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(19) **United States**(12) **Patent Application Publication****Feng et al.**(10) **Pub. No.: US 2014/0080638 A1**(43) **Pub. Date: Mar. 20, 2014**(54) **SYSTEMS AND METHODS FOR PROVIDING TRAINING AND INSTRUCTION TO A FOOTBALL KICKER**

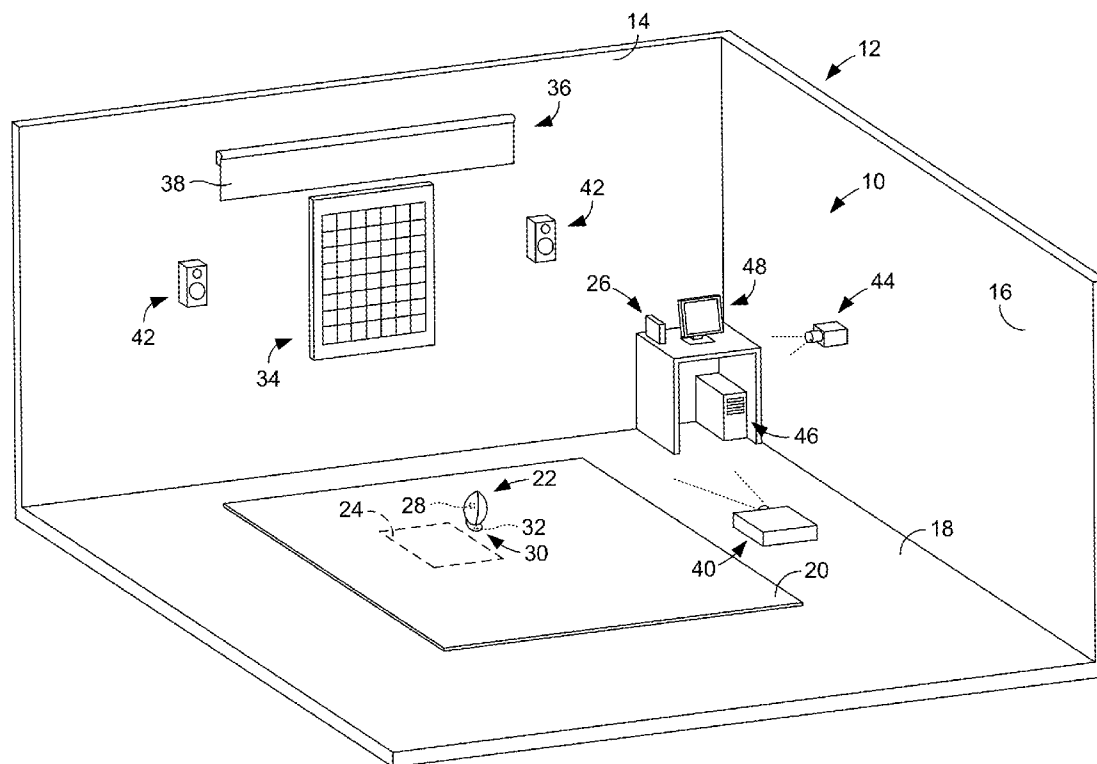
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Publication Classification(51) **Int. Cl.***A63B 69/00* (2006.01)*A63B 24/00* (2006.01)(52) **U.S. Cl.**CPC *A63B 69/002* (2013.01); *A63B 24/0006* (2013.01)USPC **473/439**; 473/422; 473/438(71) Applicants: **Yusheng Feng**, San Antonio, TX (US); **Alyssa Ann Schaeftbauer**, League City, TX (US); **Cole Meyers**, Boerne, TX (US); **Aaron Stout**, San Antonio, TX (US); **Ehren William Biglari**, San Antonio, TX (US); **Jacob Lee Kantor**, San Antonio, TX (US)(72) Inventors: **Yusheng Feng**, San Antonio, TX (US); **Alyssa Ann Schaeftbauer**, League City, TX (US); **Cole Meyers**, Boerne, TX (US); **Aaron Stout**, San Antonio, TX (US); **Ehren William Biglari**, San Antonio, TX (US); **Jacob Lee Kantor**, San Antonio, TX (US)(73) Assignee: **Board of Regents, The University of Texas System**, Austin, TX (US)(21) Appl. No.: **14/032,179**(57) **ABSTRACT**

In one embodiment, kicking training is provided to a kicker in real time by collecting data while the kicker kicks a ball toward a display screen, determining the trajectory of the ball from the collected data, and displaying to the kicker on the display screen a simulation of the flight of the ball within a virtual world.



