(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 April 2020 (30.04.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/086909 A1

(51) International Patent Classification:
A63B 24/00 (2006.01) *G01H 11/00* (2006.01)
A63B 60/46 (2014.01) *A63B 71/06* (2006.01)

(21) International Application Number:
PCT/US2019/057957

(22) International Filing Date:
24 October 2019 (24.10.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/750,214 24 October 2018 (24.10.2018) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) **Title:** SYSTEM AND METHOD FOR DETERMINING SCALAR VALUES FROM MEASUREMENTS AND TELEMETRY RELATED TO A STRUCTURE SUBJECTED TO MOTION AND FORCE

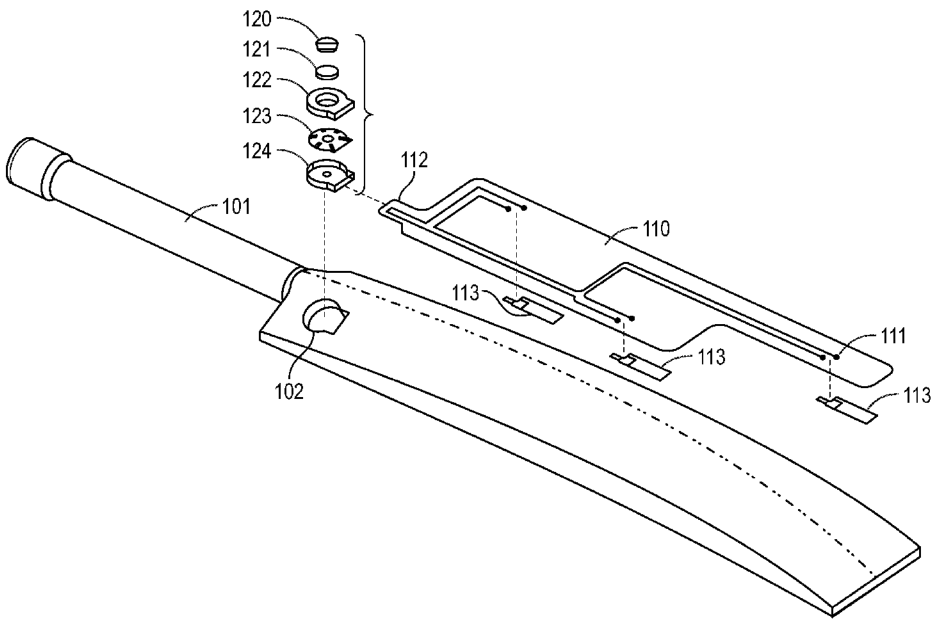

FIG. 1A

(57) **Abstract:** This system and method can transmute complex measurements of structural phenomena into simple, human understandable scalars, which, in turn, can be used in informatics such as infographics. The system and method are particularly suited to, though not limited to, summarizing common phenomena in bat-and-ball sports such as baseball, cricket, golf, hockey and tennis. A set of metrics can comparatively summarize player performance and how to efficiently compute them from high frequency vibration data collected from sports equipment. Computational parameters can be manipulated in order to produce ideal metrics which account for human bias and the desire for familiar info-metric scales (such as a scale from 1 to 100).

WO 2020/086909 A1

[Continued on next page]

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

SYSTEM AND METHOD FOR DETERMINING SCALAR VALUES FROM MEASUREMENTS AND TELEMETRY RELATED TO A STRUCTURE SUBJECTED TO MOTION AND FORCE

FIELD OF THE INVENTION

This invention relates to motion-sensing devices that deliver data for use in analyzing such motion and forces associated therewith, and more particularly to various systems and methods for processing such data.

BACKGROUND OF THE INVENTION

Several useful deductions can be made from observing the vibrations present in a structure post an impact event involving that structure. For instance, information regarding the structural properties, the clamping force, the force of the impact, the amount of energy impacted on the structure, the state of the structure and so forth are examples of information that can be deducted from the vibration signals in the structure.

In bat-and-ball sports, the skill of the player and the effectiveness of a hit can be correlated to how ideally the player placed the point of impact on the bat. Other factors, such as grip, speed and orientation of the bat at the time of impact, can contribute to the overall assessment of player performance as well. The degree to which such factors can be calculated quickly and consistently and can be summarized concisely, contributes to their value in televised sports, coaching and player self-improvement.

Broadcasters of televised sports rely on advertising revenue for their business. Any on-screen infographics which provide additional viewer enjoyment or understanding of the game are an opportunity to improve audience engagement and increase advertising revenue. Simple to represent metrics which can be shown during live play and immediately after such as in replays are particularly valuable to broadcasters and advertisers, as live play is the time of maximum viewership.

Any consistent metrics which can be issued in real time about player performance during practice or game play are valuable to both coaches and players alike. Whether scouting new talent or focusing on a particular player's competitiveness, concise, comparable and understandable metrics are desirable.

Manufacturers of sporting equipment are constantly seeking to include features that give them a market advantage and give customers motivation to select their product. Providing intelligent sports equipment that can quickly summarize or compare player performance is just such a feature.

To date, there has been no practical means for producing simple, concise and consistent metrics that summarize player performance in bat-ball and other sports. For instance, video tracking is too complex, expensive and cumbersome to be used in any practical way by coaches, teams and individual players. Further, no consistent set of metrics has been established from such techniques.

A system and method is therefore desired by which practical implementations can be constructed in order to produce consistent and concise summary metrics of player performance in bat-ball sports. A further desire is that the system and method be computationally efficient such that these metrics can be calculated quickly on relatively low-power computational devices, appropriate for smart sports equipment and that these metrics can be relayed quickly to broadcasters during live matches or to coaches and players as they practice and play.

SUMMARY OF THE INVENTION

The system and method described herein overcome disadvantages of the prior art by transmuting complex measurements of structural phenomena into simple, human understandable scalars, which, in turn, can be used in informatics such as infographics, as well as practical feedback for coaches, teams, and players. The system and method are particularly suited to, though not limited to, summarizing common phenomena in bat-and-ball sports such as baseball, cricket, golf, hockey and tennis. Moreover, this disclosure describes a set of metrics which can comparatively summarize player performance and how to efficiently compute them from high frequency vibration data collected from sports equipment. The invention further describes how to manipulate computational parameters in order to produce ideal metrics which can account for human bias and the desire for familiar info-metric scales (such as a scale from 1 to 100).

In an illustrative embodiment, the system and method concisely summarizes player performance in (e.g.) bat-ball sports through data received from an acquisition device that measures motion on a piece of sporting equipment with two unit-less metrics. The system and method, thus, provides a first metric based upon quality, and a second metric based upon power. Illustratively, the quality metric can be computed using a polynomial which combines a ratio of high-frequency vibrational energy to low-pass vibrational energy measured in the piece of sporting equipment with a scale factor ratio of low-pass vibrational energy to low-pass vibrational peak amplitude. The high-frequency vibrational energy can be computed by integrating band-pass filtered measured vibrational energy over time and the low-frequency vibrational energy is computed by integrating low-pass filtered measured vibrational energy over time. Each of the ratios of the quality metric can be tuned with a corresponding set of adjustable coefficients and the quality metric can be offset by a bias in order to produce a desired range of outputs. The power metric can be computed from a square of a measured tip velocity of the piece of sporting equipment at a time of impact with another object. The power metric can be scaled by a polynomial involving the quality metric and a tunable coefficient.

In an exemplary embodiment, a method for concisely summarizing player performance in bat-ball sports through data received from an acquisition device that measures motion on a piece of sporting equipment can include providing a unit-less first quality metric indicating hit quality, and providing a unit-less second power metric indicating hit power. In various embodiments, the method can include computing the quality metric using a polynomial which combines a ratio of energies present within different frequency ranges, for instance a ratio between low-frequency and high frequency energies, vibrationally measured in the piece of sporting equipment and normalized for amplitude. The method can determine these energy ratios through a number of processes including but not limited to relative peak-to-peak calculation and signal area integration. The method further can include tuning each of the ratios of the quality metric with a corresponding set of adjustable coefficients and offsetting the quality metric by a bias in order to produce a desired range of outputs. The method can include computing the power metric from a square of a measured tip velocity of the piece of sporting equipment at a time of impact with another object. The method can include scaling the power metric by a polynomial involving the quality metric and a tunable coefficient.

In an exemplary embodiment, a method for concisely summarizing player performance in bat-ball sports can include collecting vibration signals induced in a sporting equipment by an impact event, applying signal processing to the signals, calculating metrics from the processed signals, and discriminating, using the calculated metrics, between signals correlating to a predetermined performance metric score from signals correlating to a different performance metric score. In various embodiments, the applying signal processing can include low-pass and band-pass filtering and integration of the selective filters to obtain a first set of differentiating metrics. The method can include dividing the differentiating metrics by the peak amplitude of the signal in order to provide a second set of differentiating metrics. The method can include combining the first and second sets of differentiating metrics in a polynomial equation where the differentiating metrics are multiplied and added to constants in order to generate a differentiating score.

In an exemplary embodiment, a method for of concisely summarizing player performance in bat-ball sports via a first computed unit-less metric can include acquiring a vibration signal induced in a sporting equipment in response to an impact event, processing the acquired signal to generate a first scalar and a second scalar, applying the first and second scalar to a polynomial, and outputting from the polynomial a unit-less vibration scalar. In various embodiments, the method can include labeling the unit-less vibration scalar a quality metric. In various embodiments, the method can include labeling the unit-less vibration scalar a sweetness metric or “smash-factor” metric. Acquiring the vibration signal can be acquiring a vibration signal from a bat-ball contact. The method can include computing a unit-less motion scalar, and computing a unit-less motion scalar can include acquiring a motion signal induced in a sporting equipment by an impact event, time-synchronizing the acquired motion signal with the acquired vibration signal, processing the acquired motion signal to generate a generated scalar, applying the generated scalar and the vibration scalar and motion scalar from to a polynomial, and outputting from the polynomial a unit-less metric. The method can include labeling the unit-less motion scalar a power metric.

In an exemplary embodiment, a system for sensing data and using the sensed data to generate one or more scalars to provide information about batting performance can include one or more dynamic strain sensor or vibration sensor, a data capturing module, a data storing module, a data manipulator module, a data analyzer module, a data transmission determination module, and a wireless transmitter. The system can include at least one motion sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention description below refers to the accompanying drawings, of which:

Fig. 1A is an exploded perspective view of an exemplary sensing system on a cricket bat, according to an illustrative embodiment;

Fig. 1B is a cut-away view of sports equipment with an integrated sensing system, showing the inner layers that make up the integrated sensing system, according to an illustrative embodiment;

Fig. 1C is a schematic diagram of a sensing system architecture for detecting high-frequency vibrations on cricket bats, according to an illustrative embodiment;

Fig. 1D is a schematic diagram of an exemplary processor for use in a sensing system, according to an illustrative embodiment;

Fig. 1E is a chart showing voltage from a piezoelectric sensor indicating vibrations over time for a poorly placed shot, according to an illustrative embodiment;

Fig. 1F is a chart showing voltage from a piezoelectric sensor indicating vibrations over time for a shot in the sweet spot, according to an illustrative embodiment;

Fig. 2A is a chart showing the effect of applying a low-pass filter and a band-pass filter with different cut-off frequencies to a poorly-placed shot, according to an illustrative embodiment;

Fig. 2B is a chart showing the effect of applying a low-pass filter and a band-pass filter with different cut-off frequencies to a well-placed shot, according to an illustrative embodiment;

Fig. 3 is a chart showing an example of how the integral of a lowpass filter is distributed over an exemplary cricket bat, according to an illustrative embodiment;

Fig. 4 is a chart showing an example of how the integral of a normalized lowpass filter is distributed over an exemplary cricket bat, according to an illustrative embodiment;

Fig. 5 is a chart showing an example of how the integral of a bandpass filter distributed over an exemplary cricket bat, according to an illustrative embodiment;

Fig. 6 is a chart showing an example of how the integral of a normalized bandpass filter distributed over an exemplary cricket bat, according to an illustrative embodiment;

Fig. 7 is a chart showing an example of the distribution of a relative quality calculated by utilizing a set of parameters over an exemplary cricket bat, according to an illustrative embodiment;

Fig. 8 is a chart showing an example of the distribution of a relative quality calculated by utilizing a set of parameters over an different exemplary cricket bat from the bat in Fig. 7, according to an illustrative embodiment; and

Fig. 9 is a chart showing an example of the distribution of a relative quality over a cricket bat, calculated by utilizing a slightly different set of parameters from those shown in Fig. 7, according to an illustrative embodiment.

