by the gyrometer. The gyrometer is preferably provided in or at the handle section.

[0017] In the following, preferred embodiments of the present invention are described in more detail with reference to the drawings.

[0018] FIGS. **1***a-c* show the measuring result of an experiment;

[0019] FIG. **2** shows a flowchart of an exemplary algorithm for determining the y-coordinate; and

[0020] FIG. **3** shows a flowchart of an exemplary algorithm for determining the x-coordinate.

[0021] FIGS. **1***a* to **1***c* show the result of an experiment which will be used to illustrate the basic idea of the present invention. In the drawing of FIGS. **1***a* and **1***b*, a schematic of

a tennis racquet is shown (for this particular experiment, the model "Extreme MP" from the company Head was used) which has two sensors provided in the racquet head whose positions are schematically indicated by an "x" and the designation HP**1** and HP**2**. The sensors are acceleration sensors of the type "Bruel & Kjoer 4501". The strings of the tennis racquet were hit with a hammer at defined points whereby the force is irrelevant since it can be normalized. The points of contact (hitting points) of the hammer HP**11** to HP**19** are marked with an "x" in the inserted sketch in FIGS. **1***a* and **1***b*. During the impact and immediately after, the acceleration was measured by the sensors at the positions HP**1** and HP**2**, respectively. The Fourier transformed signal of the sensor at the position HP**1** is shown as a function of the frequency for the points of contact or impact HP**11** to HP**15** in FIG. **1***a*. For the points of contact or impact HP**13**, HP**17** and HP**18**, the corresponding signal is shown in FIG. **1***b*. As can clearly be seen, the shapes of the various curves significantly differ from each other depending on the point of contact or impact. For example, all the curves show a minimum which occurs at distinctly different frequencies depending on the respective points of contact. In the case of a logarithmic scale, as shown for the curves of FIG. **1***a* in FIG. **1***c*, these minimum values are even more pronounced and it can clearly be seen how the minimum shifts toward higher frequencies as the distance d of the point of contact or impact to the racquet handle increases.

[0022] The idea of the present invention is based on creating a correlation between the specific curve shape in the frequency domain and the actual point of contact of the ball on the strings. Once such a correlation has been empirically established, the point of contact of the ball can easily be determined by measuring the acceleration and transforming the measured signal into the frequency domain. As is apparent from the example of FIG. **1**, fundamentally different characteristic values can be defined for this purpose, on the basis of which the assignment can then be carried out. Thus, the curves in FIG. **1** not only differ in the position of their minimum values but also for example in a differently pronounced maximum or different amplitudes for example at 120 Hz. It is therefore emphasized that the examples of specific algorithms for determining the x- and/or y-coordinates of the point of contact described below merely represent preferred embodiments and should not be regarded as limiting the present invention in any way. Rather, other characteristics of the various curves can be determined in the frequency domain, by means of which conclusions can be drawn as to the position of the point of contact.

[0023] FIGS. **2** and **3** show a specific embodiment of a process according to the present invention for determining an x-coordinate and a y-coordinate. The inserted sketch in FIG. **2** shows a schematic ball game racquet with a definition of the x- and y-coordinates whereby the origin of the coordinate system is formed by the center of the strung area. At one or more of the positions S_1, S_2 and S_3, an acceleration sensor can be provided. However, the acceleration sensor S_3 is not necessary for this particular example. Only the acceleration sensors S_1 and S_2 are required which are preferably provided at the two arms or at the transition between arm and bridge. Preferably, the acceleration sensors S_1 and S_2 measure the acceleration over a time period of preferably 2 s with a measuring rate of preferably 10,000 s^{-1} along the z-direction, i.e. perpendicular to the x- and y-coordinate. The measured signal of the acceleration as a function of time of the two sensors S_1 and S_2 is schematically represented as $S_1(t)$ and $S_2(t)$, respectively, in FIGS. **2** and **3**. FIG. **2** shows a preferred flowchart for the determination of the y-coordinate, while FIG. **3** shows a preferred flowchart for the determination of the x-coordinate.

