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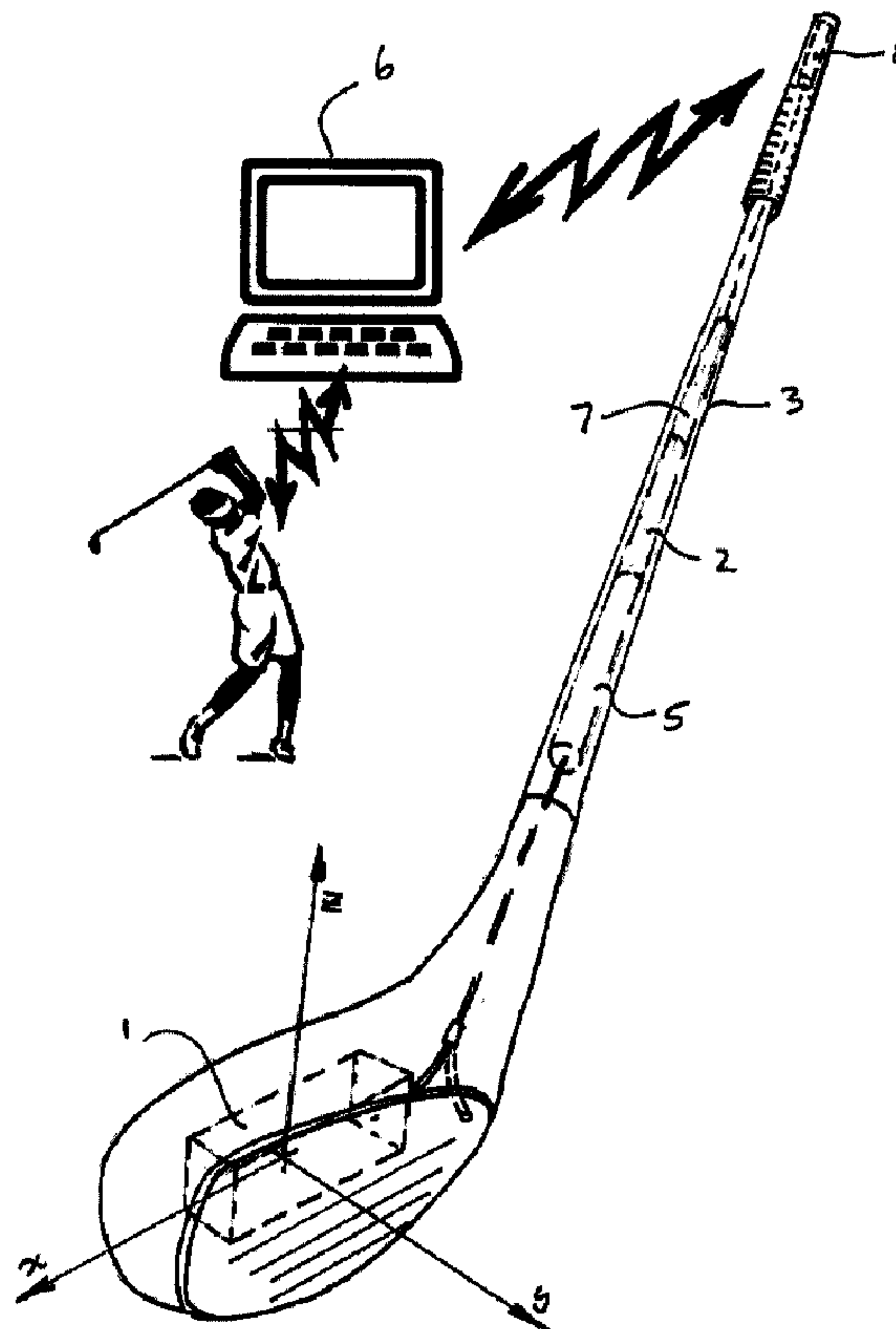
(71) Demandeur/Applicant:
MECHWORKS SOFTWARE, INC., CA

(72) Inventeurs/Inventors:
TUER, KEVIN, CA;
GOLNARAGHI, FARID, CA

(74) Agent: OGILVY RENAULT

(54) Titre : BATON DE GOLF PROPRIOCEPTIF PERMETTANT L'ANALYSE, LA CORRECTION ET LE CONTROLE

(54) Title: PROPRIOCEPTIVE GOLF CLUB WITH ANALYSIS, CORRECTION AND CONTROL CAPABILITIES



(57) Abrégé/Abstract:

A method of analysing the swing of a sport implement and player over time in three dimensional space involving implanting implement sensors at numerous locations in the implement adapted for measurement of linear motion on three axes and angular motion on said three axes, such as: linear motion inertial sensors; angular motion sensors; axial strain gauges; flexural



(57) Abrégé(suite)/Abstract(continued):

strain gauges; and torsional strain gauges. Player sensors are set at a number of locations on the player's body, also adapted for measurement of linear motion on three axes and angular motion on said three axes. Data from the sensor suites are communicated via a wireless communications device to a processing unit by: infrared; radio frequency; or the Bluetooth system. Data is processed from the sensor units to derive an output communicated to the player via an interface such as: visual graphics display; text display; sound interface; tactile device; and vibratory device. The output includes an actuator signal communicated to actuator units engaging at least two actuatable portions of the sport implement moveable relative to each other, such as: solenoids; fluid power cylinders; piezoelectric actuators; magnetic actuators; magneto-restrictive actuators; and rheological fluid actuators.