DETAILED DESCRIPTION

I. Related Hardware Devices and Processes

Vibration sensors can be incorporated into bats and other sporting equipment. These sensors can be highly-sensitive, high-frequency, soft-polymer vibration sensors and can be incorporated into stickers with logos or other artwork. These stickers can appear like stickers currently utilized in equipment so as to make the sensors unobtrusive. U.S. Published Patent Application Serial No. 15/608,965, entitled SYSTEM AND METHOD FOR SENSING HIGH-FREQUENCY VIBRATIONS ON SPORTING EQUIPMENT, filed 5/30/2017, which is herein incorporated by reference in its entirety, describes a system and method of sensors incorporated into various equipment, including sporting equipment. The principles of the system and method described herein can operate within the illustrative platform, which can include sensors incorporated into the sticker of a bat.

The system described herein can provide low-power electronics with the ability to capture and analyze specific signals of concern. The low power electronics can be utilized to increase the operational lifetime of the system and decrease the number of recharge or battery changes per match. High-frequency vibration data can be captured and stored locally on the equipment where user-defined code can analyze data and pick specific parameters of concern to send via a wireless communications link to a receiver. The receiver can capture the data and re-construct events of interest. This architecture can reduce the power and bandwidth requirements of the device while maintaining functionality and the ability to transmit and report parameters and incidents of interest.

The sticker can include piezo electric materials, which can be piezoelectric polymers. The sampling rate of the sensor arrangement can be up to and higher than 2 kHz. Contact can be made with the piezoelectric material via conductive traces in the sticker. The conductive traces can be printed as part of the sticker, and in various embodiments can be copper on polyamide.

Illustratively, an exemplary method for measuring vibrations in sporting equipment that utilizes the sensor arrangement can include the steps of integrating the sensor arrangement into the decorative coating of the equipment, and moving the sporting equipment to generate sensor data that is transmitted to an analyzing device. Illustratively, the sticker, and any associated electronic component, can include a wireless transmitting capability, and data can be transmitted exclusively in response to a predetermined event. The predetermined event can be determined by a preset threshold. The signal of the sensor arrangement can be monitored in a low-power mode until the predetermined event occurs, and high-frequency data can be acquired for a predetermined period in response to the event occurring. The high frequency data can be analyzed by the electronic component and specific information regarding the data can be determined. The specific information can be transmitted exclusively via the wireless network. Illustratively, the sensor arrangement and the electronic component can be constructed and arranged to utilize minimum amounts of battery power for sensing, recording, and transmitting data. The analyzing arrangement can also allow reconstruction of the data traces at a receiving end.

Fig. 1A is an exploded perspective view of an exemplary sensing system on a cricket bat, according to an illustrative embodiment. This illustrative embodiment of sensors integrated into sport equipment is used for general discussion of the system and method described herein, however various different arrangements are possible, including integration of sensors and related equipment into various different types of bats, rackets, clubs and other equipment related to various sports.

Ubiquitous to cricket bats and sports gear in general are logos and artwork that can be applied to the equipment as one of the final steps in manufacturing. This artwork performs the function of identifying the manufacturer, make and model of the equipment as well as providing aesthetics to incentivize the purchase of the equipment. To date this artwork comes in the form of a sticker that has a transparent polymer layer on which the artwork is printed. A double sided adhesive is applied to the printed side to complete the sticker. This sticker is supplied to the bat/equipment manufacturer who peels off the protective paper on the other side of the double sided adhesive and applies the sticker to the equipment. The adhesive is designed to adhere to the bat or other equipment for the life of the equipment. The sticker is usually applied to a part of the bat/equipment that does not come into contact with other pieces of equipment such as balls, further enhancing the lifetime of the artwork. This process allows artist to create all forms, shapes and artwork of stickers that are applied to the bats and equipment. To date these stickers have only performed a visual esthetic and identification function and have not performed a measurement function.

As shown in Fig. 1A, sticker 110 is not yet attached to the bat 101. Multi-functional sticker 110 can include not only artwork (not shown), but also conductive traces 111 that electrically connect to electrodes on vibration sensors 113. Vibration sensors 113 can be piezo electric ceramics such as PZT-5 (A,H), PZT-4, piezo electric polymers such as PVDF, piezo resistive materials such as silicone, or any other sensing material capable of sensing vibration in frequencies higher than 2kHz, as known to those skilled in the art. In various embodiments, the vibration sensors 113 can detect dynamic strain. Although this disclosure describes the sensing of vibration data throughout this disclosure for simplicity, it should be clear that the sensing of vibration data should be read to include sensing vibration data and/or sensing dynamic strain. The vibration sensors 113 can sense vibrations events in the equipment 101 and can transmit vibration signals from the vibration events to sensing electronics 123. These conductive traces 111 can be screen printed conductive ink, copper etched traces on material such as polyamide or FR4 or other flexible materials as known to those skilled in the art. Conductive traces 111 can take on any form to allow flexibility in the design of the artwork as well as the layout and cut of the sticker, as known to those skilled in the art. This provides artists the opportunity to design and produce logos and artwork that have the desired form but maintain the conductive function. Conductive tracks 111 allows multi-functional sticker 110 to conduct electric signals generated by sensor 113 to sensing electronics 123.

Fig. 1B is a cutaway view of sports equipment with a sensing system, showing the inner layers that make up the integrated sensing system, according to an illustrative embodiment. Various layers can be amalgamated to form multi-functional sticker 110 on the wood of bat 101, as shown. It should be obvious to those skilled in the art that the equipment can be of various of materials such as fiber glass, aluminum, titanium, fiber-reinforced plastics, wood, polymer, metal-ceramic composites, ceramics or any other material utilized in the equipment of different sports. Thin, double-sided, adhesive layer 33 can bond multi-functional sticker 110 to bat 101. Adhesive layer 33 can be thin and stiff in order to transmit high frequency mechanical vibrations efficiently to sensor 113. The other side of double sided adhesive 33 is in contact with sticker di-electric layer 34, conductive tracks 111 and sensor 113. Di-electric layer can be of any electrically insulating material such as polyester, polyamide, fiber re-enforced plastics etc. Adhesive 33, conductive tracks 111, sensor 113 and di-electric 34 make up the sensing layer of multi-functional sicker 110. Adhesive gasket 36, multi-layer artwork 37 and sticker base 38 make up the logo/artwork layer. This layer can be produced just as current logo/artwork stickers today with a double sided adhesive 36 enclosing multi-layer 37 artwork on one side and sticker base 38 on the other. The manufacturing of logo/artwork layer is well known to those skilled in the art. Printing conductive tracks 111 on di-electric layer 34 is also well known to those skilled in the art.

One or more vibration sensors 113 can be integrated with conductive traces 111 with the logo/artwork sticker. The sensors can be attached to sporting equipment in such a manner that mechanical vibrations are efficiently transmitted to vibration sensors, and the signal of the vibration sensors are captured and transmitted to electronics. Sensors 113 and traces 111 can be sufficiently isolated from the environment by the sticker 110, and the sticker can allow the designer of the logo/artwork to place the artwork onto the sticker without being inhibited by the incorporated sensing layer. Furthermore, the simplicity and non-intrusiveness of adding the sensing layer will not interfere with the weight or balance of the bat in such a way that it will be noticeable to the player or operator of the equipment. The sticker with incorporated equipment can conforms to all equipment standards required for sporting equipment in various sports, including cricket. The sticker and sporting equipment can conform to all standards and regulations for that sport, and a user would not be able to tell from the outside whether or not the sporting equipment had sensors incorporated into the sticker.

In the exemplary embodiment of Fig. 1A, sensing electronics 123 can be housed in bottom cover 124 that can contain male pins that slide into mounting holes 112 cut into sticker 110. These mounting holes can line up traces 110 with electric connecting pads on electronics 123 so that electrical contact can be made between electronics 123 and sensors 113. This mounting technique allows for mechanical strain relief from the electric contact point between the conductive traces and the electronics. In certain embodiments it might be desired to mount electronics 123 flush with the bat or equipment faces and mounting hole 102 can be machined or otherwise mechanically created. Bottom cover 124 fits into mounting hole 102 and can be mechanically secured by means of adhesives, press fit, screws or any other mechanical fastening method known to those skilled in the art.

Electronics 123 can be electrically connected to conductive traces 111 via connectors, conductive adhesives, crimp fits or any other method that electrically and mechanically join two conductive surfaces known to those skilled in the art. Electronics 123 can be affixed to bottom cover 124 by crews, press fit, adhesives or any other method known to those skilled in the art. The mechanical fixing can happen before or after electronics 123 are electrically connected to conductive traces 111 as will be appreciated by those skilled in the art. By the end of the process, electronics 123 can be both electrically connected to conductive traces 111 and affixed to bat 101.

As an example, electronics 123 can be protected by top cover 122 that can also house battery 121 and battery cover 120. In this illustrative embodiment easy access to battery 121 is provided by battery cover 120 so that battery 121 can be replaced very quickly when needed. As will be appreciated by anyone skilled in the art, the example of protection for electronics 123 and the methods of integrating the battery are one of many possible ways to perform the task of protecting electronics 123 and supplying power to electronics 123. For example, electronics can be integrated into sticker 110 by means of flex-circuitry, as known to those skilled in the art. Flex circuitry protects electronics 123 completely from all sides by mean of a polymer in an adhesive process well known to those skilled in the art. Other protection mechanisms can include potting the electronics, integrating thermoset materials, and other mechanisms known to those skilled in the art

Electric power to electronics 123 can also be provided in multiple ways as those skilled in the art will appreciate. For instance, battery 121 can replaceable or be re-chargeable by means of a cord such as a USB or micro-USB or any other ubiquitous power cord device. Wireless and contactless power transfer methods known to those skilled in the art can also be utilized to re-charge battery 121. The battery can also be completely removed/remote from the electronics, and placed in the handle for example. Depending on the technology of sensor 113, in various embodiments the electric energy of the sensor can be used to recharge battery 121. Capturing and utilizing power generated by piezoelectric devices in response to vibration is well known to those skilled in the art. Sticker 110 can also incorporate a solar cell to capture energy from light as is well known to those skilled in the art. A-Si thin film solar cells are particularly well suited to recharge energy storage devices when incorporated into flexible materials. Battery 121 can also be a super capacitor or any other material capable of storing electric energy as will be apparent to those skilled in the art.

A system and method for determining scalar values from measurements and telemetry related to a structure subjected to motion and force is described below as using a sensing system integrated into a bat, as shown in Fig. 1A and 1B, however, if should be clear that various other arrangements of sensors and sporting equipment are possible. Although the below system and method is described in the interest of clarity as utilizing piezoelectric polymer sensors in combination with printed conductive traces in a cricket bat, it should be clear that other combinations and methods can be utilized to capture high frequency vibration data within sporting equipment.

Fig. 1C is a schematic diagram of a sensing system architecture for detecting high-frequency vibrations on cricket bats, according to an illustrative embodiment. Turning to Figs. 1A-C, sensors 113 generate electric charge in response to mechanical strain. When an object comes into contact with bat 101, the mechanical vibrations generated by this event can manifest as a charge over the poles of sensors 113. The charge can be discharged in the form of current and voltage over the poles of the sensor and can be conducted via conductive traces 111 to electronics 123. Electronics 123 can consist of a low noise charge amplifier 41 that can convert the generated electric charge of sensor 113 into a voltage trace free of ambient noise, as will be known to those skilled in the art. Charge amplifier 41 can be integrated with electronics 123 or can be located closer to sensor 113 in order to reduce the influence of external noise. When piezo sensors are utilized, over-voltage protection can be utilized to protect electronics 123, as known to those skilled in the art. The amplified voltage trace from each sensor can then be fed through an analog to digital converter to produce a digital representation of the voltage trace generated by the sensors in a ubiquitous process known to those skilled in the art.

This digital signal can then be fed to a microprocessor that can perform a range of signal processing steps on the trace to identify events of concern. A modern microchip 42 can combine Analog to Digital convertor (A/D) and computational power as well as sufficient internal memory. In various embodiments, it can be desirable to utilize external A/D's for higher frequency sampling. Additional sensors 40 such as accelerometers, gyro meters, magnetometers, microphones, cameras or any other instrument that can provide additional information can optionally be incorporated into the electronics 123 and connected to microchip 42. Software/Firmware code 43 can instruct microchip 42 on how to access, store, record, manipulate and transmit data collected by the sensor array. Microchip 42 can be equipped with wireless signal communications device 44 that can communicate information wirelessly from electronics 123 to a receiver 46 located within range of the transmitting electronics. Receiver 46 can be operated by a user of the sporting equipment, or by a party related to the user of the sporting equipment, or by a third party, or by any other party. Wireless communication receivers and transceivers 44 and 45 can be of a multitude of industry standards known to those skilled in the art, such as Bluetooth®, WiFi, Ultra-Wide Band WiFi, Zigbee, laser etc. Signal communicator 44 can also be a separate piece of hardware.