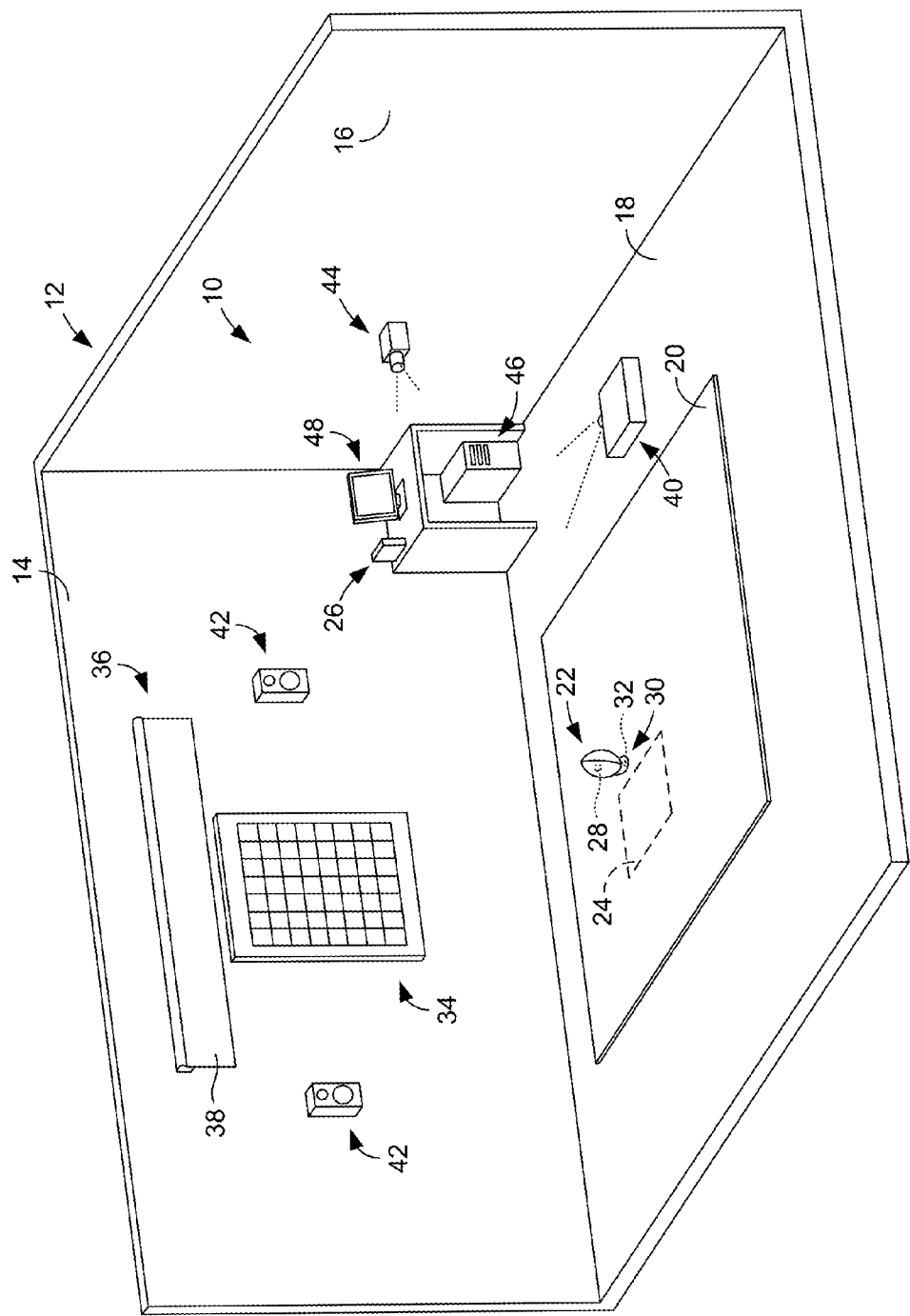


FIG. 1

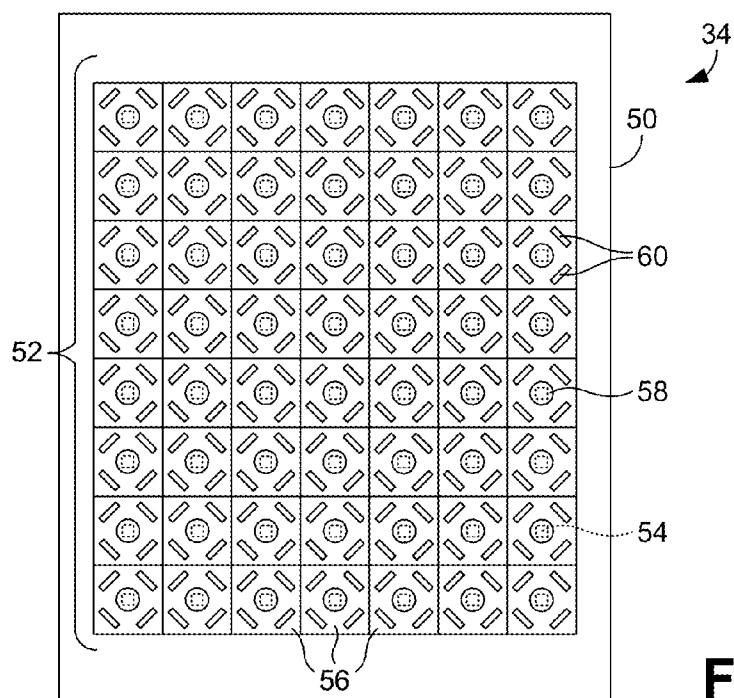


FIG. 2