ABSTRACT

A method of analysing the swing of a sport implement and player over time in three dimensional space involving implanting implement sensors at numerous locations in the
5 implement adapted for measurement of linear motion on three axes and angular motion on said three axes, such as: linear motion inertial sensors; angular motion sensors; axial strain gauges; flexural strain gauges; and torsional strain gauges. Player sensors are set at a
10 number of locations on the player's body, also adapted for measurement of linear motion on three axes and angular motion on said three axes. Data from the sensor suites are communicated via a wireless communications device to a processing unit by: infrared; radio
15 frequency; or the Bluetooth system. Data is processed from the sensor units to derive an output communicated to the player via an interface such as: visual graphics display; text display; sound interface; tactile device; and vibratory device. The output includes an actuator
20 signal communicated to actuator units engaging at least two actuatable portions of the sport implement moveable relative to each other, such as: solenoids; fluid power cylinders; piezoelectric actuators; magnetic actuators; magneto-restrictive actuators; and rheological fluid
25 actuators.

**PROPRIOCEPTIVE GOLF CLUB
WITH ANALYSIS, CORRECTION AND CONTROL CAPABILITIES**

TECHNICAL FIELD

5 The invention relates to a method of sensing motion, analysing, correcting and controlling the use of sporting implements such as golf clubs, tennis racquets, and baseball bats, that are swung in 3D space using intelligent active electronic sensing, signal processing,
10 actuating, vibration dampening, motion computing and displaying components. The invention may also be used in other applications involving sensing and/or controlling of motion in 3D space such as automotive, aerospace, mining, and self sensing, autonomous toys, to name a few.

15 **BACKGROUND OF THE ART**

A proprioceptive golf club or other sporting instrument is one which includes sensors and electronics to provide signals from within the golf club itself.

U.S. Patent No. 3,945,646 to Hammond, for example,
20 includes a golf club with measurement system having accelerometers in the golf club head, a torque strain gauge in the golf club shaft as well as a flex strain gauge, radio transmitter and battery power source. FM radio transmission is received by a remote receiver and
25 signals are fed into a computer, which analyses the data and organizes it for display and processing.

U.S. Patent No. 5,779,555 to Nomura et al. provides another example of prior art swing type athletic equipment with a tri-axial acceleration sensor that

accurately determines whether or not a golf ball has been hit on the "sweet spot" of a golf club head.

U.S. Patent No. 5,941,779 to Zeiner-Gundersen also provides a golf club swinging training device which
5 includes two directional gyroscopes, power source, a set of sensors and alarms to give an audible or tactile alarm when the golf swing is outside of each gyroscope's predetermined and set rotating direction.

U.S. Patent No. 3,717,857 to Evans discloses a wrist
10 mounted measurement system for transmitting a signal from strain gauges and accelerometers to analyse, compare and correct the swing of a baseball player wrist during practice sessions.

U.S. Patent No. 5,056,783 to Matcovich et al. discloses a
15 baseball bat with acceleration measurement that transmits a signal to a processor for display of the swing performance.

Further objects of the invention will be apparent from review of the disclosure, drawings and description of the
20 invention below.

DISCLOSURE OF THE INVENTION

The invention comprises a method of sensing motion, analysing, correcting and controlling the use of sporting implements such as golf clubs, tennis racquets, and
25 baseball bats, that are swung in 3D space using intelligent active electronic sensing, signal processing, actuating, vibration dampening, motion computing and displaying components.

Specifically, the invention provides a method of analysing the swing of a sport implement and player over time in three dimensional space involving implanting implement sensors at numerous locations in the implement adapted for measurement of linear motion on three axes and angular motion on said three axes, such as: linear motion inertial sensors; angular motion sensors; axial strain gauges; flexural strain gauges; and torsional strain gauges. Player sensors are set at a number of locations on the player's body, also adapted for measurement of linear motion on three axes and angular motion on said three axes. Data from the sensor suites are communicated via a wireless communications device to a processing unit by: infrared; radio frequency; or the Bluetooth system. Data is processed from the sensor units to derive an output communicated to the player via an interface such as: visual graphics display; text display; sound interface; tactile device; and vibratory device. The output includes an actuator signal communicated to actuator units engaging at least two actuatable portions of the sport implement moveable relative to each other, such as: solenoids; fluid power cylinders; piezoelectric actuators; magnetic actuators; magneto-restrictive actuators; and rheological fluid actuators.

For example, a golf club can be constructed according to the invention with a suite of inertial sensors, specifically a combination of MEMS (Micro Electro-Mechanical Systems) accelerometers and rate gyro sensors, able to sense and measure the club's own motion. The invention also considers the golfer wearing one or more

sensor suites to measure the motion of the golfer throughout the golf swing. The measurements made by the sensor suites are then used in combination to analyse the dynamics and mechanics of the golfer's swing and club/ball impact using Inertial Navigation Systems (INS) techniques, compare the swing performance to the optimal case, make recommendations for improvement, and effect active control to reduce vibrations as a result of club impact with the ball. In order to remove sensor or other sources of noise, sophisticated methods of filtration and signal processing such as Kalman Filters, state observers, low pass filters, and other means of embedding modelled and/or empirical knowledge of the motion of the golf club are used in hardware and software.