[0024] For the determination of the y-coordinate shown as an example in FIG. **2**, first the power spectral density (psd) of the measured signals $S_1(t)$ and $S_2(t)$ is calculated. In other words, a transformation of the measured kinematic basic parameter into the frequency domain is carried out. For this purpose, a discrete Fourier transform such as for example FFT (fast Fourier transform) can be used. The transformed signal is subsequently filtered. The filtering can be carried out using known methods such as for example a digital band pass filter (e.g. a third order Butterworth filter). Then a characteristic value of the transformed signal is calculated based on a characteristic frequency interval. In the example shown in the drawing, the characteristic frequency interval is [50 Hz, 100 Hz] and the characteristic value is the mean value of the transformed function in this frequency interval. If the thus determined mean values of sensors S_1 and S_2 are designated S_{1y} and S_{2y}, respectively, the y-coordinate of the point of contact can be determined using the following formula, wherein the values of S_{1y} and S_{2y} are to be entered with the unit m/s^2 and the result indicates the y-coordinate in cm:

$$y=(S_{2y}-S_{1y})2.39$$

[0025] This formula was calculated heuristically for a certain tennis racquet. For a different type of racquet, the various numerical values of the above formula can differ significantly from the example discussed herein. Furthermore, for a different type of racquet, it can be advantageous to determine a different characteristic frequency interval and/or a different characteristic value. FIG. **3** shows the corresponding algorithm for the exemplary determination of the x-coordinate in a flowchart. In this example, the two measured signals $S_1(t)$ and $S_2(t)$ of sensors S_1 and S_2 are first added and the resulting signal S(t) is converted to a power spectral density S(f) using for example a discrete Fourier transform (DFT). Then, an upper limit frequency f_{og} and a lower limit frequency f_{ug} of the characteristic frequency interval $[f_{ug}, f_{og}]$ are determined. Preferably, the interval is [10 Hz, 200 Hz]. On the basis of this characteristic frequency interval, the minimum of S(f) and the associated frequency f_{min} are then calculated. The x-coordinate is then a function of the associated minimal frequency f_{min}: $x=x(f_{min})$. In a preferred embodiment, the x-coordinate of the point of contact can be determined using the following formula, wherein the frequency values are to be entered with the unit Hz and the result indicates the x-coordinate in cm:

$$x=(f_{min}-150)/5.7, \text{ if } f_{min}<170$$

$$x=(f_{min}-210)/10, \text{ if } f_{min}>170$$

[0026] Alternatively, the x-coordinate can also be a function of the minimal frequency and of the two frequencies of the characteristic frequency interval:

$$x=x(f_{min}f_{ug}f_{og})$$

[0027] As has already been mentioned repeatedly, these two embodiments are specific examples which should by no means be regarded as limiting the invention. Rather, using this example, it is merely demonstrated that it is possible to find a precise algorithm which assigns a coordinate of the point of contact to a kinematic basic parameter in the fre-

quency domain. However, this algorithm can basically be modified in many ways and adapted empirically to specific racquet geometries.

1. Process for determining at least one first coordinate of the point of contact of a ball on the strings of a ball game racquet with a racquet head and a handle section, wherein the longitudinal axis of the ball game racquet defines an x-coordinate, the transverse axis of the ball game racquet defines a y-coordinate and the line perpendicular to the strings defines a z-coordinate, comprising the following steps:

a) measuring at least one kinematic basic parameter in a first direction as a function of time at a first point of the ball game racquet, preferably with a measurement rate of at least 200 Hz;

b) transforming the measured kinematic basic parameter into the frequency domain; and

c) calculating the first coordinate of the point of contact on the basis of the transformed kinematic basic parameter in the frequency domain.

2. Process for determining a first and a second coordinate of the point of contact of a ball on the strings of a ball game racquet with a racquet head and a handle section, wherein the longitudinal axis of the ball game racquet defines an x-coordinate, the transverse axis of the ball game racquet defines a y-coordinate and the line perpendicular to the strings defines a z-coordinate, comprising the following steps:

a) measuring a first kinematic basic parameter in a first direction as a function of time at a first point of the ball game racquet, preferably with a measurement rate of at least 200 Hz;

b) measuring a second kinematic basic parameter in a second direction as a function of time at a second point of the ball game racquet, preferably with a measurement rate of at least 200 Hz;

c) transforming the measured first kinematic basic parameter and the measured second kinematic basic parameter and/or a linear combination of the measured first and second basic parameter into the frequency domain; and

d) calculating the first and second coordinates of the point of contact on the basis of the transformed kinematic basic parameter(s) in the frequency domain.

3. Process according to claim **2**, wherein the first direction is essentially identical to the second direction.

4. Process according to claim **2**, wherein the first point is different from the second point.

5. Process according to claim **1**, wherein the determination of the first and/or second coordinate of the point of contact on the basis of the transformed kinematic basic parameter(s) in the frequency domain comprises:

a) determining a characteristic frequency interval;

b) determining at least one characteristic value of the first and/or second kinematic basic parameter with respect to the characteristic frequency interval; and

c) calculating the first and/or second coordinate of the point of contact on the basis of the at least one characteristic value.