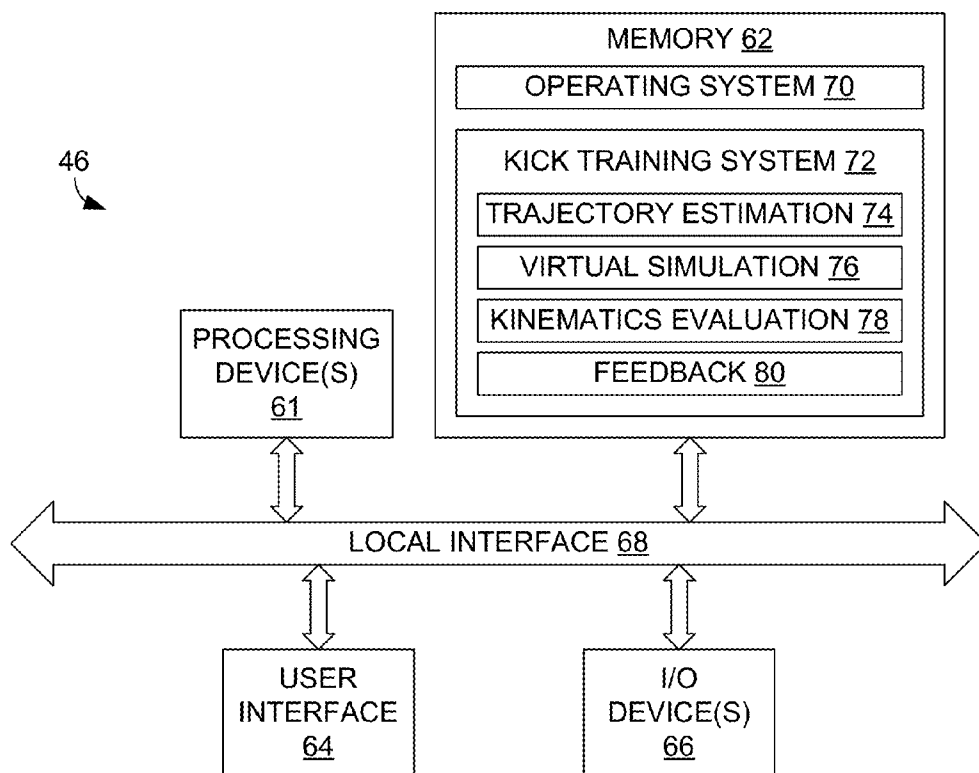
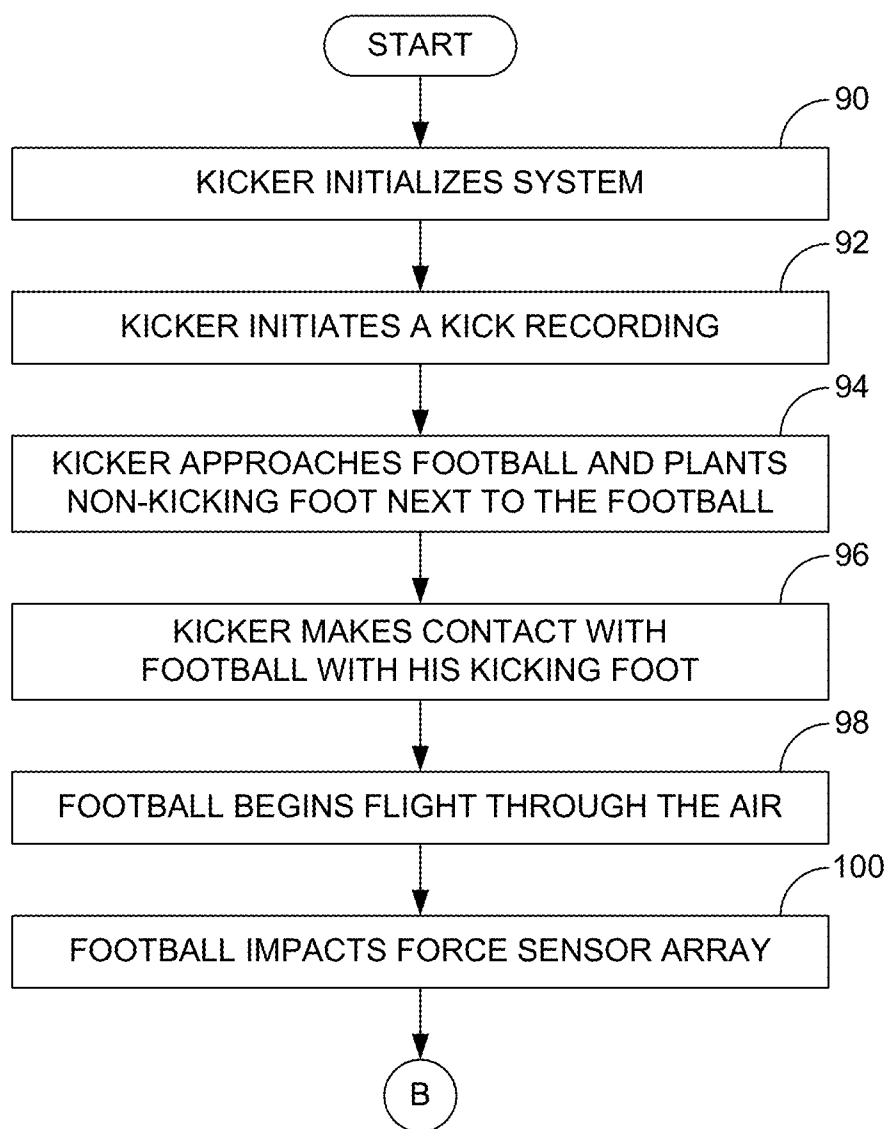
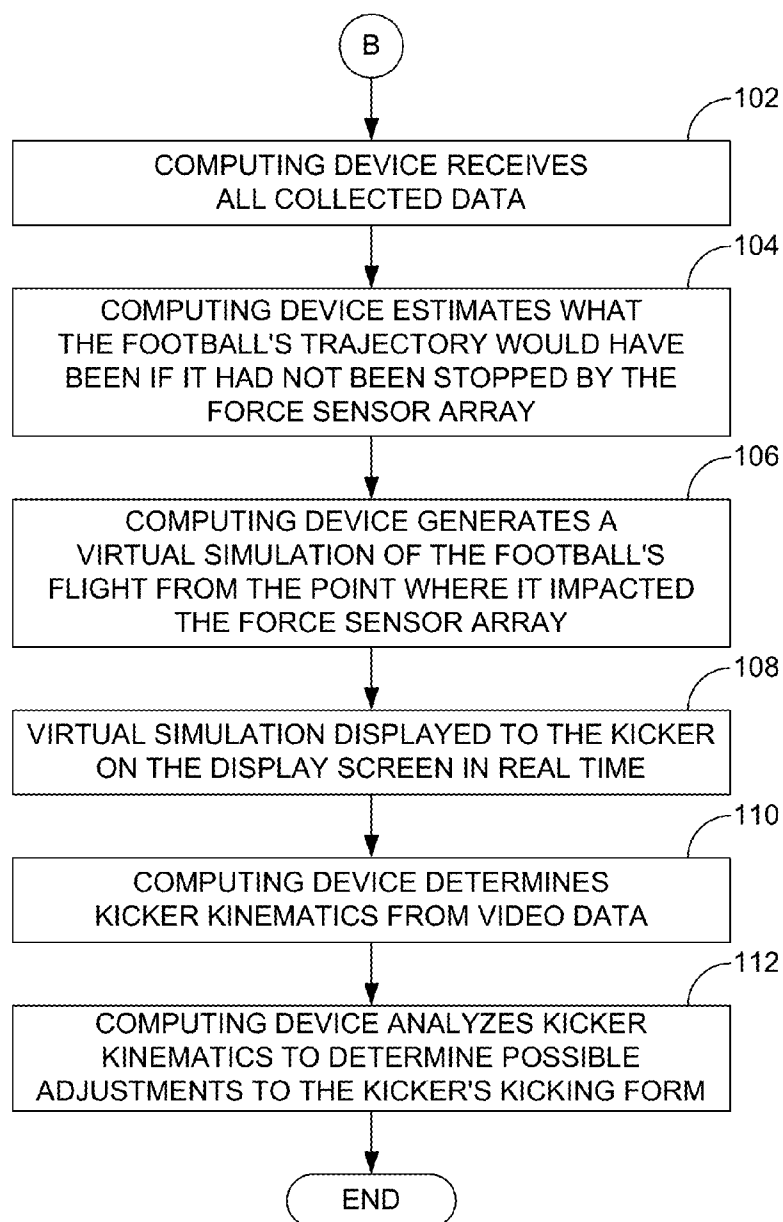