The invention can be applied to any sporting implement and includes software and hardware with one or more inertial/vibrational/torsional Sensor Suite(s) installed on/within the sporting implement and attached to the user, an Electronics Package, a Power Source, a Computational Capability, a Display Device, an Actuator Suite, and Communications Links to facilitate the exchange of information between components.

The invention may also be used in other applications involving motion in 3D space such as automotive, aerospace, mining, and self sensing, autonomous toys to name a few. Further advantages of the invention will be apparent from the following detailed description and accompanying drawings.

DESCRIPTION OF THE DRAWINGS

In order that the invention may be readily understood, one embodiment of the invention is illustrated by way of example in the accompanying drawings.

5 Figure 1 is a schematic perspective view of a golf club containing a sensor suite comprised of linear and rotational sensors located in the club head, a sensor suite comprised of linear and rotational sensors attached to the user, vibration dampening actuators in the shaft
10 as well as shaft sensors, a RF transmitter and power source for each sensor suite, with a computer housing RF receiver and the computational capability, electronics package, and display devices.

Figure 2 is a schematic diagram indicating the
15 integration of various components.

Figure 3 is a schematic diagram indicating the physical and communications interfacing of the components.

Figure 4 is a schematic diagram of the underlying software/hardware/firmware platform of the invention
20 indicating the communications, signal processing, Inertial Navigation System techniques, embedded modelled and/or empirical knowledge, and interfacing of the components.

Further details of the invention and its advantages will
25 be apparent from the detailed description included below.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The device is comprised of software and hardware comprising one or more Sensor Suites (club mounted and

user mounted), an Electronics Package, a Power Source, a Computational Capability, a Display Device, an Actuator Suite, and Communications Links to facilitate the exchange of information between components.

5 Features of the Sensor Suite include the following:

The Sensor Suite will be able to measure up to 6 degrees of motion (linear motion in three axes and angular motion in three axes).

Linear motion shall be measured using inertial sensors
10 (i.e. sensors that can measure low frequency and constant signals) such as MEMS accelerometers or custom sensors. This signal will be integrated in hardware or software to provide acceleration, speed and position information relative to an earth based reference frame.

15 Angular motion shall be measured using inertial sensors such as MEMS gyroscopes, angular accelerometers, multiple linear accelerometers, or custom sensors. This signal will be integrated in hardware or software one or more times to provide angular speed and position information
20 relative to the moving reference frame. In addition to defining club face angles, this information will be used to resolve the linear accelerometer signals into the appropriate earth based co-ordinates (prior to integration) and to facilitate the implementation of a
25 gravity compensation mechanism.

The Sensor Suite will accommodate a GPS or DGPS positioning system capability. The Sensor Suite will measure sufficient signals to provide all or some of the following information: acceleration, speed, position, in

both translation and rotation, of one or more points on the club head, on the club shaft, or on the user (e.g. the shift of the centre of swing rotation, the wrist cock angle, etc.); ball/club head impact point; point of
5 ball/club impact with respect to the club head speed curve; angle of the club face at impact; the effective loft angle of the club at impact; tempo of the swing; and vibration induced within the club shaft.

The Sensor Suites will be embedded in the club head
10 (block 1 shown in Fig. 1) or shaft (block 2), mounted on the club shaft 3, or attached to the user 4 (e.g. wrist, waist, neck, etc.).

Features of the Electronics Package may include circuits
5 mounted in the club shaft 3 and as follows. The Electronics Package is comprised of a microcontroller and
15 memory for storage of collected information. The Electronics Package may also contain drivers and hardware to support communication of data. The Electronics Package will possess the capability of initialising,
20 resetting and otherwise controlling the Sensor Suites.

The microcontroller will read in information from the sensors at a pre-specified rate and associate a time base with each piece of data. The microcontroller may contain part or all of the Computational Capability. The
25 microcontroller may also implement vibration or other control laws. The microcontroller may also drive control actuators 7, such as solenoids, fluid power cylinders, piezoelectric materials, magnetic devices, magneto-restrictive or rheological fluids, or other custom
30 designed actuation means. The microcontroller will

control the communication of information to the display device, such as computer monitor or a specially designed display console.

5 The Electronics Package 8 will be embedded within the golf club head or shaft, will be mounted externally on the shaft, or will be attached to the user.

Features of the Power Source include the following. The Sensor Suite will be powered using the device's battery power pack. The Electronics Package will be powered
10 using the device's battery power pack. The Display Device local to the golf club will be powered using the device's battery power pack or its own power source. The Display Device local to the golfer will be powered via its own power source. The Display Device remotely
15 located will be powered via its own power source. The Actuator Suite will be powered using the device's battery power pack.

Features of the Computational Capability include the following. The Computational Capability will derive,
20 from the sensor data, acceleration, speed, and position information in both translation and rotation, movement of the centre of swing rotation, club head/ball impact characteristics, club face angle at impact, effective loft angle at impact, wrist cock angle, and tempo
25 profiles.