Receiver 46 can be a device such as a computer or a handheld device and can be equipped with or connected to a wireless communications module 45 to receive signals from and transmit to electronics 123 as well as software or applications that can interpret and display the information transmitted from electronics 123. Receiver 46 can also be equipped with an internal camera or connected to an external camera or series of cameras to enable the combination of visual data with the vibration information supplied by electronics 123. Specifically the camera of a handheld device that is capable of taking high-speed images such as the slow-motion (Slo-mo) function of an iPhone camera can be used. For sporting events, Receiver 46 can also be connected to the broadcaster of the event in order to deliver content to the broadcaster or receive content in the form of audio, visual and other information from the broadcaster. A specific objective of this invention is to combine the images from ultra-motion cameras set up around a sports stadium and calibrating the output from electronics 123 with the feed of these cameras for entertainment and officiating purposes. This entire process should be well known to those skilled in the art.

By way of non-limiting example, the following exemplary parameters and/or specifications can be applicable to the system according to an illustrative embodiment:

1. Comparator: always on, and can consume between approximately 500 nano-amperes and 1 micro-ampere.

2. Microprocessor: always on, and can consume between approximately 5 and approximately 10 micro-amperes in deep sleep mode. The microprocessor can consume approximately 1.5 to approximately 5.5 milli-amperes in operation, i.e. sampling data. The duration of operation can be approximately 0.1 to approximately 0.5 seconds.

3. Accelerometer: can consume 100 micro-amperes in slow/wait mode and approximately 500 micro-amperes in data acquisition mode (0.1 to 0.5 seconds).

4. RF connection: can consume approximately 900-1100 micro-amperes during data transmission.

The device can have an approximate maximum baseline consumption of 111 micro-amperes hours (i.e. 1 +10 + 100) during sleep. During operation, the device can consume the baseline 111 micro-amperes + the 5.5 milli-amperes consumed for operation, for an approximate maximum operation consumption of 6 milli-amperes during the approximate maximum operation time of 0.5 seconds. This consumption can result in approximately 7 nanoAmps hours per use. This usage can consume approximately 3 milli-ampere seconds, or approximately 833 nano-ampere hours per operation.

The RF connection can consume approximately 1 milli-ampere and can run approximately 1/3rd of a second for 640 8-bit samples. This usage can consume approximately 330 micro-ampere seconds, or approximately 92 nano-ampere hours, per event. Sending more detailed 12-bit samples can consume approximately 275 nano-ampere hours.

Therefore, a standard coin cell of ~150mAh mounted within the device:

1. Can last ~1,300 hours without operating;
2. Can collect data and send it out at a high resolution ~ 160,000 times; or
3. Can collect data and send it out at a low resolution ~ 130,000 times.

Hence, where a player, on average, bats 3 hours per week and makes contact with 200 balls, and has twice as many other events, this arrangement can provide an estimated 600 events plus 3 hours of operation per week. Therefore, power consumption is approximately 111 microAmp hours * 3 + 600*(0.107 microAmp hours) = 175 microAmp hours per week. This can allow 380 weeks of playing in a high-power mode on a single battery. Alternatively, in low-power mode the device can operate approximately 430 weeks on a single battery. In most bat sports (e.g. cricket) this time outlasts the useful life of the actual bat.

It is also desirable to provide the system with a power source that is optimized for low weight, small footprint and long life. As discussed above, batteries and ultra-capacitors of all forms and sizes with different charging and replacement techniques can be utilized to optimize performance. However, consuming less power while delivering the content rich vibration information to receivers is a challenge and one that is specifically addressed by this invention. By way of further example, the arrangement described herein can include rechargeable batteries as a power source. The battery technology used herein can be highly variable—for example NiMH, Li-Poly, NiCd, hydrogen fuel cells, etc. Recharging technologies can include solar and light-based, high-output photovoltaics, inductive charging, direct conductor connections, etc.

To date, prior art dose not provide an adequate solution for communications between vibration sensors and receivers. For instance prior art refers to WiFi or Bluetooth® communication without providing any details of the process. Also, prior art is not specific with regard to the sampling frequency and the type of information that needs to be delivered from the vibration sensor to the third party device. The problems with previous approaches include the following:

A problem with the previous approach is that continuous wireless communication between two devices requires significant amounts of power and will therefore limit system operational lifetime or require a power source of a size that will interfere with the use of the equipment. The present disclosure overcomes the problems of the prior art at least because power consumed by electronics 123 can scale with frequency and data bit rate.

Another problem with the previous approach is that low-frequency sampling (<2KHz) does not provide the signal fidelity to identify events accurately, while continuous high-frequency (>2kHz) sampling and transmitting requires significant amounts of power. The present disclosure overcomes the problems of the prior art at least because power usage can scale with both frequency and data bit-rate.

To overcome the deficiencies in the prior art our system can operate on the following principles:

1. Low-frequency, low power, continuous sampling of sensors to identify the occurrence of an event.
2. Optional buffering of high-frequency data in response to the identification of an event.
3. Real time or near-real time analysis of the event to identify predetermined parameters of the event.
4. Transmitting certain parameters of an event over lower frequency, highly efficient wireless communications.
5. Reconstructing the event at the receiver device utilizing transmitted parameters to allow for data rich content.
6. As an example, low frequency response accelerometers can be monitored by microchip 42 in a low power mode where no transmission or high data rate sampling is happening. However, in response to a predetermined set of events captured by the accelerometer the system can identify that the bat is in motion and that the player is about to make contact with the ball. Furthermore, the accelerometers can be used to identify if the player is merely tapping the bat on the ground, in which case data capturing will not be initiated, or swinging it freely, in which case data capture is enabled, as will be known to those skilled in the art. Microchip 42 can wake up and start to take and capture high frequency data from sensors 113 for a pre-determined period, and can manipulate and analyze the signals and determine information to be transmitted via wireless communicator 44.

In various embodiments, a comparator, a device well known to those skilled in the art, can monitor the output from sensors 113 over conductive traces 111. Comparators are ultra-low power devices that can identify when the differential analog output between two traces is over a pre-determined limit. By way of non-limiting example, off-the shelf comparators such as the MAX9027 can monitor two signals at 70kHz while consuming 1 μA of power. Comparators that operate at higher frequencies and consume more power are also available. Once the comparator identifies this event, it can send a digital signal to microchip 42 to initiate the collection of data. The duration of the data collection event can be determined by code 43.

The events that can be captured by microchip 42 can be maximum vibration amplitude, arrival time of vibration signal at a specific sensor, frequency of vibration, duration of vibration, damping coefficient of vibration, and others. This information can then be translated into a number of useful bits of information that can be transmitted to receiver device 46. The following non-exhaustive list of parameters can be determined and calculated via this process: the power of impact of a ball on bat; whether or not there was impact between equipment and ball or other equipment; the location of impact between equipment; the type of equipment being impacted; the speed of the equipment at impact; the position of the equipment versus time; the flexing of equipment versus time; etc.

The events described above can be determined and accessed via code 43 running on microchip 42. Microchip 42 can also determine the transmitted parameters of these events to share via wireless communicator 44. Transmitted parameters can be less than all of the collected data. The entire event does not need to be transmitted between communication devices 44 and 45, instead an abbreviated, information rich, low power transmission can indicate the type of event, the timing of the event, and other useful parameters such as power and location. Instead of thousands and thousands of bits of data being transmitted, only certain data is transferred. This, in turn, will not only speed up communications between electronics 123 and third party device 46, but it can also conserve energy of the power source of electronics 123, thereby extending useful life of the entire device.

Fig. 1D is a schematic diagram of an exemplary processor for use in sensing vibration data and using the sensed data to generate one or more scalars to provide information about batting performance, according to an illustrative embodiment. A sensing system can include a processor 50 that can be operatively connected to sensors 113 and to wireless communicator 44. Turning to Figs. 1C and 1D, the processor 50 can include microchip 42 and code 43. Processor 50 can include a data capturing module 52, a data storing module. 54a data manipulator module 56, a data analyzer module 58, a data comparing module 60, and/or a transmission determination module 62. Data capturing module 52 can access and store data from the sensors 113 and 40. Data storing module can store data captured from the sensors.

Data manipulation module 56 can manipulate the data captured from the sensors, explained more fully below. Data analyzing module 58 can analyze the data. Data comparing module 60 can compare data from two sources. Transmission determination module 62 can determine the data that will be transmitted to the receiving device.

II. Illustrative System and Method and related Processes

In most bat-on-ball sports like tennis, baseball, hokey, cricket, and so forth, there is often a reference to the "*sweet spot*" of the bat, club, racket and stick. One will hear a common phrase in commentary from experts, from batmen/woman, from coaches etc.: "That was hit in the sweet-spot". What this often refers to is an optimal area of the bat within which to strike the ball which yields the best transfer of power to the ball.

It has been shown in numerous academic literature how bat speed, relative sweet spot, past impact bat twist, and launch angle of a cricket shot determines the distance the ball will travel through the air. With conventional, ubiquitous, inertial measurement units, the pre-impact bat speed, the amount of twist after impact and the launch angle at impact can be determined. The present disclosure allows for adding the sweet spot of the shot to the equation, and can enable the prediction of the distance of how far the ball will travel.

The" sweet spot" is the point of the bat where the minimum amount of the impact energy between ball and bat is absorbed by the bat. This in turn means that most of the impact energy is transferred to the ball. Thus, because most of the kinetic energy of the impact is transferred to the ball, it's momentum change is larger and therefore its change is speed is greater, leading to a shot that travels further, which is an outcome desired by most players in bat-on-ball or stick-on puck sports.

Conversely, when the ball is not hit in the "sweet-spot", a lot more of the impact energy is transferred to the bat. Typically when the ball impacts the lower or upper part of the bat, the amount of energy transferred to the bat is larger, causing kinesthetic feedback in the player's hands, sometimes to the point where the player is physically injured. The result is that less of the impact energy is transferred to the ball, causing less momentum change in the ball, resulting in a lower post-impact speed of the ball and a worse result since the ball does not travel far.

Only recently did low profile, accurate and high-frequency sensors that can be applied to bats become available in the market. These type of sensors are described in the above-incorporated U.S. Patent Application Serial No. 15/608,965 The data being provided by the high frequency sensors on these bats contain the information required to determine how well a batsmen has hit the ball or how close to the “sweet spot” of the bat the ball impacted the bat. The illustrative system and method, described below is intended to operate in conjunction with or instantiated within the processor(s) of such sensors and/or in networked processing devices (e.g. computers, servers, handheld devices, etc.)

By way of non-limiting example, Figs. 1E and 1F illustrate the difference in the high-frequency traces of a poorly placed shot and a “sweet” shot. Fig. 1E is a chart showing voltage from a piezoelectric sensor indicating vibrations over time for a poorly placed shot, and Fig. 1F is a chart showing voltage from a piezoelectric sensor indicating vibrations over time for a shot in the sweet spot. Fig. 1E shows exemplary vibration data 1A from a poorly-placed shot, and Fig. 1F shows exemplary vibration data 2A from a shot in the sweet spot. As can be seen, the initial impact amplitude of the two shots are almost similar, however the amount of residual vibration and the amount of dampening of the vibration trace is quite different. In the exemplary data shown in Fig.s 1E and 1F, the vibrations of poorly placed shot 1A does not dampen out and there is still significant vibration energy in the bat after 40ms. Furthermore, poorly placed shot 1A has significant high frequency oscillations in the initial phase that only dampens at around 9 ms after initial impact. In contrast, the vibrations of sweet shot 2A has almost no vibration after 12 ms and the high frequency oscillations end at around 6 ms after impact. Therefore it is possible to distinguish between poorly placed 1A and sweet shot 2A based on the analysis of their respective frequency traces.

As is known by those skilled in the art, digital and analog filtering can remove certain parts of a signal and keep other parts of the signal. Lowpass filters remove frequencies higher than the cutoff frequency, leaving only low-frequency signal in the trace. Similarly, high-pass filters remove all signal below the cutoff frequency, leaving only the parts of the signals that have energy in the frequencies higher than the cutoff frequency. Band-pass filters have both a low frequency cutoff and a high frequency cutoff, removing all signal from the trace that is blow the low frequency cutoff and above the high frequency cutoff. Band-stop filters do the opposite of bandpass and leave only the parts of the trace that is below the low frequency cutoff and above the high frequency cutoff.

Various beams can be constrained in various ways vibrate (or ring-down) after an initial impact with various dominant frequencies, as is known to those skilled in the art. These dominant frequencies are called the modes of the beam, as is well known. By picking the low-pass and band-pass cutoff frequencies carefully, the first, second and all subsequent modes in a vibration signal can be isolated. Once isolated, these modes can then be utilized to determine how much relative vibrational energy is in each mode for every location of the impact. Those points where the measured vibrational energy is lowest can correlate to locations where the bat is highly dampened for that particular mode. Conversely, higher measured vibrational energy can indicate that the particular mode is excited.