FIG. 3

**FIG. 4A**

**FIG. 4B**

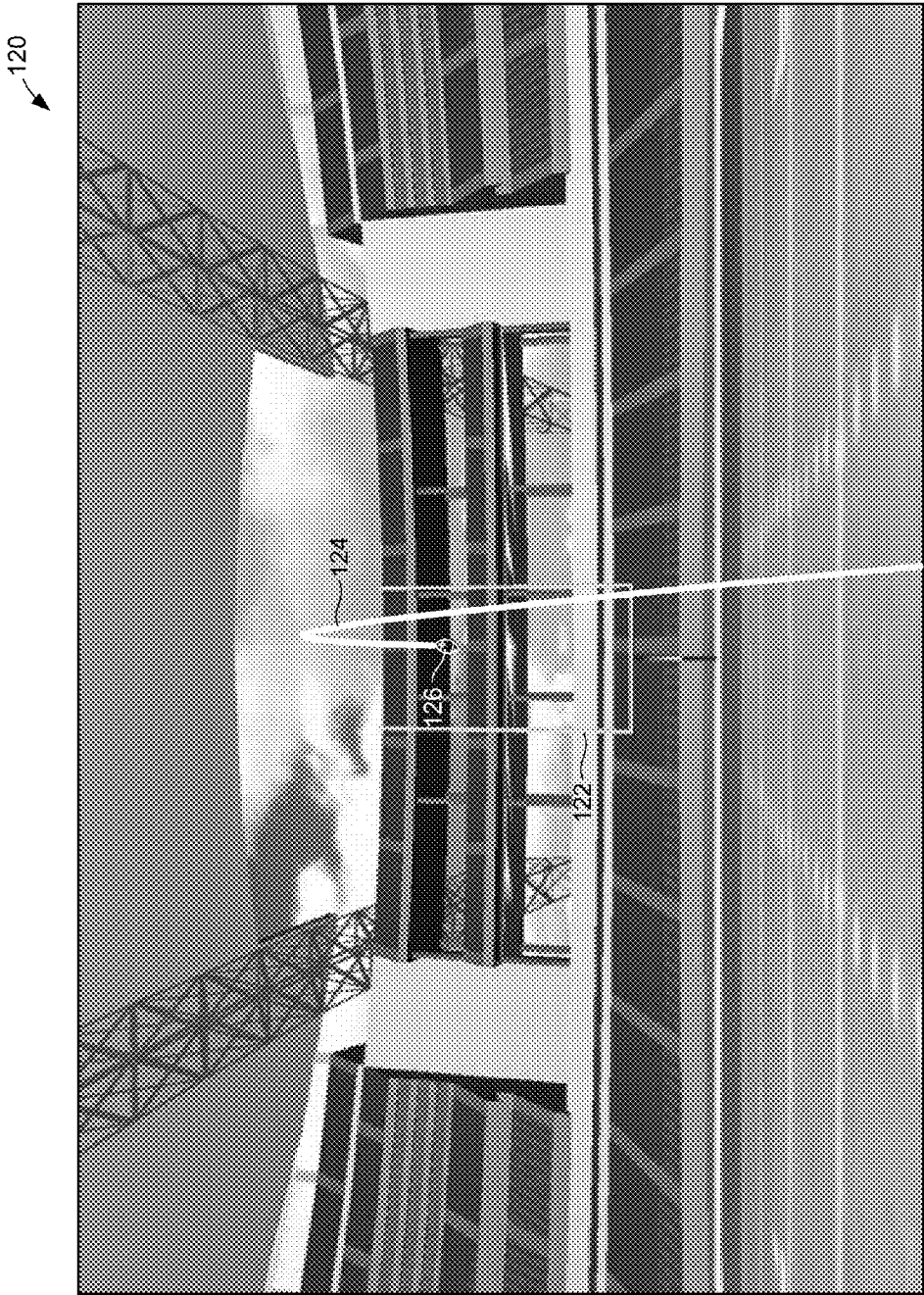


FIG. 5

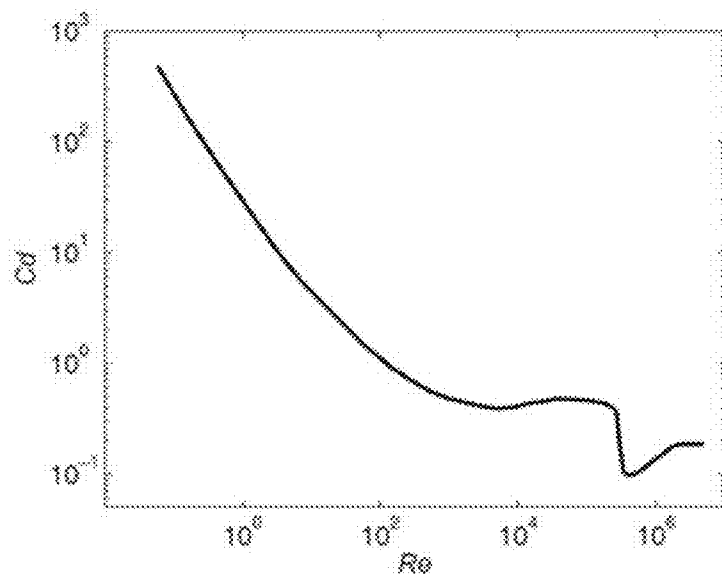


FIG. 6

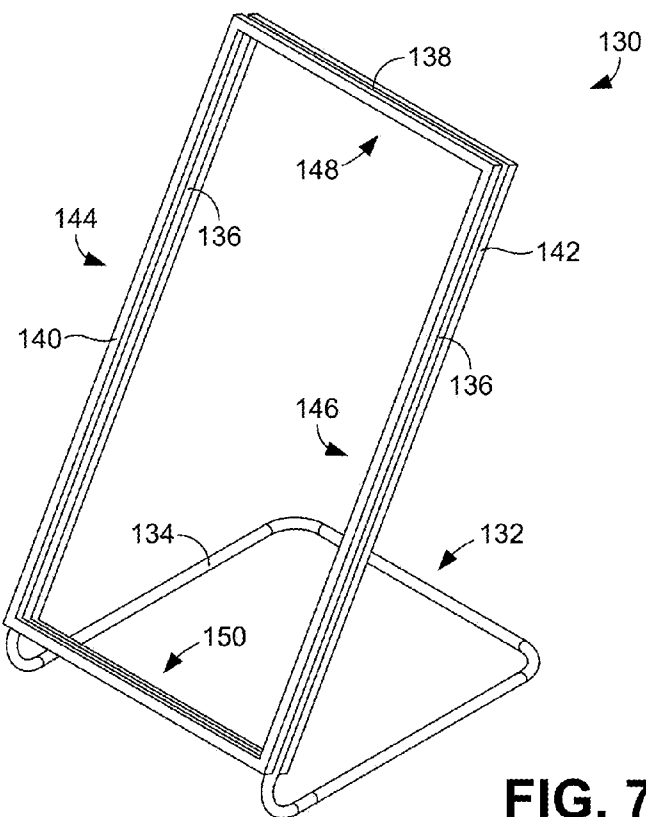


FIG. 7

SYSTEMS AND METHODS FOR PROVIDING TRAINING AND INSTRUCTION TO A FOOTBALL KICKER

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority to co-pending U.S. Provisional Application Ser. No. 61/703,156, filed Sep. 19, 2012, which is hereby incorporated by reference herein in its entirety.

BACKGROUND

[0002] In American football, a kicker is relied upon to score points after every touchdown and each time a field goal is attempted. Often times, whether a football team wins or loses a game comes down to whether or not points are scored from such kicks.

[0003] Unlike most other positions on a football team, the kicker tends to get little instruction from the team coaches. Fortunately, there are training camps across the United States that specialize in football kicking training and instruction. Some of these camps have an entire team of coaches that assists the kicker to help him improve the range and accuracy of his kicks. Although these camps are helpful to kickers, they are only temporary and do not ensure desirable results throughout the football season.

[0004] In view of the above discussion, it would be desirable to be able to provide kicking training and instruction to a kicker whenever the kicker wishes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The present disclosure may be better understood with reference to the following figures. Matching reference numerals designate corresponding parts throughout the figures, which are not necessarily drawn to scale.

[0006] FIG. 1 is a perspective view of an embodiment of a system for providing training and instruction to a football kicker.

[0007] FIG. 2 is a front view of an embodiment of a force sensor array shown in FIG. 1.

[0008] FIG. 3 is a block diagram of an embodiment of a computing device shown in FIG. 1.

[0009] FIGS. 4A and 4B together form a flow diagram of an example method of operation of the system of FIG. 1.

[0010] FIG. 5 is a screen shot of an example video simulation of the flight of a football that can be displayed to the kicker during the training described in relation to FIG. 4.

[0011] FIG. 6 is a typical graph that plots drag coefficient versus Reynold's number.

[0012] FIG. 7 is a perspective view of an embodiment of a kicking net frame that can be used in an alternative system for providing training and instruction to a football kicker.

DETAILED DESCRIPTION

[0013] As described above, it would be desirable to be able to provide kicking training and instruction to a kicker whenever the kicker wishes. Disclosed herein are systems and methods for providing such training and instruction. In one embodiment, a system is configured to simulate, in the virtual domain, the trajectory of a football that is kicked by a kicker, for example, into a wall or a kicking net. The system comprises sensors that collect various data about the movement of the football that can be used to estimate the football's trajec-

tory and to display a simulation of that trajectory in real time to the kicker so that he can get a sense of the quality of the kick. In further embodiments, the system is also configured to collect and analyze kinematic data about the kicker's kicking form, as well as physiological data, that can be recorded and communicated to the kicker and/or his coach. In still further embodiments, the system is configured to provide feedback to the kicker and/or coach as to how the kicker may improve his kicks and/or decrease the likelihood of injury when kicking.

[0014] In the following disclosure, various specific embodiments are described. It is to be understood that those embodiments are example implementations of the disclosed inventions and that alternative embodiments are possible. All such embodiments are intended to fall within the scope of this disclosure.

[0015] FIG. 1 illustrates an embodiment of a system 10 for providing training and instruction to a football kicker. Although the discussion of the system 10 that follows is focused on the action of kicking a football, it will be appreciated that the described principles can be applied to other actions of other sports, such as kicking a soccer ball, throwing a football, throwing a baseball, swinging a baseball bat, swinging a golf club, and the like. Therefore, although football kicking is identified as an example application, it is noted that the system, with minor adjustments, could be applied to such other actions.

[0016] As shown in FIG. 1, the system 10 is well suited for use indoors, such as within a training room 12 that is configured for use in football kicking training. The room 12 can be conventional in layout and dimensions and need not have the dimensions of an outdoor or indoor football field where kicking training is normally performed. The room 12 can be defined in part by four orthogonal walls, including a kick wall 14, at least one side wall 16, and a floor 18.

[0017] Provided on the floor 18 at a location several feet (e.g., 6-10 feet) in front of the kicking wall 14 is a kicking mat 20 on which a football 22 can be placed for kicking. In some embodiments, the kicking mat 20 comprises a patch of synthetic turf such as the type typically used in indoor football stadiums. Although the dimensions are not critical, the mat 20 is at least large enough to enable a kicker to take all the steps he normally would in approaching and kicking a football. In some embodiments, a force sensing mat 24 that is capable of detecting the position of the kicker's planted foot (i.e., the foot that supports the kicker while kicking), as well as measure the force distribution of the planted foot, is placed under the kicking mat 20. This data can be transmitted, either through a wired or wireless communication channel, to a central control unit 26 that is located within the training room 12. As shown in FIG. 1, the force sensing mat 24 can be positioned to one side of the football 22 where the kicker is likely to plant his non-kicking foot. Alternatively, a force sensing mat 24 can be placed beneath the kicking mat 20 on each side of the football 22.

[0018] The football 22 can comprise a conventional football that is normally used in competition. However, in some embodiments, provided on or inside the football 22 is a data collection and transmission unit 28 that is used to collect information about the movement of the football and wirelessly transmit this information to the central control unit 26. In some embodiments, the unit 28 comprises a microcontroller, memory, an inertia measurement unit, and a wireless transceiver. In such cases, the inertia measurement unit can, under the control of the microcontroller, collect football

movement data, which can be temporarily stored within memory and intermittently transmitted to the central control unit 26 using the wireless transceiver. By way of example, the data can be transmitted in response to a request received from the central control unit 26.

[0019] The sensors of the data collection and transmission unit 28 can comprise an accelerometer that can detect the impact of the kicker's foot against the football 22 and the impact of the football against a force sensor array described below. Detection of these events reveals the time it took for the football 22 to reach the array once kicked, which can be used to determine the velocity at which the football is traveling. In addition, the sensors can comprise a gyroscope or one or more other sensors that together function as a gyroscope. In either case, gyroscopic data can be obtained that provides an indication of the rotation of the football 22, which has a significant impact on the speed at which the football would have traveled through the air and what distance it would have traveled. In some embodiments, the data collected by the accelerometer and the gyroscope (or gyroscopic sensors) can be combined together on the data collection and transmission unit 28 to determine the magnitude and direction of rotation of the football 22. In such a case, the data that is transmitted to the central control unit 26 can be this rotation data. In still other embodiments, the gyroscopic data can be cross-checked by a compass sensor that is also comprised by the data collection and transmission unit 28.