The Computational Capability will process sensor data and generate a control signal to drive the actuator suite. The Computational Capability will generate a time base which is to be associated with the data. The
30 Computational Capability will be able to compare raw and

derived information to an optimal case and make recommendations for improved performance. The Computational Capability will formulate an interactive mathematical model using the collected swing data and
5 provide a swing simulation capability. In addition, the user will be able to change key parameters of the swing model to ascertain the effect on swing performance. The Computational Capability will include advanced filtration and signal processing techniques such as Kalman filters,
10 state estimators, observers, and low pass filters to effectively reduce noise and to estimate and predict motion. The Computational Capability will be capable of storing, re-displaying and printing graphical and/or numeric data associated with the golf swing.

15 Features of the Communications Links include the following. There will be three primary Communications Links - Sensor Suite(s) to Electronics Package, Electronics Package to Actuator Suite, and Electronics Package to Display Device. The Sensor Suites to
20 Electronics Package Communications Link is used to transmit signals from each sensor in the sensor suite to the microcontroller. The Electronics Package to Actuator Suite Communications Link is used to transmit control signals generated by the Electronics Package to the
25 actuators. The Electronics Package to Display Device Communications Link is used to transmit performance information for display to the user. This link also passes commands issued by the user via the Display Device to the Electronics Package. Each of these Communications
30 Links will be via wired or wireless means (e.g. infrared (IR), radio frequency (RF), Bluetooth, etc.).

Features of the Display Device 6 include the following. Information regarding the golfer's swing statistics will be communicated to a Display Device. The Display Device is local to the golfer, local to the golf club, or
5 remotely located. The Display Device local to the golf club may be mounted on the golf club shaft. A Display Device local to the golfer could be wrist mounted (e.g. watch), belt or waist mounted or a device hung around the golfer's neck. A Display Device remotely located may
10 include a personal data system (e.g. PalmPilot™), a laptop or notebook computer, a desktop computer, a personal gaming device (e.g. Gameboy™) or any other remote device capable of computation and display of data. The Display Device may contain part or all of the
15 Computational Capability. The Display Device will have the capability to store raw data and display raw or processed data in graphical or numeric format. The Display Device will be capable of accepting commands from the user regarding the operation of the invention via a
20 graphical user interface, a text based menu or a command line.

Features of the Actuator Suite include the following. The Actuator Suite will be comprised of active or passive actuators for the purpose of controlling the dynamics of
25 the club head or club shaft, including vibration. The Actuator Suite 7 will be attached to or embedded within the club head or club shaft. This technology is applicable to a variety of sports instruments for which golfing is but one example. Other examples include
30 baseball bats, tennis or racquetball racquets, cricket bats and fencing swords. Although the above description

relates to a specific preferred embodiment as presently contemplated by the inventor, it will be understood that the invention in its broad aspect includes functional equivalents of the elements described herein.

5 The invention may also be used in other applications involving sensing and/or controlling motion in 3D space such as automotive, aerospace, mining, and self sensing, autonomous toys to name a few.

The invention includes full 6 degree-of-freedom (DOF)
10 motion sensing and measurement capabilities (3 DOF in translation, 3 DOF in rotation). Prior art typically incorporates a sensor suite of reduced measurement capability (i.e. less than 6 DOF) and the adoption of assumptions regarding the motion of the club (e.g. US
15 5779555, US 5233544, US 3717857).

Both the golf club and the player be instrumented with sensor suites and data be collected from each. This collected data will be fused to perform the analysis. For example, the club path information derived from the club
20 mounted sensor suite will be combined with the shift motion of the user measured using the player mounted sensor suite to isolate characteristics of the swing. Prior art shows instrumentation of the club (e.g. US 5779555, US 5233544) or instrumentation of the user but
25 not instrumentation of both and the combined use of data to analyse the swing.

Given a complete data set, the swing can be scrutinised to indicate source of problems - not just indicate that a problem exists. Quite often, prior art shows devices
30 with capabilities to indicate that there is a problem

with the swing (e.g. US 5779555) but there are often several possible sources of the problem, which the devices fail to identify.

Given the ability to define sources of problems,
5 recommendations for correcting swing problems can be made. Many of the analysis and training devices are able to provide feedback (e.g. audible, tactile) that a problem exists (e.g. US 5941779) but fail to quantify the depth of the problem or suggest recommendations for
10 corrections.

Using the data collected from the swing, an accurate mathematical model of a user's golf swing is developed. This model can be used for parametric analysis studies to see how changing aspects of the swing can change the
15 swing performance. Prior art shows some devices with the capability to replay the swing or display characteristics of the swing (e.g. US 5056783) but none have been found that develop a mathematical model of the swing. Further, the use of Inertial Navigation Systems and advanced
20 signal processing methods such as Kalman Filters, state estimators and observers, as well as embedded modelled or empirical knowledge of golf club motion have not been addressed.

An optimal trajectory and swing parameters may be
25 obtained for the player. Using the data collected from the sensor suite, a full dimensional path of the club can be defined in an earth fixed or inertial reference frame. Most of the prior art shows the use of video systems or external, earth fixed measuring devices to measure club
30 trajectory.

Using the club head orientation information, the acceleration, velocity, and position data can be resolved into their components to identify problems with the swing. Once again, prior art does not show this being
5 done to the proposed level of kinematics detail (i.e. 6 degrees of freedom).