Fig. 2A is a chart showing the effect of applying a low-pass filter and a band-pass filter with different cut-off frequencies to a poorly-placed shot, according to an illustrative embodiment, and Fig. 2B is a chart showing the effect of applying a low-pass filter and a band-pass filter with different cut-off frequencies to a well-placed shot, according to an illustrative embodiment. Figs. 2A and 2B show how applying filters to the high-frequency vibration traces reveal measurable differences in the traces.. In this example the cut-off frequencies for Lowpass, and Bandpass are the same for both traces. As can be seen, the signal remaining after the lowpass filter has been applied is very different between the two hits. Low-pass filtration 21A of the poorly placed shot shows significant amplitude after impact and the trace does not dampen after the 40ms window. Conversely, low-pass filtration 22A of the sweet shot has very little initial amplitude and dampens quickly after 12ms. A similar trend is visible in band-pass filtration of poorly placed and sweet shots. Band-pass1 filtration 23A of the poorly placed shot has high initial amplitude and dampens only after 25 ms. Band-pass1 filtration 24A of the sweet shot has low initial amplitude and is completely dampened at 11 ms.

From Figs. 2A and 2B it will be apparent to those skilled in the art that sweet shot 2A has much lower energy in both the raw and filtered traces when compared to poorly placed shot 1A. Therefore it should be apparent to those skilled in the art that cumulating the energy of these traces will yield differentiating features that can be used to distinguish between different traces.

Impact data from high frequency sensors on a bat can be matched to the relative position of the impact on the bat, as described in the following example. As shown in Figs. 1E , 1F, 2A, and 2B, the input data contains visible differences in the raw vibrational energy signal, as well as in various filtered vibrational energy signals. The amount of energy in a vibration signal is correlated to the area under the amplitude-time signal, or the time integral of the signal. Integrating the absolute value of the measured vibrational amplitude over time yields an approximation of the vibrational energy.

Fig. 3 is a chart showing an example of how the integral of a lowpass filter is distributed over an exemplary cricket bat, according to an illustrative embodiment. Fig. 3 illustrates an effect of integrating the absolute value of the measured and low-pass filtered vibrational signals, induced by striking a cricket bat at various locations and intensities, and plotting the resulting energy approximation with respect to the ideal point of ball impact or “sweet spot.” Fig. 3 indicates that there is a region from about 7.5 inches to about 9.5 inches from the bottom of that bat where the computed energy approximation is lowest, indicated by region 31A, which is the “sweet spot.” A region around 4 inches from the toe, indicated by region 32A, shows where energy is highest, indicating a poorly placed spot. Fig. 3 also shows that the amount of dampening occurring in the low-pass integral can correlate to where on the bat the ball impacted, regardless of the intensity of the impact.

However, upon closer inspection, one can see that there are several locations 33A and 34A where there are several impacts in close proximity to each other where the lowpass integral is substantially different. This can be attributed to the fact that the intensity of the hits, defined by the speed of the ball and the speed of the bat before impact, at these locations were substantially different.

One way to account for the difference in intensity of the hit is to observe that the magnitude of the initial impulse has a direct correlation to the intensity to the hit. Therefore it might be possible to account for the intensity of the hit by normalizing the signal with the initial impulse amplitude. Normalization of data with specific parameters is a well-known skill. Fig. 4 is a chart showing an example of how the integral of a normalized lowpass filter is distributed over an exemplary cricket bat, according to an illustrative embodiment. Fig. 4 illustrates what happens when the signals are normalized before integration by utilizing the initial peak amplitude or peak-to-peak of the signal. Several differences between Fig. 3 and Fig. 4 can be observed. Turning to both Fig. 3 and Fig. 4, the region of lowest integral magnitude 41A in Fig. 4 is both smaller in size and has migrated to 8-10 inches from the toe of the bat. The region of highest integral magnitude, 42 A, has also moved to span 4 through 6.5 inches from the toe of the bat. Where there were some substantial differences in integral values of different intensities at similar locations, these seem to have been reduced in locations 43A and 44A as compared to 33A and 34A in Figure 3. Another observation is how quickly the transition from low integral to high integral happens. Where the integral value at 7 is still relatively low, the integral at 6.5 inches is very high in comparison. It was observed by tapping on this particular bat with a mallet that there is indeed a very fast transition from within the sweet spot to outside the sweet spot in this region.

Fig. 5 is a chart showing an example of how the integral of a bandpass filter distributed over an exemplary cricket bat, according to an illustrative embodiment. Fig. 5 illustrates the same principles applied to the bandpass filter signals. Here the bandpass filter is applied to capture a specific frequency range of the signal and thus capture a specific mode from the bat. The area of relatively lowest computed energy 51A is between 6.5 and 8.3 inches from the toe. The area with the highest computed energy 52A is between 3.5 and 5 inches from the toe. Again, there are several locations (53A and 54A) where the different intensity of the hits resulted in significantly different computed energy values at the same approximate location on the bat, according to this example.

Fig. 6 is a chart showing an example of the integral of a normalized bandpass filter is distributed over an exemplary cricket bat, according to an illustrative embodiment. Fig. 6 shows the effect of normalizing the bandpass filter with the initial peak-to-peak amplitude. The area with the lowest computed energy 61A is a lot smaller and located between 7 and 8 inches from the toe. The area of highest computed energy 62A is located significantly lower on the bat around 5.5 inches from the toe. Again, normalizing the signals before integration results in a tighter distribution of results in the same locations (63A and 64A).

Turning to Figs. 3-6, various frequency ranges can be utilized to isolate various vibration modes of a bat. Since some modes are more dominant in amplitude than others, the relative contribution of each mode can be accounted for in order to properly attribute excitation of that mode to the excitation of the sweet spot of that bat.

From the above it is clear that the method of integrating the various filtered vibration signals reliably and consistently produces an energy approximation of vibrational modes, and that can be correlated to good or poor placement of the ball.

What follows is an illustrative example of how to transmute these energy approximations into reliable and consistent, human digestible scalars which can be tuned for infographics. The below example utilizes these variables derived from the vibration signal to identify how close to the sweet spot of the bat the ball has impacted. In such a case this proximity to the sweet spot of the bat is an indication of how well the batsman has hit the ball. In other words, this calculated value will be an indication of the quality of the shot. Therefore a quality metric of a shot can be defined as 100% when it is hit in the center of the sweet spot and lower if it is hit on the tip or in the worst spot of the bat.

As an illustrative example of a formula to determine this quality or % proximity to the sweet spot of the bat can be written as Quality equation (1), below:

$$Qual = C_1 - C_2 * (\langle K_1 * LP + K_2 * LP_N + K_3 * BP_1 + K_4 * BP_{1N} + K_5 * BP_2 + K_6 * BP_{2N}\rangle .. + K_n * BP_n + K_{n+1} * BP_{nN}) \quad (1)$$

In the above equation, C_1 is the offset, C_2 the gain, K_1 the Lowpass constant, LP the Lowpass integral, K_2 the normalized Lowpass constant, LP_N the normalized Lowpass integral, K_3 the first bandpass constant, BP_1 the bandpass integral of the first bandpass filter, K_4 the normalized first bandpass constant, BP_{1N} the normalized first bandpass integral, K_5 the second bandpass constant, BP_2 the Bandpass integral of the second bandpass filter, K_6 the normalized second banspass constant, BP_{2N} the normalized second bandpass integral and so forth with n indicating the nth repetitive bandpass and normalized bandpass integral's constants, integrals and normalized integrals above. The subscripts 1 though n indicate that numerous bandpass filters can be used to isolate the frequencies of interest. As will be known by those skilled in the art, by making the upper cutoff frequency at or higher than the Nyquist frequency, one will have essentially created a highpass filter, and as such it is include in the Quality equation (1).

It should be clear to those skilled in the art that the constants K_1, K_2, K_3, K_4, K_5 , K_6 through K_n determines the relative strength of influence of the different filtered integrals on the quality score. Thus, referring back to Figs. 3, 4, 5 and 6, setting the constants will move the quality score of the bat around. Therefore, it is possible to adjust the quality of the score to take into account the contribution of each mode to the quality score. Furthermore, the score can also be adjusted to account for some human bias that might make viewers doubt the quality of a shot versus the location of the impact. Additionally, as will be well known to those skilled in the art, the offset C_1 and gain C_2 can be utilized to adjust the Quality so that the bat's range will be between 0 and 100 for a certain set of constants. For most applications, if the score is below 0 it should be noted as such a bad shot that it needs to be corrected to 0 and if a score is higher than 100, it should remain 100.

Fig. 7 is a chart showing an example of the distribution of a relative quality calculated by utilizing a set of parameters over an exemplary cricket bat, according to an illustrative embodiment. Fig. 7 is an illustrative example of the product of Quality formula (1) for a range of shots on a particular bat with the constants and the filter cutoff frequencies set to the values of Case 1 in the table below. The highest quality scores for this particular bat and set of coefficients is from 7.5 inches to 9.5 inches from the toe of the bat. The scores fall off toward the toe and the handle however the reduction in quality toward the handle which is located at 22 inches is less rapid with respect to the Y distance.

It is interesting to note in Fig. 7 is that shots with similar impact positions have similar scores, regardless of the impact force, bat speed or the batsman operating the bat. It should be noted that the error of impact measurement is about 0.5 inches in all directions. The quality score get progressively worse as the shot impact location moves away from the sweet spot. The sweet spot is indicated by the darker dots. This is true for moving in both the Y and the X direction, as defined in Fig. 7, although the effect is more pronounced in the Y direction.

Fig. 8 is a chart showing an example of the distribution of a relative quality calculated by utilizing a set of parameters over a different exemplary cricket bat that is different from the bat in Fig. 7, according to an illustrative embodiment. For comparison, Fig. 8 illustrates the same constants as Case 1 but applied to a different bat. It is clear that the sweet spot of the bat (high quality scores) are smaller and also moved from 8 inches to about 9 inches from the toe of the bat. This indicates that the physical propertied of the bat is in fact different and that the bat has a sweet spot at a different position relative to the end of the bat than the bat of Fig. 7.

Parameter	**Case 1**	**Case 2**
C_1	104	111
C_2	-8.5	0.85
LP Cutoff f	150 Hz	150 Hz
BP_1 *Lower Cutoff f*	250 Hz	250 Hz
BP_1 *Higher Cutoff f*	500 Hz	500 Hz
K_1	0.5	0.35
K_2	1	0.5
K_3	0.5	1
K_4	1	3

Fig. 9 is a chart showing an example of the distribution of a relative quality over a cricket bat, calculated by utilizing a slightly different set of parameters from those shown in Fig. 7, according to an illustrative embodiment. Fig. 9 illustrates how the constants in Quality formula (1) will influence the outcome of the score with the same bat. Here, as another illustrative example, the constants and cutoff frequencies are as listed as Case 2 the table above. Comparing the quality scores of Fig. 9 and Fig. 7, it is clear that the location, distribution and scores have been altered due to the change in constants. This illustrates the utility of adjusting the constants in Equation (1) to adjust the output of quality.

As will be apparent to those skilled in the art, the constants K1, K2, K3, K4 through Kn can be set to 0 in order to ignore a particular filters integral's influence. Furthermore, as will be obvious to those skilled in the art, additional integrals and constants can be added to Quality equation (1) in order to adjust the score based on other modes of the bat or stick that is instrumented.

Also, as will be apparent to those skilled in the art, adjusting the frequency thresholds of the filters will also adjust the outcome of Quality equation (1) and needs to be adjusted depending on what type of bat or stick is instrumented for a particular sport. However, once a set of parameters have been defined for a specific sport, Quality equation (1) can distinguish between the ability of different sportsmen and women as well as the features, characteristics and properties of the equipment they are using.

The system and method described herein can be utilized by manufacturers of sporting equipment to tailor the equipment to have specific features, characteristics and properties as desired by the end user. Once the relative quality of a shot is known, a straight forward correlation to the relative power transferred from the bat to the ball can be made by including the speed of the bat. If the speed of the bat is also measured, the relative power transferred to the bat can be calculated as:

$$RelPower = Qual * V_B^2$$

WhereV_B^2 is the bat velocity squared and represents an estimation of the relative kinetic energy available in the bat at the point of impact and Z representing a tunable metric for adjusting the relative power according to different factors. This relative power score can then be used to compare the hitting ability of batsmen and women. If the bat velocity is further refined to the actual velocity at the point of impact the relative power will be an even better comparison metric.