[0020] As is further shown in FIG. 1, the football 22 can be supported on the mat 20 by a kicking tee 30. The kicking tee 30 can be conventional in design but can comprise a force sensor 32 upon which the football 22 rests before being kicked. When this sensor 32 is used, the moment at which the kicker's foot impacts the football 22 can be detected to provide redundancy for the accelerometer provided on or within the football.

[0021] As indicated above, the kicker kicks the football 22 toward the kick wall 14. More particularly, the kicker kicks the football 22 into a force sensor array 34 that is mounted to the kick wall 14. The force sensor array 34 comprises multiple force sensors that are arranged in a grid that extends across the height and width of the array. When the kicker kicks the football 22 forward toward the kick wall 14, the point of impact of the football with the array 34 is sensed by one or more sensors of the array. This position data can also be transmitted to the central control unit 26, either through a wired or wireless communication channel. With such position data, and the determined velocity and rotational speed of the football 22, the trajectory the football would have followed had it not been stopped by the array 34 can be determined.

[0022] With further reference to FIG. 1, a display device 36 is mounted to the kick wall 14 above the force sensor array 34. The display device 36 comprises a display screen 38 that can be extended downward so as to cover the force sensor array 34 and hide it from the kicker's view. As described below, a simulation of the flight of the football 22 can be displayed in real time to the kicker on the display screen 38. For instance, the moment at which the football 22 impacts the force sensor array 34, a video simulation of the football flying through the air, beginning at the point at which the football contacted the overlying screen 38, can be displayed to the kicker in a virtual reality context to provide the kicker with the feeling of actually watching the football fly down a football field. In some embodiments, the video simulation can be projected onto the

display screen 38 with a digital projector 40 that is mounted to the ceiling or one of the walls of the training room 12.

[0023] Further shown mounted to the kick wall 14 are speakers 42 that can provide audio information to the kicker. For example, the speakers 42 can be used to project the sounds the kicker may experience in an actual football game, such as the cheers of the crowd or the calls made by other players on the field to create a more immersive virtual environment.

[0024] With continued reference to FIG. 1, the system 10 also comprises one or more high-speed video cameras, such as the camera 44 shown mounted to the wall 16. The camera(s) 44 are used to capture high-speed video data of the kicker before, during, and after contact with the football 22 so that the kinematics of the kicker's body can be quantified and analyzed. For example, the video data can be used to determine, at any given time during the kicking sequence, the angles of the joints, the positions and orientations of the thighs, shins, and feet, the velocities of the thighs, shins, and feet, and so forth. This data is useful both to provide feedback to the kicker as to these quantities, but also to determine ways in which the kicker may alter his kicking form to obtain better kicking results and/or avoid injury. In addition, the video data can be used to determine the position and orientation of the football 22 as it flies through the air. This information can also be used to determine the magnitude and direction of rotation of the football 22 to provide system redundancy. While only one video camera 44, positioned to the side of where the kicker would kick the football 22, is illustrated in FIG. 1, one or more cameras can be placed at different orthogonal positions within the training room 12. For example, a further video camera 44 can be placed behind the kicker, above the kicker, or both. Regardless, the data collected by the video camera(s) 44 can be provided to a computing device 46 that is either located within the training room 12 or elsewhere.

[0025] In addition to the aforementioned components, the system 10 includes a user interface 48 that the kicker can use to interface with the computing device 46 and the central control unit 26, which is in communication with the computing device. As described later, the user interface 48 can be used to initialize the system 10, select various system settings, and review any data collected by the system during the kicker's training session, including high-speed video data.

[0026] Although not illustrated in FIG. 1, the system 10 can further comprise a mobile device, such as the kicker's own smart phone or other handheld device, which, as described below, can be used to initiate a kick recording.

[0027] FIG. 2 illustrates an example embodiment for the force sensor array 34. The array 34 generally comprises a frame 50 that supports an array 52 of force sensors 54. The frame 50 can be based upon the industrial standards for stud separation in both residential and commercial buildings, which require 16 and 24 inch separation between studs. By mounting directly to the kick wall 14, the force sensor array 34 occupies a minimal amount of space in the training room 12.

[0028] To calculate the trajectory of the kicked football 22, three variables are needed: the time interval beginning when the ball leaves the ground and ending the moment it hits the force sensor array 34, the distance the football traveled from the floor to the force sensor array, and the angle at which the football traveled. As described above, the beginning of the time interval (i.e., first time stamp) can be detected using the accelerometer provided in the football 22 and/or the force

sensor 32 provided on the tee 30. The force sensor array 34 can be used to detect the end of the time interval (i.e., second time stamp). In addition, the distance and angle at which the football 22 traveled can be determined from the position at which the football hit the array 34. This position can be determined by determining which sensor(s) 54 registered the impact.

[0029] In the embodiment illustrated in FIG. 2, the force sensor array 34 comprises 56 force sensors 54, which are equidistantly spaced from each other in a grid composed of multiple rows and columns. By way of example, the force sensors 54 can comprise FSR-406 force sensors from Interlink Electronics, which are single-zone force sensing resistors. The FSR-406 sensors are polymer thick film (PTF) sensors that exhibit a decrease in resistance with an increase in force applied to the surface of the sensor. Each FSR-406 sensor has a 1.5 inch×1.5 inch active area.

[0030] As is further shown in FIG. 2, each force sensor 54 is covered by a polymeric (e.g., plexiglass) shield 56 that increases the coverage area for each sensor. By way of example, the total coverage area for the array 34 can be approximately 4 feet×3.5 feet. An adhesive backing provided on the force sensors 54 allows the sensors to be semi-permanently attached to the frame 50. In some embodiments, a spherical disk 58 is attached to the center of each shield 56 in front of its associated force sensor 54 to help distribute forces across the shield. By way of example, the disks 58 can be created from a thermo resin material.

[0031] In some embodiments, the shields 56 can be secured in place over the force sensors 54 using strips 60 of medium-compression foam tape that provides stability to the shields and further helps distribute force. For example, a strip 60 of compressible foam tape can be placed in each of the four corners of each shield 56, as shown in FIG. 2. When the football 22 hits any part of a shield 56, even its side or corner, the force is distributed back to the associated force sensor 54. This improves the accuracy of the force measurements as well as the calculation of the trajectory of the football 22.

[0032] With the array dimensions described above and assuming the football 22 is placed a distance of 8 feet away from the kick wall 14, the football will be able to travel within a range of approximately 26° to 45° in the vertical direction (i.e., the typical range for a football kick) and still contact the force sensor array 34. In addition, the football 22 will also be able to travel 10.6° to the left or right of center, which is more than the maximum angle allowed in a zero cross-wind kick (i.e., 8.7° kick) to the left or right of center. This 8.7° may occur during a football game when the kicker is called upon to kick an extra point kick, which is kicked from approximately 20 yards (60 ft.) away from a field goal post having an 18.5 foot width. Each force sensor 54 has its own vertical angle (θ) and horizontal angle (ϕ), as well as a vertical, a horizontal, and a total distance from where the football is initially placed.

[0033] FIG. 3 illustrates an example configuration of the computing device 46 shown in FIG. 1. As indicated in FIG. 3, the computing device 46 includes one or more processing devices 61, memory 62, a user interface 64, and at least one I/O device 66, each of which is connected to a local interface 68. The processing devices 61 can include a central processing unit (CPU) and a graphics processing unit (GPU) designed to rapidly manipulate and alter memory to accelerate the creation of images intended for output to the projector 40. The memory 62 includes any one of or a combination of volatile memory elements (e.g., RAM) and nonvolatile

memory elements (e.g., hard disk, ROM, Flash, etc.). The user interface 64 comprises the components with which a kicker or coach interacts with the computing device 46, such as a keyboard and a display screen, and the I/O devices 66 are adapted to facilitate communications with other devices. The memory 62 (a non-transitory computer-readable medium) comprises programs (logic) including an operating system 70 and a kick training system 72. The kick training system 72 can comprise multiple software modules, which can each include one or more subprograms or algorithms that are used to perform discrete functions related to the kicker training and instruction. In the example of FIG. 3, the kick training system 72 comprises a trajectory estimation module 74 that estimates the trajectory of the football 22 relative to data collected by the system sensors and/or video camera, a virtual simulation module 76 that renders video data for projection onto the display screen 38 that simulates the flight of the football as it “passes through” the screen, a kinematics evaluation module 78 that determines the kinematics of the kicker’s body during the entire kick sequence, and a feedback module 80 that is adapted to determine how the kicking form may be changed, to either improve the kick’s range and/or accuracy or to prevent kicker injury.