Parameter by parameter comparison capability to a standard or optimal swing is possible. This is made possible by the availability of full kinematics
10 information, which is not present in the prior art.

Given complete kinematics information and a mathematical model, information regarding the use of the player's muscles can be derived. Although prior art includes muscle trainers, none are known to quantify the degree of
15 use of muscles in generating a swing.

The invention has the ability to communicate via wired or wireless means to a variety of new display and computational devices, such as a PalmPilot™, a GameBoy™, etc.. Although prior art shows the use of both wired and
20 wireless communication (e.g. US 5233544, US 5056783), specific application level details differ with the availability of new display devices.

The user mounted sensor suite can be used to define body characteristics such as trunk angle tilt, body rotation, shift of the centre of rotation, arm motion, weight
25 shift, etc., all of which are known to effect swing performance. US Patent 5233544, Claim 4 makes some mention of this concept but in little detail.

Depending on the display device of choice, the invention can be self-contained and portable.

Having a complete set of swing information available means that many aspects of the swing can be analysed
5 using the same device. Prior art shows existing devices target only certain aspects of a swing.

Club face angle can be measured in two directions because of full orientation data being available. One of these angles will provide information on the effective loft
10 angle of the club, which is known to affect ball trajectory. Prior art shows measurement of club face angle in one direction (e.g. US 3945646) but none have been identified that are able to measure the club face angle that defines the effective loft angle of the club.

15 The location of the club face/ball impact point is defined using impact measurements made by the sensor suites. Prior art shows the use of special club faces or sensor arrays (e.g. US 4991850) to accomplish this task.

Active vibration control. Most prior art systems use
20 passive means (e.g. US 5718643, US 5935027) to reduce shaft vibrations. The sensor suite supports the interchangeability of sensors to maximise versatility. Improved performance are realised from the sensor suite by quantifying characteristics of the sensor and
25 embedding this knowledge, be it modelled or empirical, into the platform software.

Significant performance enhancement is achieved via embedded knowledge of the motion of the golf club and the sensor suite. Moreover, embedded knowledge of the motion

of the gold club may result in a reduction in the number of sensors required to generate the full kinematic/dynamic details of the golf swing/club leading to a more cost effective solution.

- 5 Although the above description relates to a specific preferred embodiment as presently contemplated by the inventors, it will be understood that the invention in its broad aspect includes mechanical and functional equivalents of the elements described herein.

WE CLAIM:

1. A method of analysing the swing of a sport implement and player over time in three dimensional space, the
5 sport implement having a manual grip on a shaft supporting a head with a strike face, the method comprising:

10 implanting an implement sensor suite comprising a plurality of implement sensors disposed at a plurality of locations in the implement, the implement sensors adapted for measurement of linear motion on three axes and angular motion on said three axes, the implement sensors selected from the
15 group consisting of: linear motion inertial sensors; angular motion sensors; axial strain gauges; flexural strain gauges; and torsional strain gauges;

 attaching a player sensor suite comprising a
20 plurality of player sensors disposed at a plurality of locations on the player's body, the player sensors adapted for measurement of linear motion on three axes and angular motion on said three axes, the player sensors selected from the group
25 consisting of: linear motion inertial sensors; and angular motion sensors;

 communicating data acquired from the sensor
suits via a wireless communications device to a
30 processing unit, the wireless device selected from

the group consisting of: infrared; radio frequency;
and the Bluetooth system;

5 processing data from the sensor units with the
processing unit to derive an output;

10 communicating the processor output to the
player via an interface selected from the group
consisting of: visual graphics display; text
display; sound interface; tactile device; and
vibratory device; and

15 wherein the output includes an actuator signal
communicated to an actuator suite of actuator units
engaging at least two actuatable portions of the
sport implement moveable relative to each other, the
actuator units selected from the group consisting
of: solenoids; fluid power cylinders; piezoelectric
actuators; magnetic actuators; magneto-restrictive
20 actuators; and rheological fluid actuators.

2. A method according to claim 1 wherein the linear
motion sensor is a micro electromechanical accelerometer.

25 3. A method according to claim 1 wherein the angular
motion sensors are selected from the group consisting of:
micro electromechanical gyroscopes; angular
accelerometers; a plurality of coacting linear
accelerometers.

4. A method according to claim 1 wherein the implement is a golf club and the actuator units are programmed to control the level of vibration induced within the shaft of the golf club.

5

5. A method according to claim 4 wherein the processor output is selected from the group consisting of: sensor position relative to a selected reference; sensor velocity; sensor acceleration; movement of swing rotation center; golf club head impact position; golf club face angle at impact; effective loft angle at impact; wrist cock angle; and swing tempo profile.

6. A method according to claim 1 wherein the processor output includes a parameter by parameter comparison of sensor data with an optimal model data set.

7. A method according to claim 1 wherein the processor output includes player body characteristics selected from the group consisting of: trunk angle tilt; body rotation; center of rotation shift; arm motion trajectory; and center of gravity shift.

8. A method according to claim 1 wherein processor output includes a control signal communicating with the actuator suite.

9. A method according to claim 1 wherein the processing step includes processing techniques selected from the group consisting of: Kalman filtration; state estimation; and extrapolation of data to predict motion.