Note, by way of further example, the data acquisition device associated with (e.g.) the bat or other piece of moving sporting equipment can be a remote device, for example, located at the "stump" that measures vibrations with respect to the moving equipment piece. One form of device can be a microphone assembly that picks up acoustic signature(s) from the equipment. Another form of device can be a laser-based vibration sensing system, or one based upon radar. The data gathered by such sensing devices can be transmitted to the processor(s) operating the system and method to provide the desired outputs. Thus, for the purpose of this description, in various embodiments such remote sensing assemblies can be substituted for the sticker-based assembly described above.

III. Conclusion

It should be clear that the above-described system and method desirably provides simplified summarizing of (e.g.) batting performance to two fundamental and unit-less numbers, namely power and quality. These numbers can then be further transformed in manners clear to those of skill to produce numbers that can be given artificial units, which can then be used to compare (e.g.) batting performances.

The foregoing has been a detailed description of illustrative embodiments of the invention. Various modifications and additions can be made without departing from the spirit and scope of this invention. Features of each of the various embodiments described above may be combined with features of other described embodiments as appropriate in order to provide a multiplicity of feature combinations in associated new embodiments. Furthermore, while the foregoing describes a number of separate embodiments of the apparatus and method of the present invention, what has been described herein is merely illustrative of the application of the principles of the present invention. For example, as used herein the terms “process” and/or “processor” should be taken broadly to include a variety of electronic hardware and/or software based functions and components (and can alternatively be termed functional “modules” or “elements”). Moreover, a depicted process or processor can be combined with other processes and/or processors or divided into various sub-processes or processors. Such sub-processes and/or sub–processors can be variously combined according to embodiments herein. Likewise, it is expressly contemplated that any function, process and/or processor herein can be implemented using electronic hardware, software consisting of a non-transitory computer-readable medium of program instructions, or a combination of hardware and software. Additionally, as used herein various directional and dispositional terms such as “vertical”, “horizontal”, “up”, “down”, “bottom”, “top”, “side”, “front”, “rear”, “left”, “right”, and the like, are used only as relative conventions and not as absolute directions/dispositions with respect to a fixed coordinate space, such as the acting direction of gravity. Additionally, where the term “substantially” or “approximately” is employed with respect to a given measurement, value or characteristic, it refers to a quantity that is within a normal operating range to achieve desired results, but that includes some variability due to inherent inaccuracy and error within the allowed tolerances of the system (e.g. 1-5 percent). Accordingly, this description is meant to be taken only by way of example, and not to otherwise limit the scope of this invention.

What is claimed is:

CLAIMS

1. A method of concisely summarizing player performance in bat-ball sports through data received from an acquisition device that measures motion on a piece of sporting equipment, the method comprising the steps of:

providing a unit-less first quality metric indicating hit quality; and

providing a unit-less second power metric indicating hit power.

2. The method of claim 1, further comprising computing the quality metric using a polynomial which combines a ratio of high-frequency vibrational energy to low-pass-filtered vibrational energy measured in the piece of sporting equipment with a scale factor ratio of low-pass-filtered and high-pass-filtered vibrational energy to raw signal vibrational peak amplitude.

3. The method of claim 2, further comprising, computing the high-frequency vibrational energy by integrating band-pass-filtered measured vibrational energy over time and the low-frequency vibrational energy is computed by integrating low-pass-filtered measured vibrational energy over time.

4. The method of claim 2, further comprising, tuning each of the ratios of the quality metric with a corresponding set of adjustable coefficients and offsetting the quality metric by a bias in order to produce a desired range of outputs.

5. The method of claim 1, further comprising, computing the power metric from a square of a measured tip velocity of the piece of sporting equipment at a time of impact with another object.

6. The method of claim 5, further comprising, scaling the power metric by a polynomial involving the quality metric and a tunable coefficient.

7. A method for concisely summarizing player performance in bat-ball sports comprising the steps of:

collecting vibration signals induced in a sporting equipment by an impact event;

applying signal processing to the signals; and

calculating metrics from the processed signals; and

discriminating, using the calculated metrics, between signals correlating to a predetermined performance metric score from signals correlating to a different performance metric score.

8. The method of claim 7 where the step of applying signal processing further comprises low-pass filtering and band-pass filtering and integration of selective filters to obtain a first set of differentiating metrics.

9. The method of claim 8 further comprising dividing the differentiating metrics by the peak amplitude of the signal in order to provide a second set of differentiating metrics.

10. The method of claim 9, further comprising combining the first and second sets of differentiating metrics in a polynomial equation where the differentiating metrics are multiplied and added to constants in order to generate a differentiating score.

11. A method of concisely summarizing player performance in bat-ball sports via a first computed unit-less metric, the method comprising the steps of:

acquiring a vibration signal induced in a sporting equipment in response to an impact event;

processing the acquired signal to generate a first scalar and a second scalar;

applying the first and second scalar to a polynomial; and

outputting from the polynomial a unit-less vibration scalar.

12. The method of claim 11, further comprising, labeling the unit-less vibration scalar a quality metric.

13. The method of claim 11, wherein the step of acquiring the vibration signal can be acquiring a vibration signal from a bat-ball contact.

14. The method of claim 11, further comprising computing a unit-less motion scalar, the computing a unit-less motion scalar comprising the steps of:

acquiring a motion signal induced in a sporting equipment by an impact event;

time-synchronizing the acquired motion signal with the acquired vibration signal;

processing the acquired motion signal to generate a generated scalar;

applying the generated scalar and the vibration scalar and motion scalar from to a polynomial;

outputting from the polynomial a unit-less metric.

15. The method of claim 14, further comprising, labeling the unit-less motion scalar a power metric.

16. A system for sensing data and using the sensed data to generate one or more scalars to provide information about batting performance, the system comprising:

at least one dynamic strain sensor or vibration sensor;

a data capturing module;

a data storing module;

a data manipulator module;

a data analyzer module;

a data transmission determination module; and

a wireless transmitter.