[0034] Unlike existing football simulators that are used for entertainment purposes, the above-described system 10 is designed to provide useful training in a realistic and immersive environment. To achieve this goal, a large amount of data and advanced fluid and football dynamic equations are required. The data received from the various sensors of the system 10 are used as input for the equations in order to create an accurate prediction of the trajectory of the football 22 that can be visually presented to the kicker. In addition, statistics can be logged for each kicker using the system 10 so that the kickers and their coaches can track the kicker’s progress and evaluate it for consistency. Because the system 10 collects a large amount of data regarding the flight of the football 22 and the motions of the kicker, coaches are provided with a better understanding of a kicker’s ability to kick at different locations on the field. In addition, the data can be used to develop drills that will improve the kicker’s performance and reduce the likelihood of injury.

[0035] An example of operation of the system 10 will now be discussed in relation to the flow diagram of FIGS. 4A and 4B. Beginning with block 90 of FIG. 4A, the kicker first initializes the system 10. Such initialization can, for example, comprise opening and executing a control program on the computing device 46, which is in electrical communication with the central control unit 26. Through this initialization, the lines of communication between the central control unit 26 and the various sensors of the system 10 are opened and the sensors are prepared to collect data. In addition, a video image of a virtual football field can be displayed to the kicker on the display screen 38 to simulate his presence on the field and provide him with a target (e.g., field goal post) at which to aim his kick. A screen shot from an example simulation is provided in FIG. 5.

[0036] In some embodiments, the kicker can choose various settings for the kicking session. For example, the kicker can select which football stadium that is to be used in the simulation, what yard line from which the kick is to be made, the lateral position from which the kick is to be made, the local conditions in which the kick is to be made (time of day, position of sun, temperature, relative humidity, wind speed

and direction, noise of the crowd, etc.) and any other variables that may have an impact on the kick if it were being made in an actual game situation.

[0037] Next, with reference to block **92**, the kicker can initiate a kick recording. In some embodiments, the kicker can initiate the recording using his mobile device. In such a case, an application or “app” that executes on the mobile device can be used to start recording video with the high-speed camera(s) **44** and ready the other sensors for data collection. In alternative embodiments, kick recording can automatically commence upon the system **10** detecting movement of the kicker indicative of the kicker being about to kick the football **22** (e.g., using video recognition techniques).

[0038] At this point, the kicker can kick the football **22** at the target displayed on the display screen **38**. Referring next to block **94**, the kicker approaches the football **22** and plants his non-kicking foot next to the football. As described above, the force sensing mat **24** can sense the location at which the kicker plants his foot as well as the distribution of the kicker’s weight across the foot. This information can be transmitted in real time to the central control unit **26**, which can provide it to the computing device **46**.

[0039] As the kicker continues his kicking motion, his kicking foot makes contact with the football **22**, as indicated in block **96**. When this contact is made and the force of the kicker’s foot is transmitted to the football **22**, the data collection and transmission unit **28** detects the impact and records a first (start) time stamp indicative of the time at which the football begins its motion. As described above, an accelerometer of the data collection and transmission unit **28** can detect this impact. The first time stamp can then be wirelessly transmitted in real time by the data collection and transmission unit **28** to the central control unit **26**. When a force sensor **32** is also present in or on the football tee **30**, the sensor can likewise detect the motion of the football and also register the first time stamp. This time stamp can also be transmitted to the central control unit **26**.

[0040] Shortly after the impact between the kicker’s foot and the football, the football begins its flight through the air, as indicated in block **98**. As the football flies towards the display screen **38**, the data collection and transmission unit **28** determines the magnitude and direction of the rotation of the football. As described above, the data collection and transmission unit **28** can, in some embodiments, measure this information using a gyroscope or one or more sensors that together function as a gyroscope. In addition, the data collected by the gyroscope (or gyroscopic sensors) can be combined with the data collected by the accelerometer to determine the magnitude and direction of rotation of the football **22**. In such a case, the data collection and transmission unit **28** can wirelessly transmit the rotation data to the central control unit **26**.

[0041] The football **22** will eventually impact the display screen **38** and the force sensor array **34** that lies behind the screen, as indicated in block **100**. When this occurs, one or more force sensors **54** register the impact, and this data is transmitted in real time to the central control unit **26**. From the known location of the sensor(s) **54** that registered the impact, the direction of flight of the football **22**, as well as its distance from and angle with its initial position on the football tee **30** can be determined. In addition, a second (end) time stamp can be transmitted to the central control unit **26** at the time of impact. With the two time stamps, the time of flight from the tee **30** to the force sensor(s) **54** can be determined, which can

be used with the distance data to determine the velocity of the football **22** during its flight. Notably, the end time stamp can also be registered by the accelerometer of the data collection and transmission unit **28** provided in or on the football **22**.

[0042] At this point, the football **22** will bounce off of the force sensor array **34** and the display screen **38** and the simulation of the flight of the football down the virtual field can commence. To this end, the computing device **46** receives all of the data collected from the initiation of the kick by the kicker to the time at which the football **22** impacts the force sensor array **34**, as indicated in block **102** of FIG. **4B**. This information can be provided to the computing device **46** by the central control unit **26**, which is in direct communication with various sensors of the system **10**. Of course, the transmission of this data from the central control unit **26** need not be delayed until the point at which the football **22** impacts the force sensor array **34** and can instead be provided to the computing device **46** as it becomes available so as not to delay the processing needed to prepare the simulation.

[0043] With reference to block **104**, the computing device **46** uses the collected data to estimate what the football’s trajectory would have been if it had not been stopped by the force sensor array **34**. In other words, the computing device **46** estimates what the trajectory of the football **22** would have been if the football had been kicked in the real world in the conditions selected for the simulation. In some embodiments, the trajectory can be calculated using the velocity of the football during its flight to the force sensor array **34**, the angle of the flight, the rotation of the football **22** during the flight, and the prevailing conditions of the simulation. A more detailed discussion of an example method of calculating the trajectory is provided below.

[0044] Once the football trajectory has been determined, the computing device **46** can generate a virtual simulation of the football’s flight from the point where it impacted the force sensor array **34**, as indicated in block **106**. In other words, the computing device **46** can generate a virtual simulation of the football continuing its flight path “into” the virtual world depicted on the display screen **38** so that, from the perspective of the kicker, it appears that the kicked football **22** continued its flight uninterrupted down the virtual football field. The simulation is preferably generated so that there is little or no delay between the time of impact of the football **22** against the force sensor array **34** and the time the virtual football flies down the field, and so that the position from which the virtual football begins this flight coincides with the position at which the actual football impacted the display screen **38**. In such a case, a seamless simulation of the full flight path of the football can be presented to the kicker.

[0045] Referring next to block **108**, the virtual simulation is displayed to the kicker on the display screen **38** in real time. FIG. **5** comprises a screen shot **120** of an example of such a simulation. As shown in this figure, a football stadium and field are shown in the simulation, as is a goal post **122**, which can provide the target for the kicker. As indicated in this example, the trajectory **124** of the virtual football **126** is displayed to the user so that the user can evaluate the kick as being successful or unsuccessful.

[0046] As mentioned above, kicker kinematics, such as the angles of the kicker’s joints, the positions and orientations of the thighs, shins, and feet, the velocities of the thighs, shins, and feet, and the like can be captured throughout the kick sequence using the high-speed camera(s) **44**. The kinematic and physiological response can be calculated by the comput-

ing device 46 from the video data, as indicated in block 110. In some embodiments, this information can be made immediately available to the kicker on the user interface 48 and/or the display screen 38. The kicker can therefore get instantaneous feedback as to the quality of his kicking form for each individual kick. Of course, all of this data can be stored on the computing device 46 for later reference.