10. A method according to claim 1 wherein the sport
implement is selected from the group consisting of: golf
clubs; baseball bats; racquets; cricket bats; and fencing
5 swords.

Application number/ Numéro de demande : 2364919

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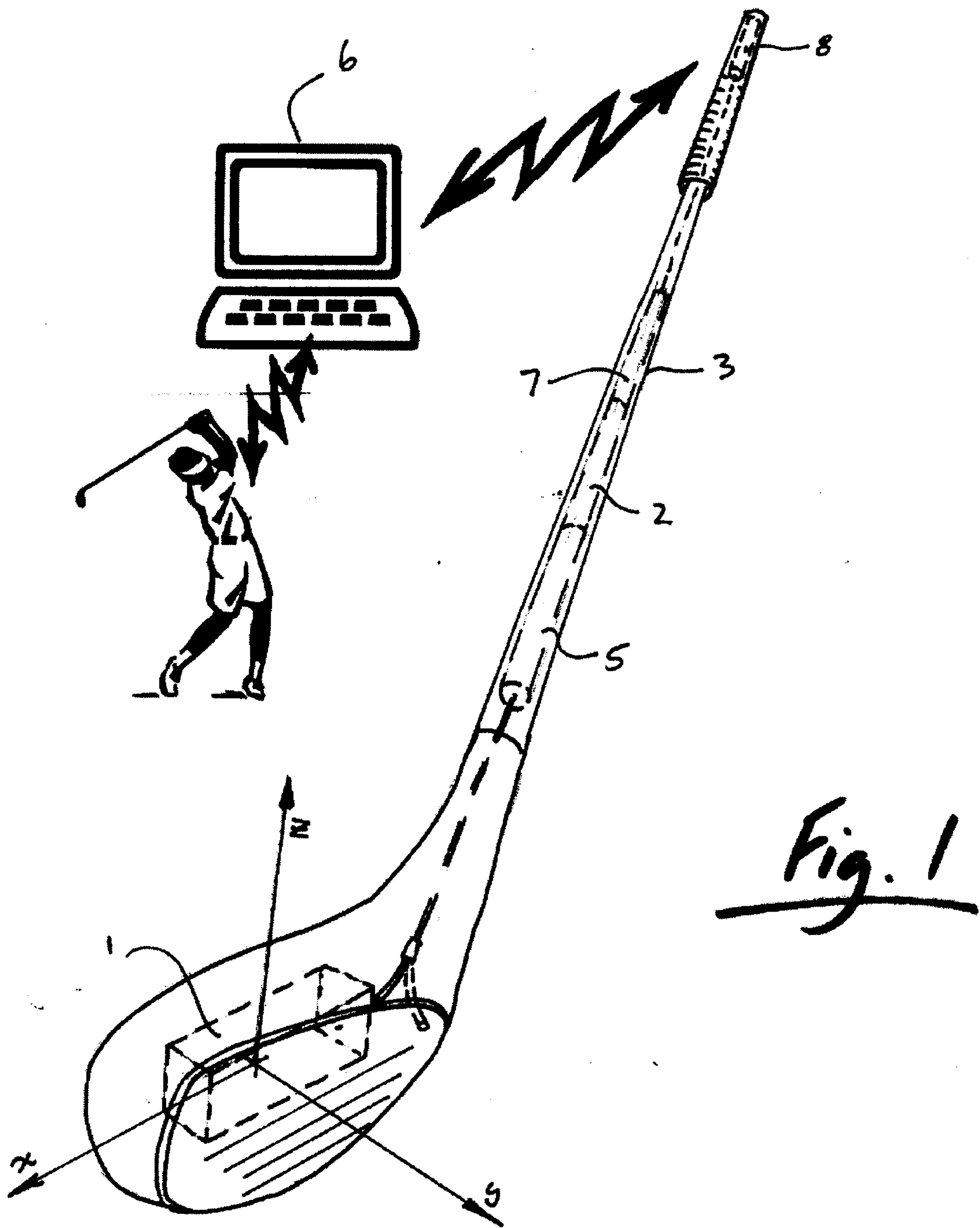
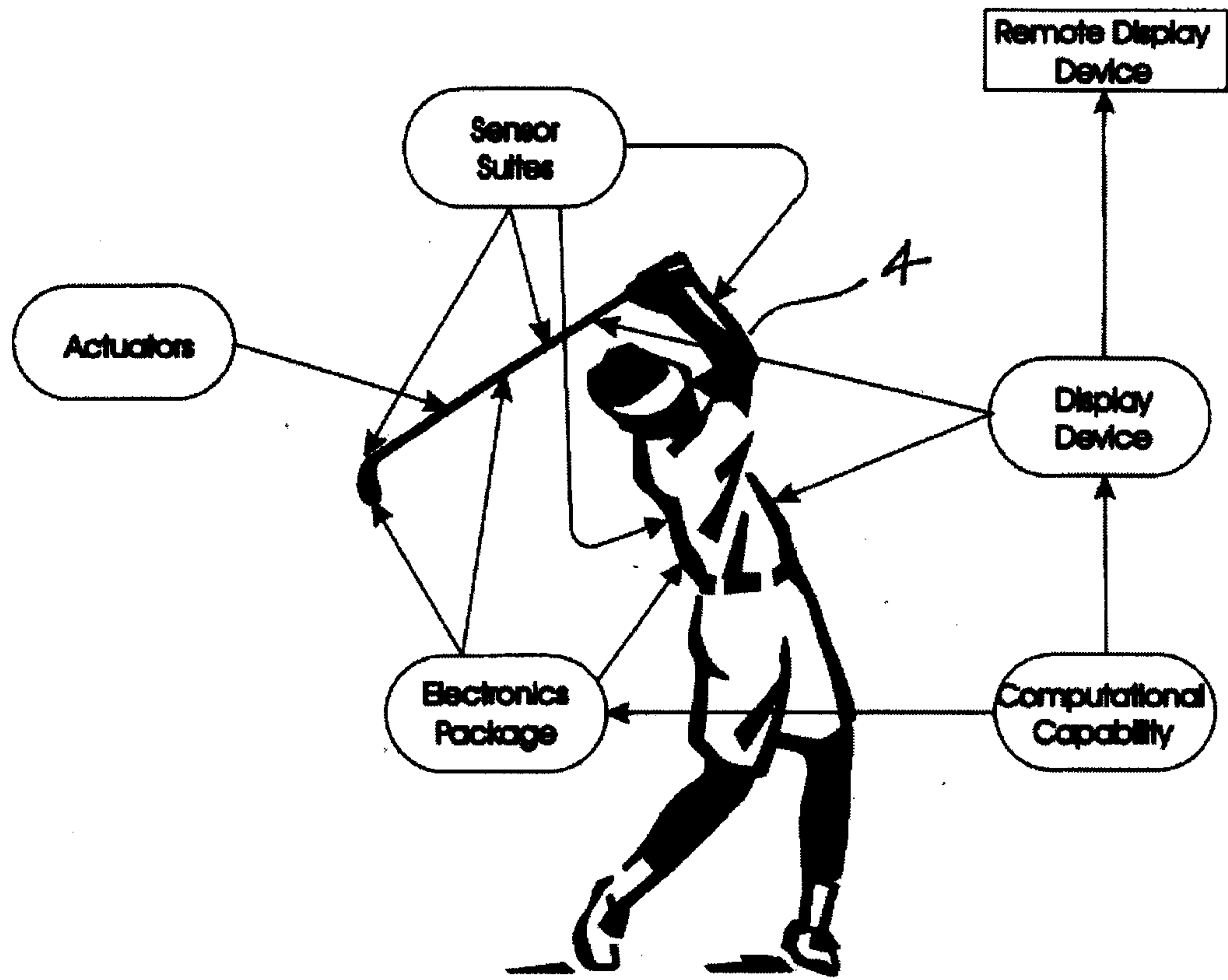