17. The system of claim 16, further comprising at least one motion sensor.

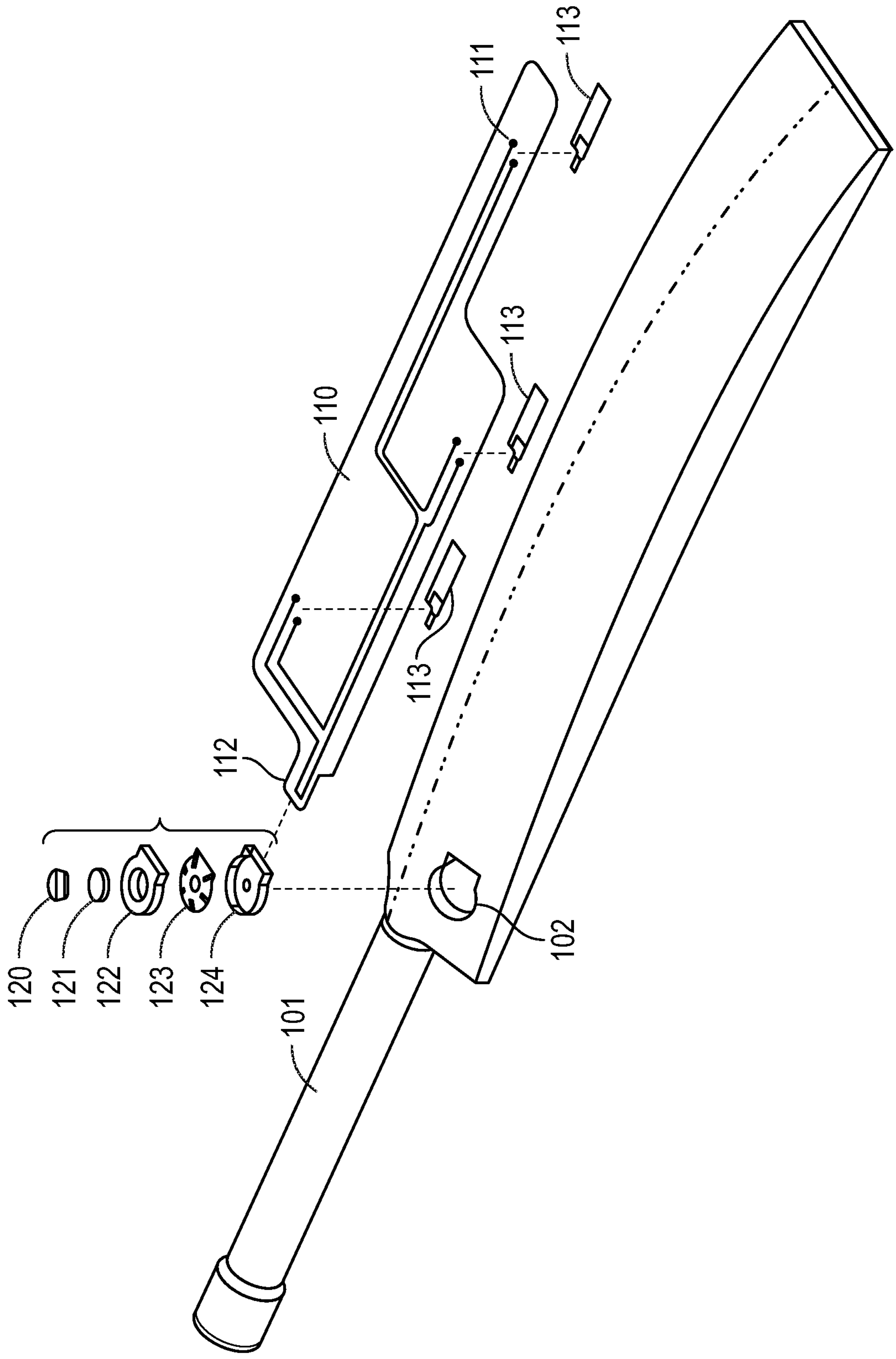

FIG. 1A

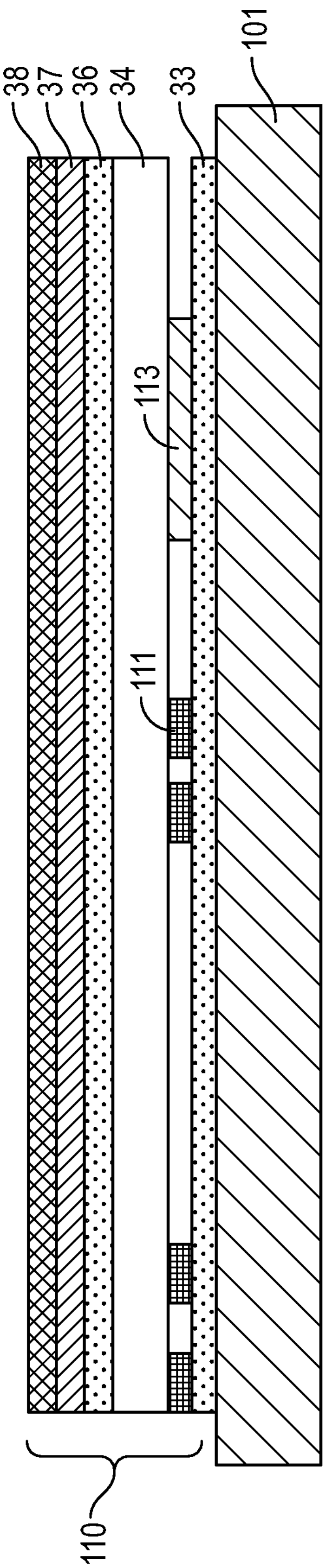

FIG. 1B

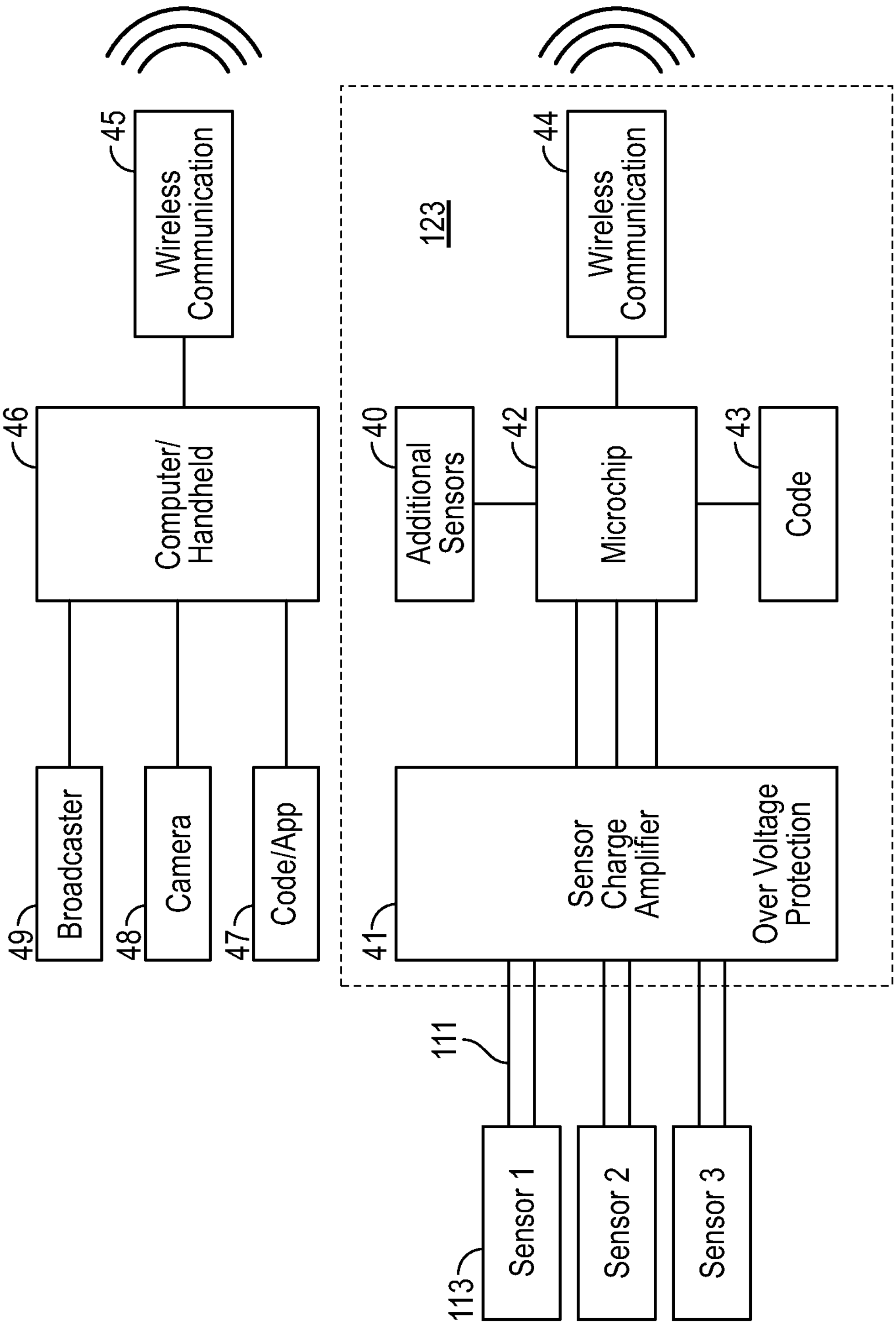
Wireless Communication
45
Computer/ Handheld
46
Broadcaster
49
Camera
48
Code/App
47
123
Wireless Communication
44
Additional Sensors
40
Microchip
42
Code
43
Sensor Charge Amplifier
Over Voltage Protection
41
111
Sensor 1
Sensor 2
Sensor 3
113

FIG. 1C

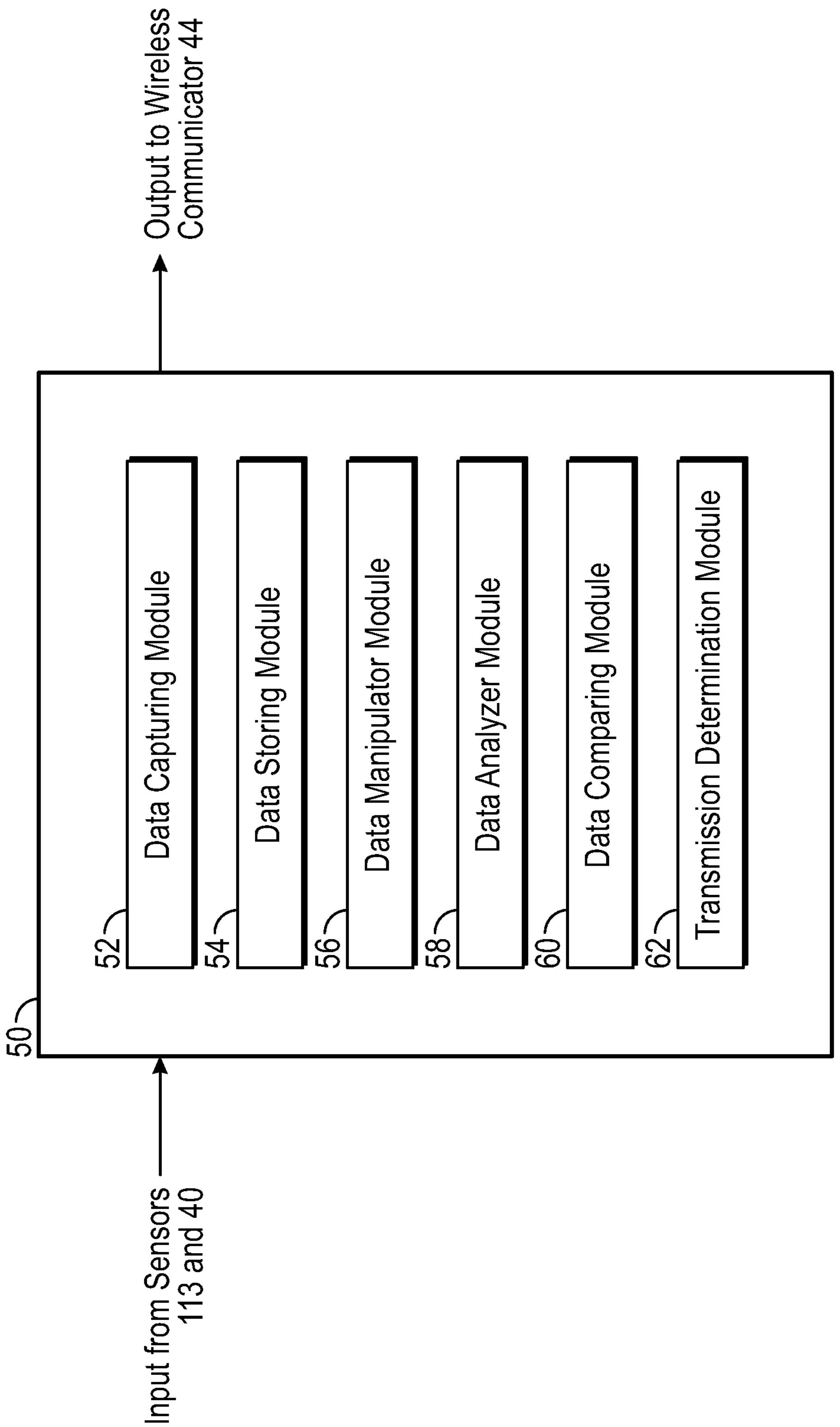
Output to Wireless Communicator 44
50
52 Data Capturing Module
54 Data Storing Module
56 Data Manipulator Module
58 Data Analyzer Module
60 Data Comparing Module
62 Transmission Determination Module
Input from Sensors 113 and 40

FIG. 1D

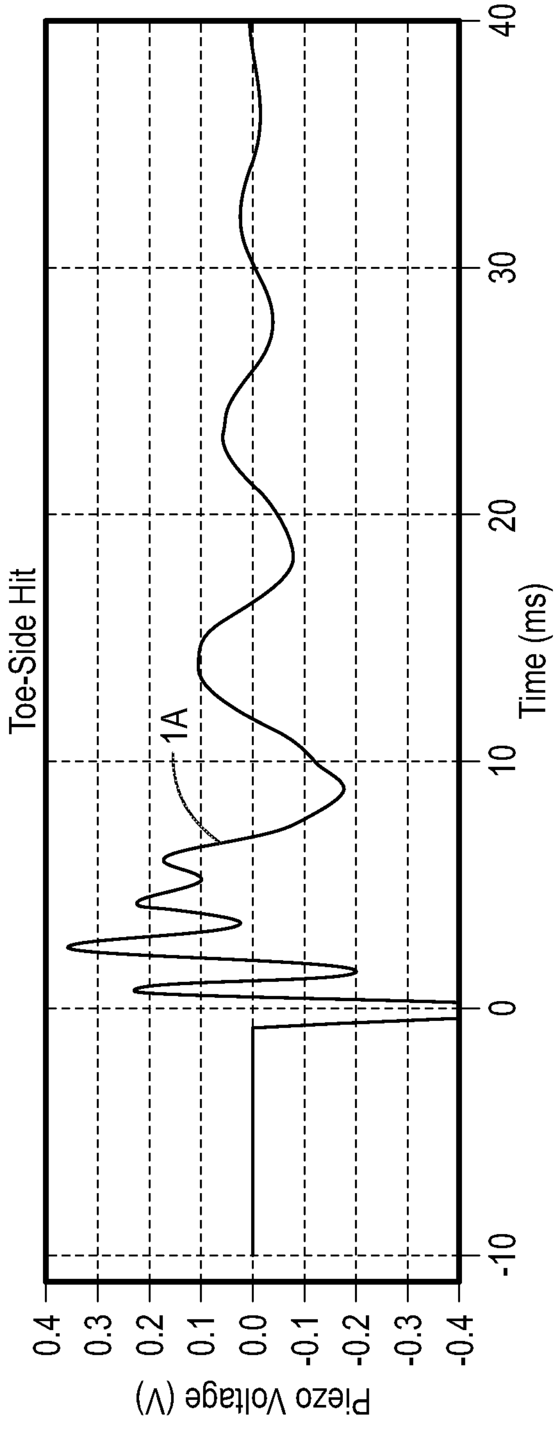
Toe-Side Hit
1A
Piezo Voltage (V)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-10
0
10
20
30
40
Time (ms)

FIG. 1E

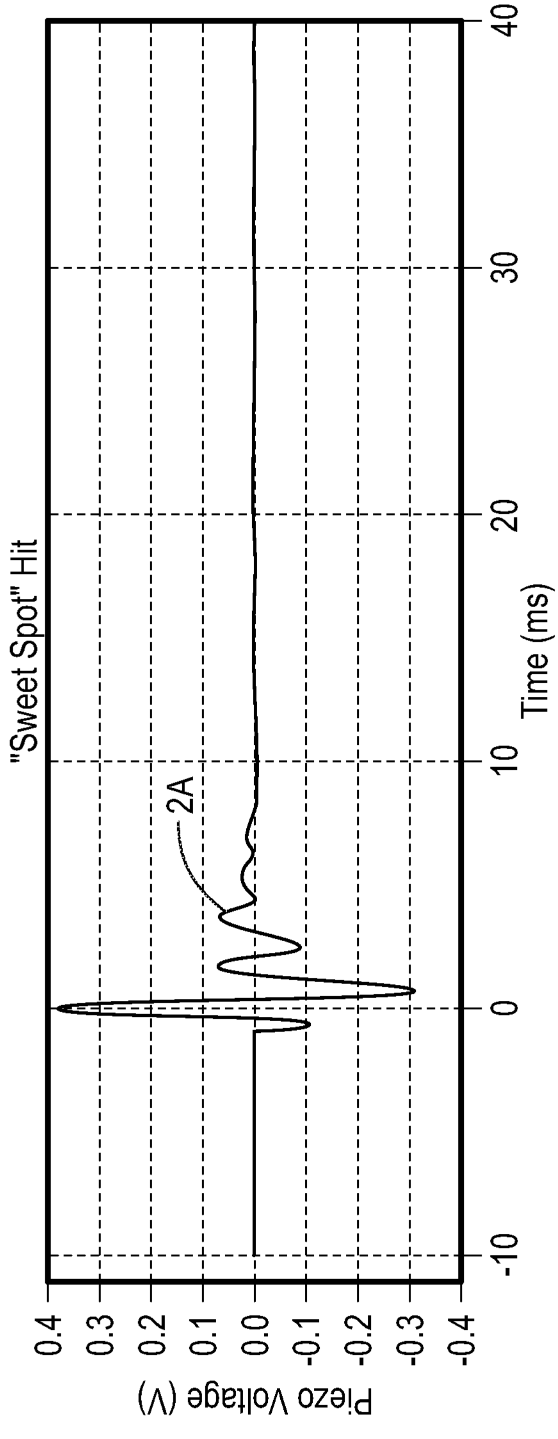
"Sweet Spot" Hit
2A
Piezo Voltage (V)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-10
0
10
20
30
40
Time (ms)