[0047] Referring next to block 112, the computing device 46 can further analyze the kicker kinematic data to determine what adjustments, if any, could be made to the kicker's kicking form to improve performance (e.g., distance and accuracy) and/or prevent injury. In some embodiments, these adjustments could be presented to the kicker as recommendations. For example, the computing device 46 could recommend that the kicker straighten his kicking leg at the time of contact with the football 22 or extend his follow-through after the football has taken flight.

[0048] As described above, the trajectory of the football 22 can be determined using the collected data and mathematical equations. Trajectory equations can be derived and built upon deformable body dynamics, advanced fluid dynamics, and fluid-structure interactions. Lift and drag forces on the football can be considered and evaluated as the football 22 rotates. The equations can be modeled for particular stadium variables such as the density of air, temperature of environment, and wind factor. The data received from multiple sensors can provide initial velocities in the x, y, and z directions, the rotation speed of the football, and angles of flight. The x direction is defined as the horizontal distance towards the field goal post, y is the horizontal distance to the left and right from the center where the football 22 was kicked, and the z is the vertical direction. Due to the oblong shape of a football and the way it rotates in air, the cross-sectional area of the football has an effect on drag and lift that, in turn, has a significant effect on the trajectory. To streamline the analysis of the dynamic equations, drag and lift can be solved by calculating the cross-sectional area and diameters of the football to apply to existing analysis of an ellipsoid. In some embodiments, the drag formula can be calculated using Owen and Ryu's curve (FIG. 6) for calculating the coefficient of drag depending on measured Reynold's number:

$$C_{drag} = \frac{24}{Re} + \frac{?}{1 + \sqrt{Re}} + 0.4 \quad [\text{Equation 1}]$$

? indicates text missing or illegible when filed

The calculation of drag coefficient can be improved by using:

$$? = 0.1 + \frac{\text{range}(?) (1 - \cos(2 + \varphi))}{2} \quad [\text{Equation 2}]$$

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A modified Milne-Thompsons equation for lift force can be used. [text missing or illegible when filed]

$$F_{lift} = ? \frac{?}{3} (2? ? ? |v|) \quad [\text{Equation 3}]$$

-continued

$$(?) - ? (?) \quad [\text{Equation 4}]$$

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The drag force formula can take the form of:

$$F_{drag} = C_{drag} \frac{1}{2} \rho A \|v\|^2 \quad [\text{Equation 5}]$$

$$(F_{drag_x}, F_{drag_y}, F_{drag_z}) = F_{drag} \frac{\|v\|}{v} \quad [\text{Equation 6}]$$

All of this can be compiled together to derive the equations below.

$$m \frac{d^2 x(?)}{dt^2} - ? - ? \left\| \frac{dx(?)}{dt} \right\| \frac{dx(?)}{dt} \quad [\text{Equation 7}]$$

$$m \frac{d^2 y(?)}{dt^2} - ? - ? \left\| \frac{dy(?)}{dt} \right\| \frac{dy(?)}{dt} \quad [\text{Equation 8}]$$

$$m \frac{d^2 z(?)}{dt^2} - ? - ? \left\| \frac{dz(?)}{dt} \right\| \frac{dz(?)}{dt} - m\mu \quad [\text{Equation 9}]$$

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[0049] In the above equations, m is the mass of the football, [text missing or illegible when filed] is the calculated lift coefficient specific to the environment, [text missing or illegible when filed] is the calculated drag coefficient specific to the environment, ω is the angular acceleration, $\|\bullet\|$ denotes a L_2 norm of a quantity, ρ is the density of air, a and b are the long and short radii respectively, and g is gravity. The x, y, and z directions have the same orientation as stated above. With the use of numerical methods, these equations can be solved with explicit values for displacement of the football. These values can, in turn, be used for visualization of the trajectory in the simulation environment. The model can be calibrated using real-time data collected by the data collection and transmission unit 28 embedded in the football 22.

[0050] The visualization component of the system 10 is intended to recreate real-world playing conditions. By implementing a digitized football stadium, parameterizing the distance and angle of approach, and recreating gameplay sounds, the kicker will feel immersed in a true game scenario. In some embodiments, the simulation algorithm can be implemented using Unity3D, which is an open source interactive gaming and visualization program that allows three-dimensional objects to be imported into the virtual environment to create realistic scenes. This virtual simulation uses appropriate perspective and scaling to emulate game-time scenarios, creating an immersive environment for the kicker.

[0051] Information about the screen contact position, in-flight rate of rotation, and velocity just prior to the point of contact, are obtained as described above, can be sent to the Unity3D engine. The in-flight rate of rotation (ω) and instantaneous velocity (v) at the point of contact can be used to solve the second-order form of the trajectory partial differential equations (PDEs). The initial conditions for the PDEs can be determined by the measured data collected from the various sensors. The PDEs can then be solved by numerical methods (e.g. 4th order Runge-Kutta solver). To obtain the final trajectory of the football in flight, a trapezoidal integration algo-

rithm coupled with smoothing algorithms can be used, an example of which is presented below: [text missing or illegible when filed]

```

function diffeq0(t, x) // t = time, x = array of variables
    return L_x/opt.m - D_x/opt.m;
function diffeq1(t, x)
    return L_y/opt.m - D_y/opt.m;
function diffeq2(t, x)
    return L_z/opt.m - D_z/opt.m - opt.g;
function evaluate(k, t, x)
{
    switch (k)
    {
        case 0: return diffeq0(t, x);
        case 1: return diffeq1(t, x);
        case 2: return diffeq2(t, x);
        default:
            return 0;
    }
}
// A version of Runge-Kutta method using arrays
// Calculates the values of the variables at time t+h
// t = last time value
// h = time increment
// v = array of variables
// N = number of variables in x array
function solve(t, h)
{
    for (i=0; i<N; i++)
        k1[i] = evaluate(i,t,v); // evaluate at time t
    for (i=0; i<N; i++)
        inp[i] = v[i]+k1[i]*h/2 // set up input to diffeqs
    for (i=0; i<N; i++)
        k2[i] = evaluate(i,t+h/2,inp) // evaluate at time t+h/2
    for (i=0; i<N; i++)
        inp[i] = v[i]+k2[i]*h/2 // set up input to diffeqs
    for (i=0; i<N; i++)
        k3[i] = evaluate(i,t+h/2,inp) // evaluate at time t+h/2
    for (i=0; i<N; i++)
        inp[i] = v[i]+k3[i]*h // set up input to diffeqs
    for (i=0; i<N; i++)
        k4[i] = evaluate(i,t+h,inp) // evaluate at time t+h
    for (i=0; i<N; i++)
        v[i] = v[i]+(k1[i]+2*k2[i]+2*k3[i]+k4[i])*h/6
    }
}
function simulate( )
{
    t = 0
    for (k=1; k<steps; t = t + h)
    {
        CalculateCoefficients( )
        solve(t, h)
        // Trapezoidal integration
        for (var j=0; j<N; j++)
        {
            v2[j][k] = v2[j][k-1] + h *      v1[j][k] = v[j]
            (v[j] + v1[j][k-1]) / 2
        }
        k = k + 1
    }
}

```

[0052] The screen contact position can be used to position the trajectory, and the Unity3D engine can be used to transform the coordinates into world-space and position the virtual football. If the football passes within a predefined region above the virtual goal post crossbeam and between the two uprights, the kick is considered successful; otherwise, the kick is considered unsuccessful. A notification can be displayed informing the kicker of the outcome of his kick.

[0053] In the above-described system 10, a force sensor array 34 is used to create an end time stamp for the flight of the football 22 and to determine the distance from and the angle

with the initial position of the football. Other devices can be used to collect this information. For example, a conventional football kicking net can be augmented to provide sensors that register start and stop time stamps and the position of the football when entering the net. FIG. 7 illustrates an example of such a kicking net frame 130. As indicated in FIG. 7, the kicking net frame 130 generally comprises a frame 132 to which a webbing can be attached (webbing not shown in FIG. 7 for purposes of clarity). The frame 132 includes a base portion 134 and an upright portion that includes opposed lateral members 136 that are joined at their top ends by a top member 138.