Fig. 1

**Fig. 2**

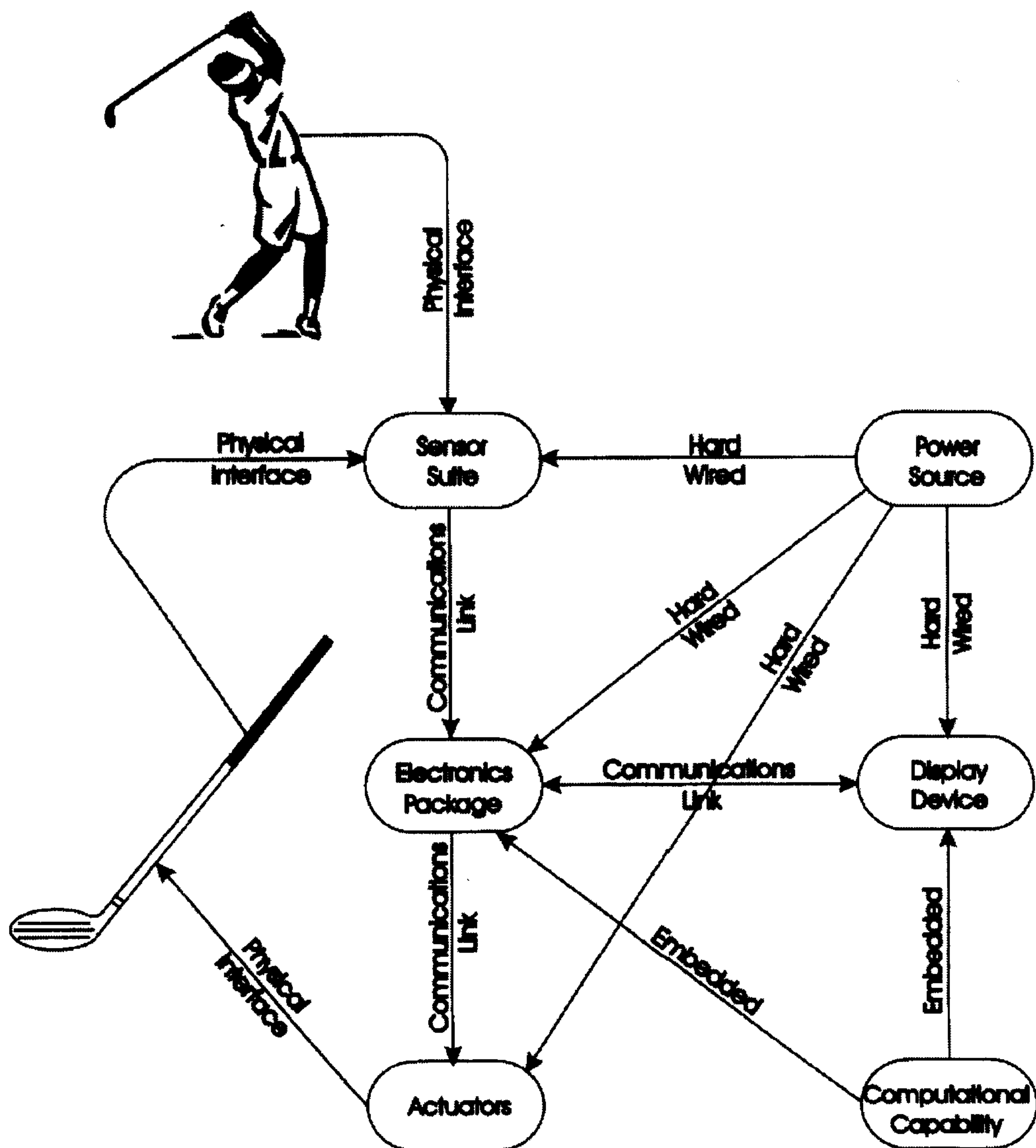
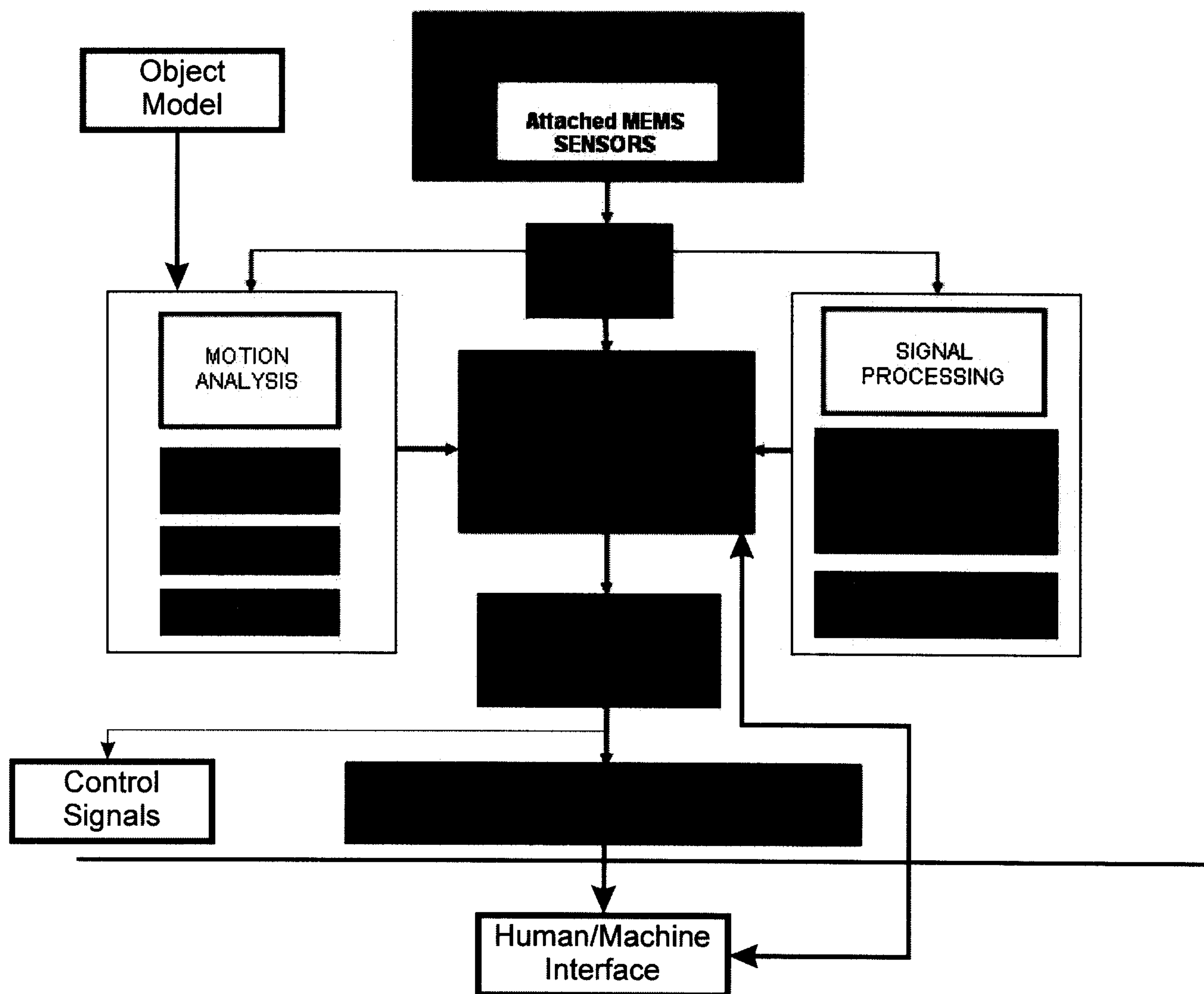


FIG. 3

**Fig. 4**