FIG. 1F

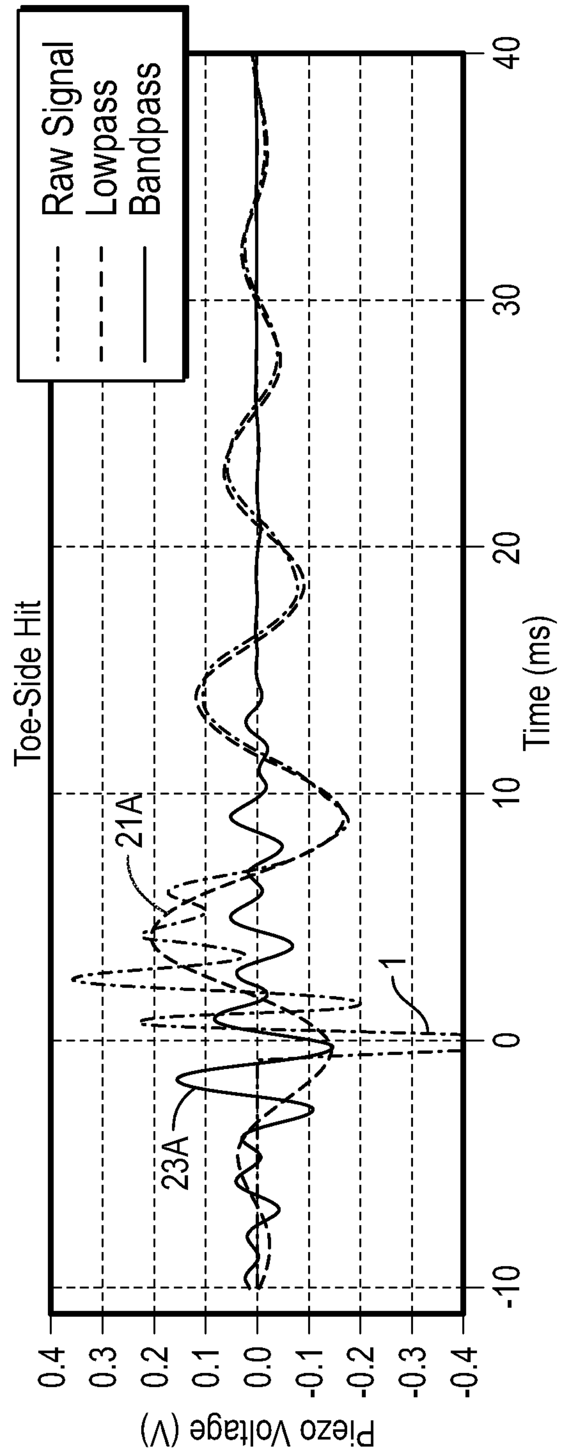
Toe-Side Hit
Raw Signal
Lowpass
Bandpass
21A
23A
1
Piezo Voltage (V)
Time (ms)

FIG. 2A

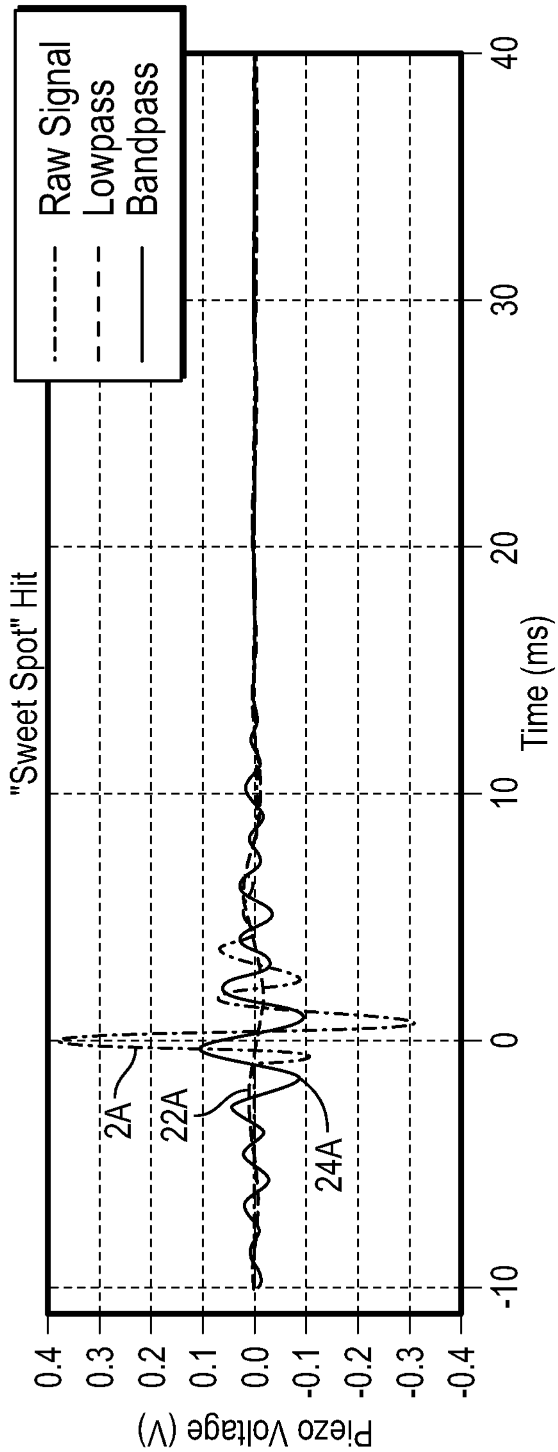
"Sweet Spot" Hit
Raw Signal
Lowpass
Bandpass
2A
22A
24A
Piezo Voltage (V)
Time (ms)

FIG. 2B

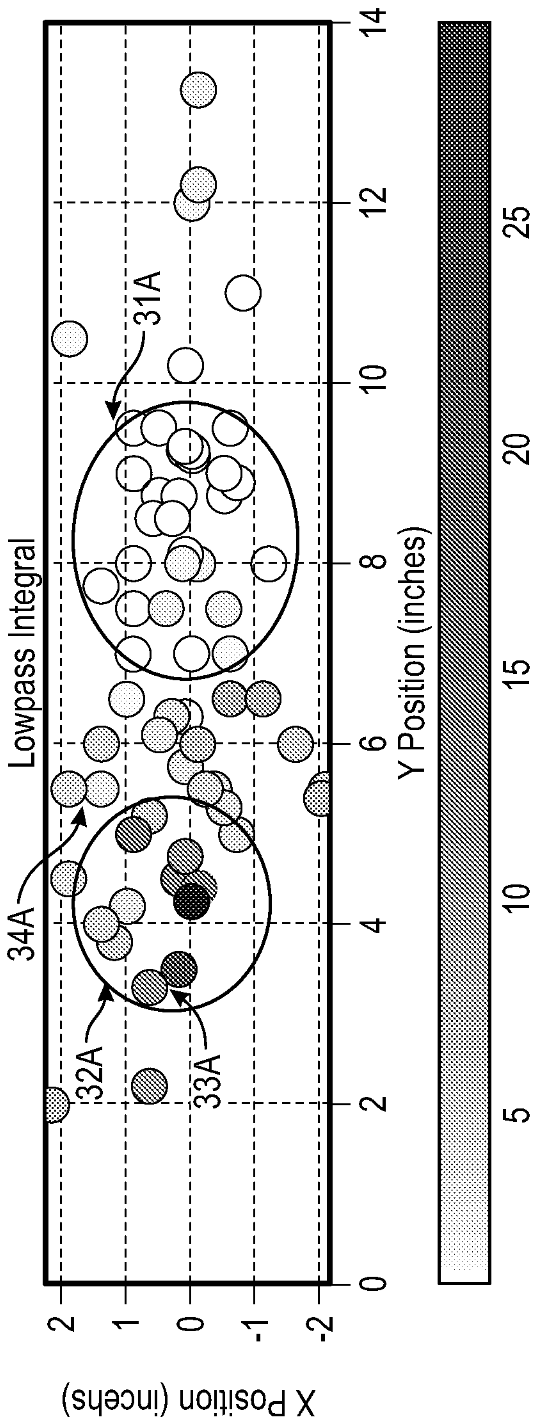
Lowpass Integral
X Position (incehs)
Y Position (inches)
31A
32A
33A
34A
2
1
0
-1
-2
0
2
4
6
8
10
12
14
5
10
15
20
25

FIG. 3

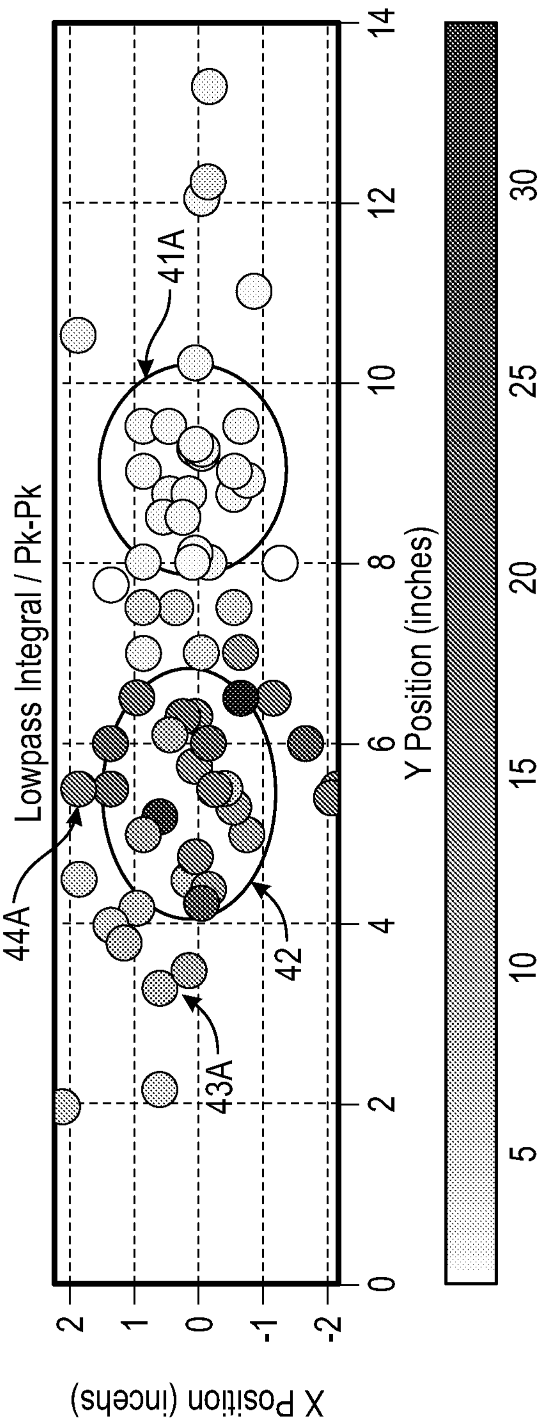
Lowpass Integral / Pk-Pk
X Position (incehs)
Y Position (inches)
41A
42
43A
44A
2
1
0
-1
-2
0
2
4
6
8
10
12
14
5
10
15
20
25
30

FIG. 4

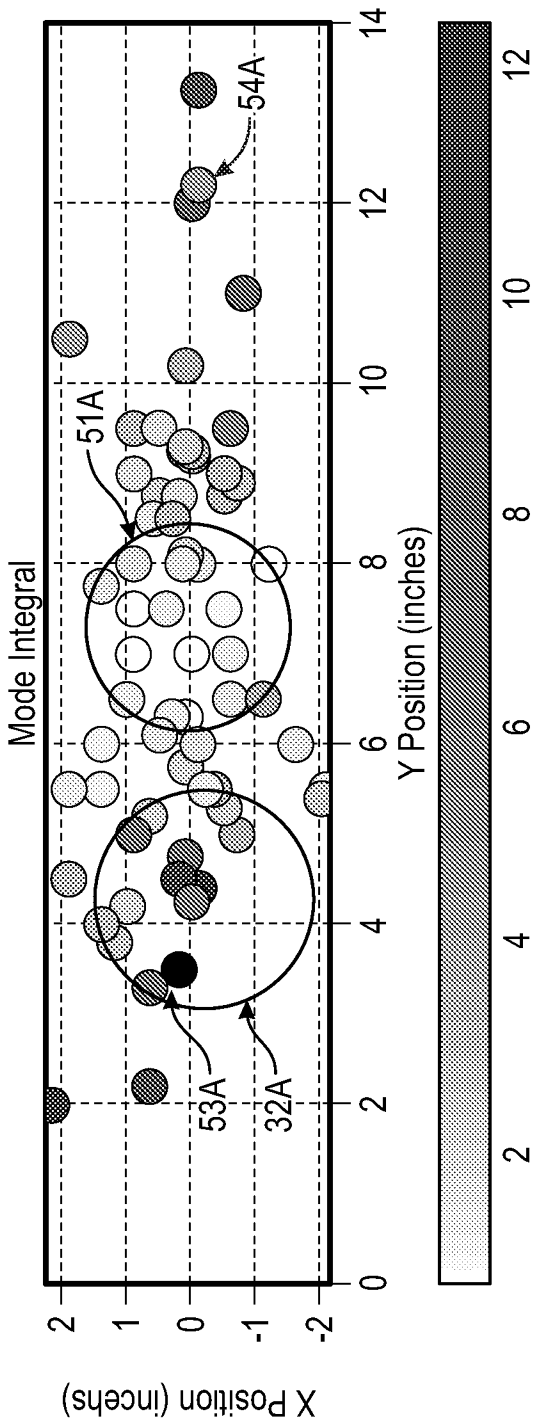
Mode Integral
X Position (incehs)
Y Position (inches)
51A
53A
32A
54A
2
1
0
-1
-2
0
2
4
6
8
10
12
14