[0054] Mounted to the upright portion of the frame 132 (i.e., to the lateral members 136 and the top member 138) are a first or front position detection gate 140 and a second or rear position detection gate 142. In some embodiments, the front position detection gate 140 is mounted to a front side of the members 136, 138, and the rear position detection gate 142 is mounted to a rear side of the members, in which case the gates lie in parallel planes but are separated from each other by a few inches. Each gate 140, 142 comprises a first (left) member 144, a second (right) member 146, a top member 148, and a bottom member 150 that are coupled together to define a rectangular frame.

[0055] Each gate 140, 142 comprises sensors that enable the gate to detect the passage of an object through the plane defined by the gate. In some embodiments, each gate 140, 142 comprise arrays of light sources, such as lasers, that emit beams of light across the plane and light detectors that detect the beams of light when no object lies within the plane. For example, an array of light sources can be provided along the left member 144 of each gate 140, 142 (facing inward) and an array of light detectors can be provided along the right member 146 (facing inward). In addition, an array of light sources can be provided along the top member 148 of each gate 140, 142 (facing inward) and an array of light detectors can be provided along the bottom member 150 (facing inward). With such a configuration, beam interruption can be used to help determine the trajectory of a football.

[0056] As the football is kicked into the kicking net frame 130, it will pass through the two gates 140, 142 in sequence. In particular, as the football travels, it will first pass through the first gate 140, interrupting light beams extending across the gate in both the x direction and the y direction. This interruption data can be provided to a central control unit and/or a computing device so that the approximate position of the football as it passes through the gate 140 can be determined. In addition, the time at which the football breaks the plane of the gate 140 can be registered as the start time stamp. As the football continues its flight it will next pass through the second gate 142 and interrupt light beams extending across the gate in both the x direction and the y direction. This interruption data can also be provided to the central control unit and/or the computing device so that the approximate position of the football as it passes through the gate 142 can be determined. In addition, the time at which the football breaks the plane of the gate 142 can be registered as the end time stamp. Therefore, the kicking net frame 130 can be used to collect data that was collected by both the force sensor array 34 as well as the data collection and transmission device 28 and the force sensor 32 (i.e., first time stamp) in the embodiment of FIG. 1.

[0057] As before, the kicking sequence can be captured with one or more high-speed cameras. The video data cap-

tured by the camera(s) can be used to determine the rotation of the football during its flight. In such a case, the data collection and transmission unit **28** need not be placed on or within the football so as to avoid any effect its presence could cause. In addition, the placement of the kicker's non-kicking foot can be determined from the video data, thereby reducing the need for the force sensing mat **24**. Furthermore, because the gates **140**, **142** and the video data can be used to determine trajectory of the football, the force sensor **32** associated with the football tee **30** may also be unnecessary. It can therefore be appreciated that the system **10** can be greatly simplified when the kicking net frame **130** is used to collect data concerning the flight of the football. In addition, a dedicated training room is not necessary when the kicking net frame **130** is used. Indeed, the kicking net frame **130** can be used outside on an actual football field, if desired, thereby increasing the flexibility of the system.

[0058] The visual simulation of the kick can still be presented to the kicker when the kicking net frame **130** is used. In some embodiments, a display screen and a rear-projection projector (not shown) can be placed behind the kicking net frame **130** and used in similar manner to that described above to show the virtual flight path of the football. In other embodiments, a display screen (not shown) can be incorporated into the kicking net frame **130** that includes slits that enable the kicked football to pass. Such a display screen can be positioned in front of or behind the gates **140**, **142**.

Claimed are:

1. A method for providing training to a kicker in real time, the method comprising:

collecting data while the kicker kicks a ball toward a display screen;

determining the trajectory of the ball from the collected data; and

displaying to the kicker on the display screen a simulation of the flight of the ball within a virtual world.

2. The method of claim **1**, wherein collecting data comprises recording a start time at which the ball first begins to move and an end time at which the ball hits the display screen.

3. The method of claim **2**, wherein the start time and stop time are recorded by a data collection and transmission unit provided on or in the ball.

4. The method of claim **2**, wherein the start time is detected by a force sensor of a tee that supports the ball.

5. The method of claim **2**, wherein the stop time is detected by a force sensor array that is positioned behind the display screen.

6. The method of claim **1**, wherein collecting data comprises detecting a location on the display screen the ball contacted.

7. The method of claim **6**, wherein detecting a location comprises detecting impact of the ball against a force sensor array positioned behind the display screen.

8. The method of claim **1**, wherein collecting data further comprises measuring rotation of the ball during its flight using a data collection and transmission device provided on or in the ball.

9. The method of claim **1**, wherein collecting information comprises detecting the time at which the ball crosses a first plane and the time at which the ball crosses a second plane that is spaced from the first plane by a known distance.

10. The method of claim **9**, wherein collecting information further comprises determining positions within the first and second planes at which the ball crosses the planes.

11. The method of claim **10**, wherein detecting the times and determining the positions are performed using first and second position detection gates mounted to parallel planes.

12. The method of claim **1**, wherein determining the trajectory comprises calculating the trajectory from the velocity, angle of flight, and rotation of the ball.

13. The method of claim **1**, wherein displaying a simulation comprises displaying in real time a virtual ball flying through the air from a point on the display screen where the kicked ball contacted the screen so that it appears to the kicker as if the kicked ball continued its flight into the virtual world.

14. The method of claim **13**, wherein the virtual world comprises a virtual football field that includes a field goal post the kicker can use as a target.

15. The method of claim **1**, further comprising capturing high-speed video of the kicker and the ball before, during, and after the kick.

16. The method of claim **15**, further comprising determining kicker kinematics and physiological data during the kick from the high-speed video and presenting this information to the kicker as feedback.

17. The method of claim **16**, further comprising analyzing the kicker kinematics and physiological data to determine ways in which the kicker can improve his kicking form and prevent injuries.

18. A system for providing training to a kicker, the system comprising:

a display screen at which the kicker can kick a ball;

sensors configured to measure data about the ball's flight after it is kicked; and

a computing device configured to generate a visual simulation of the flight of the ball within a virtual world.

19. The system of claim **18**, wherein the sensors comprise a data collection and transmission unit provided on or in the ball.

20. The system of claim **19**, wherein data collection and transmission unit comprises an accelerometer.

21. The system of claim **19**, wherein data collection and transmission unit comprises a gyroscope or a group of sensors that together function as a gyroscope.

22. The system of claim **18**, wherein the sensors comprise a force sensor of a tee that supports the ball before it is kicked.

23. The system of claim **18**, wherein the sensors comprise a force sensor array positioned behind the display screen that comprises multiple force sensors adapted to detect the impact of the kicked ball.

24. The system of claim **18**, wherein the sensors comprise a kicking net including first and second position detection gates that are each configured to detect the passage of the ball through the gate and the location of the passage.

25. The system of claim **18**, further comprising a high-speed video camera configured to capture high-speed video of the kicker and the ball before, during, and after the kick.

26. The system of claim **25**, wherein the computing device is further configured to determine kinematic and physiological information of the kicker from the high-speed video.

27. The system of claim **26**, wherein the computing device is further configured to determine ways in which the kicker can improve his kicking form and prevent injuries.

28. A non-transitory computer-readable medium comprising a kick training system comprising:

logic configured to receive data collected while a kicker kicks a ball toward a display screen;

logic configured to determine the trajectory of the ball from the collected data; and

logic configured to generate for display to the kicker on the display screen a simulation of the flight of the ball within a virtual world.

29. The computer-readable medium of claim **28**, wherein the logic configured to determine the trajectory is configured to calculate the trajectory from the velocity, angle of flight, and rotation of the ball.

30. The computer-readable medium of claim **28**, further comprising logic configured to receive high-speed video of the kicker kicking the ball and to determine kicker kinematics and physiological data during the kick.

31. A kicking net comprising:

a frame having a front side and a rear side;

a front position detection gate provided on the front side of the frame; and

a rear position detection gate provided on the rear side of the frame;

wherein each position detection gate is configured to detect the passage of a ball through the gate and the location of the passage.

* * * * *