6. Process according to claim **5**, wherein the lower limit of the characteristic frequency interval is between 0 Hz and 100 Hz, preferably between 10 Hz and 80 Hz and especially preferred between 25 Hz and 75 Hz.

7. Process according to claim **5**, wherein the upper limit of the characteristic frequency interval is between 50 Hz and 500 Hz, preferably between 75 Hz and 400 Hz and especially preferred between 100 Hz and 300 Hz.

8. Process according to claim **5**, wherein the characteristic value comprises one or a combination of the following values: local or absolute minimum of the first and/or second kinematic basic parameter in the characteristic frequency interval, local or absolute maximum of the first and/or second kinematic basic parameter in the characteristic frequency interval, mean value of the first and/or second kinematic basic parameter in the characteristic frequency interval, mean value of the first and/or second kinematic basic parameter in a subinterval of the characteristic frequency interval.

9. Process according claim **5**, wherein the first and/or second coordinate is a function of the characteristic value.

10. Process according to claim **1**, wherein the first coordinate is the x-coordinate, the first direction is essentially parallel to the z-coordinate and the first point is provided at the handle section.

11. Process according to claim **1**, wherein the first coordinate is the y-coordinate, the first direction is essentially parallel to the z-coordinate and the first point is provided at the racquet head.

12. Process according to claim **1**, wherein the first coordinate is the x-coordinate, the second coordinate is the y-coordinate and the first and second directions are essentially parallel to the z-coordinate.

13. Process according to claim **12**, wherein the first point is provided at the racquet head or at the handle section and the second point is provided at the racquet head.

14. Process according to claim **1**, wherein the first and/or second kinematic basic parameter is acceleration.

15. Ball game racquet comprising a racquet head, a handle section, at least one first sensor for measuring at least one first kinematic basic parameter and a processing unit, wherein the first sensor and the processing unit are suitable for carrying out the process according to claim **1**.

16. Ball game racquet according to claim **15**, furthermore comprising a second sensor for measuring at least one second kinematic basic parameter.

17. Ball game racquet according to claim **15**, wherein the first sensor is provided in or at the racquet head or handle section and wherein the second sensor is provided in or at the racquet head.

18. Ball game racquet comprising a racquet head accommodating strings, a handle section, an acceleration sensor and a processing unit suitable for calculating a coordinate of the point of contact of a ball on the strings of the racquet based on the acceleration in a first direction measured by the acceleration sensor.

19. Ball game racquet according to claim **18**, wherein the acceleration sensor is provided in or at the handle section.

20. Ball game racquet according to claim **18**, wherein the first direction runs along the longitudinal axis of the racquet.

21. Ball game racquet according to claim **18**, furthermore comprising a second acceleration sensor, wherein the processing unit is suitable for calculating two coordinates of the point of contact of a ball on the strings of the racquet based on the acceleration in two directions measured by the two acceleration sensors, respectively.

22. Ball game racquet according to claim **18**, wherein the processing unit is suitable for calculating two coordinates of the point of contact of a ball on the strings of the racquet based on the acceleration in a first direction measured by the acceleration sensor.

23. Ball game racquet according to claim **18**, furthermore comprising a gyro sensor wherein the processing unit is suit-

able for calculating a second coordinate of the point of contact of a ball on the strings of the racquet based on the acceleration measured by the gyro sensor.

24. Ball game racquet according to claim **23**, wherein the gyro sensor is provided in or at the handle section.

25. Process according to claim **2**, wherein the determination of the first and/or second coordinate of the point of contact on the basis of the transformed kinematic basic parameter(s) in the frequency domain comprises:

a) determining a characteristic frequency interval;

b) determining at least one characteristic value of the first and/or second kinematic basic parameter with respect to the characteristic frequency interval; and

c) calculating the first and/or second coordinate of the point of contact on the basis of the at least one characteristic value.

26. Process according to claim **2**, wherein the first coordinate is the x-coordinate, the first direction is essentially parallel to the z-coordinate and the first point is provided at the handle section.

27. Process according to claim **2**, wherein the first coordinate is the y-coordinate, the first direction is essentially parallel to the z-coordinate and the first point is provided at the racquet head.

28. Process according to claim **2**, wherein the first coordinate is the x-coordinate, the second coordinate is the y-coordinate and the first and second directions are essentially parallel to the z-coordinate.

29. Process according to claim **2**, wherein the first and/or second kinematic basic parameter is acceleration.

* * * * *