FIG. 5

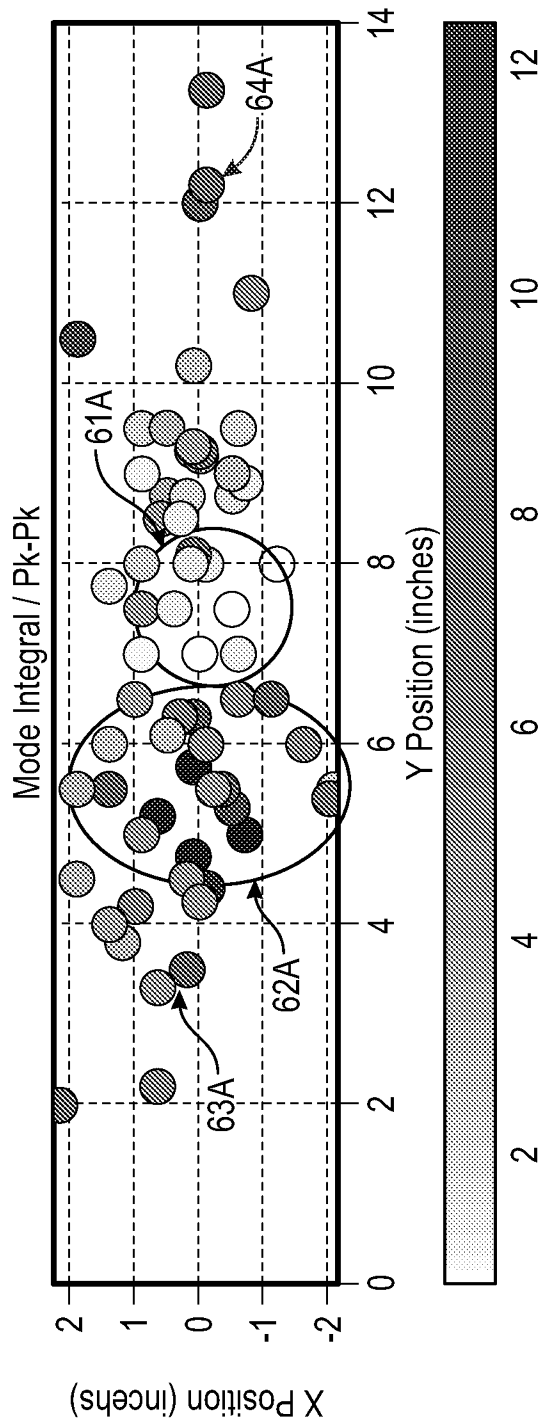
Mode Integral / Pk-Pk
X Position (incehs)
Y Position (inches)
61A
62A
63A
64A
2
1
0
-1
-2
0
2
4
6
8
10
12
14

FIG. 6

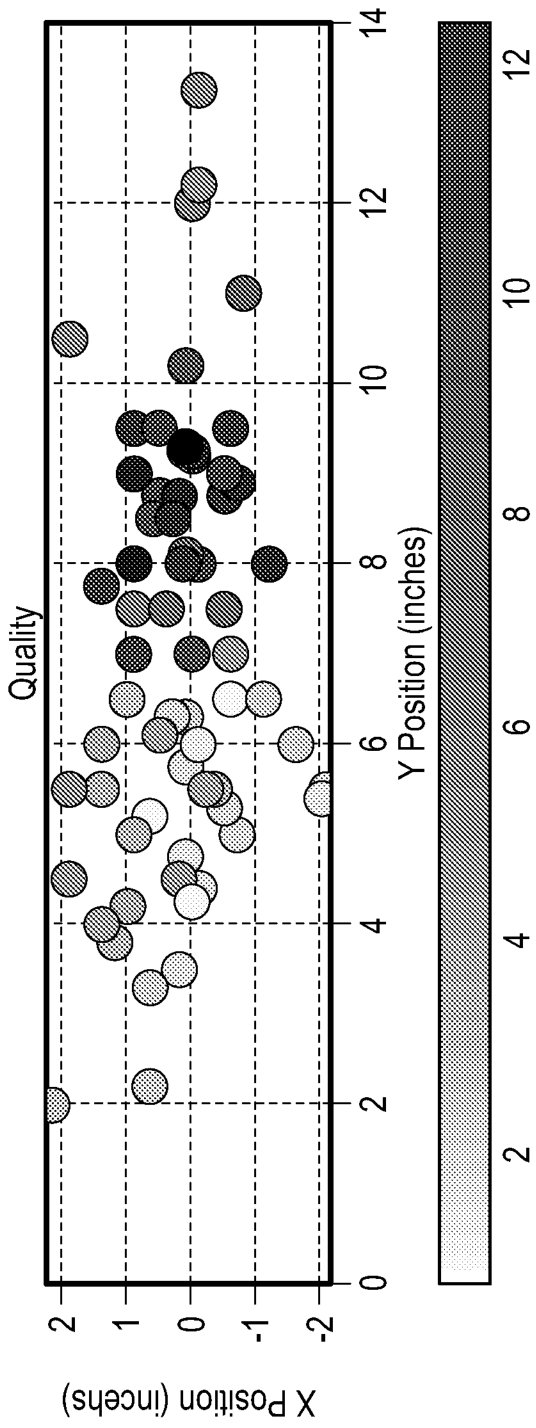
Quality
X Position (incehs)
Y Position (inches)
2
1
0
-1
-2
0
2
4
6
8
10
12
14

FIG. 7

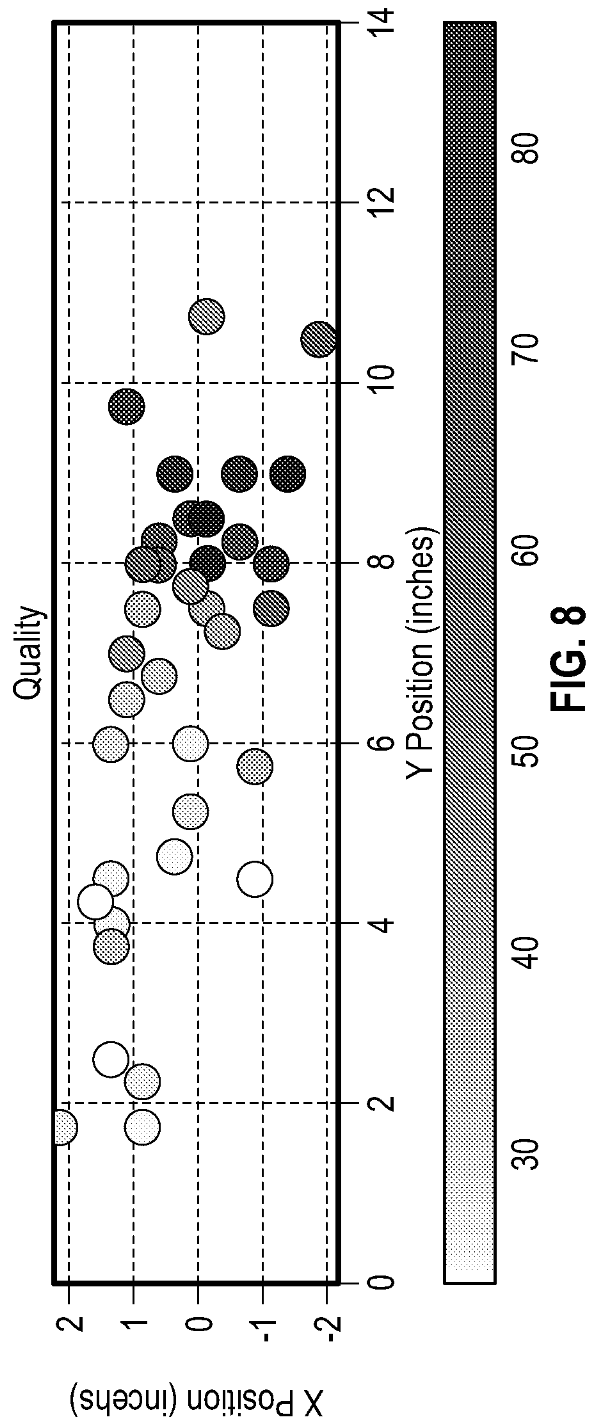
Quality
X Position (incehs)
Y Position (inches)
2
1
0
-1
-2
0
2
4
6
8
10
12
14
30
40
50
60
70
80

FIG. 8

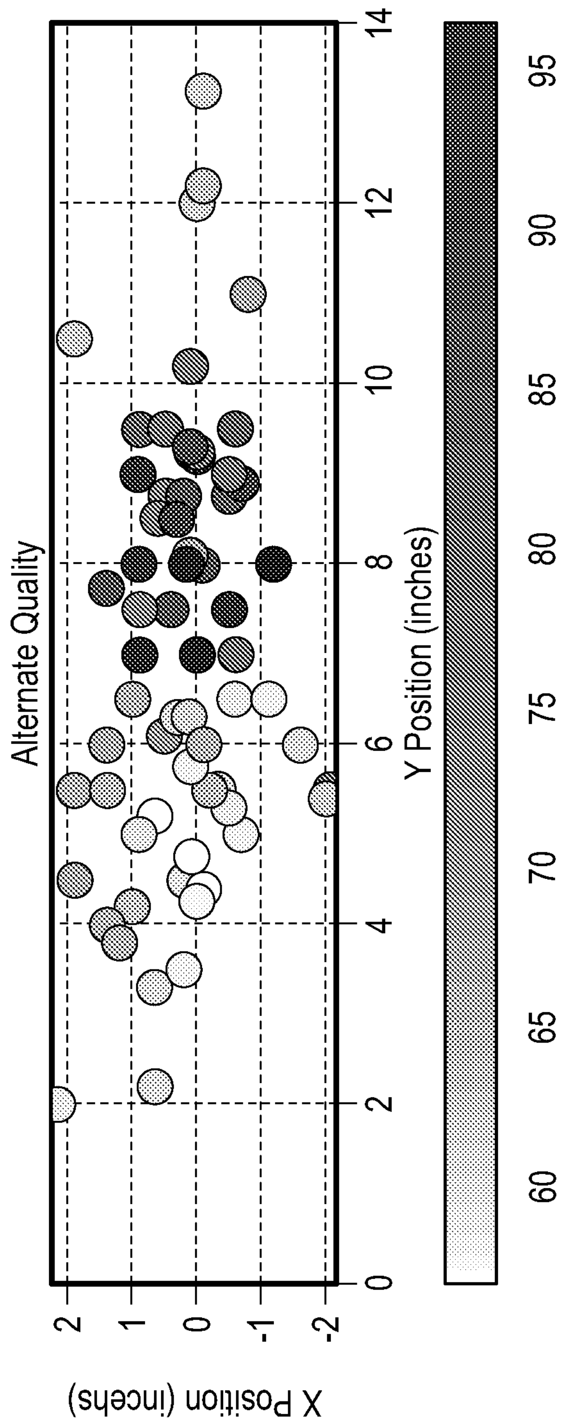
Alternate Quality
Y Position (inches)
X Position (incehs)
0
2
4
6
8
10
12
14
2
1
0
-1
-2
60
65
70
75
80
85
90
95

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/057957

A. CLASSIFICATION OF SUBJECT MATTER

A63B 24/00(2006.01)i, A63B 60/46(2014.01)i, G01H 11/00(2006.01)i, A63B 71/06(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A63B 24/00; A63B 69/00; A63B 69/36; A63B 6900; G01H 11/08; G01P 15/08; H04N 5/225; A63B 60/46; G01H 11/00; A63B 71/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: bat-ball sports, motion, vibration, detect

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018-0021653 A1 (BLAST MOTION INC.) 25 January 2018 See paragraphs [0006]-[0013], [0050]-[0064] and figures 1, 13.	1
Y		2-17
DY	US 2017-0343410 A1 (FUTURE TECHNOLOGIES IN CRICKET (FTIC)) 30 November 2017 See paragraphs [0007]-[0010], [0029]-[0062] and figures 1-3.	2-17
A	US 6173610 B1 (ROBERT L. PACE) 16 January 2001 See column 4, line 54 - column 6, line 39 and figures 1-15.	1-17
A	US 5056783 A (ROBERT R. MATCOVICH et al.) 15 October 1991 See column 9, line 18 - column 11, line 47 and figures 12-14.	1-17
A	US 2018-0169473 A1 (CASIO COMPUTER CO., LTD.) 21 June 2018 See paragraphs [0039]-[0057].	1-17

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 February 2020 (19.02.2020)	**20 February 2020 (20.02.2020)**

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