Systems, methods, and computer-readable media are disclosed for capturing gaze data for a referee over the course of a sports match, identifying a key performance indicator (KPI) corresponding to a sports domain with which the sports match is associated, and generating KPI data corresponding to the KPI. The KPI data may be analyzed to assess a likelihood that an officiating decision made by the referee during the sports match is accurate as well as to assess the likelihood that referee bias contributed to the officiating decision. KPI data for a referee may also be aggregated across multiple sports domain KPIs and multiple sports matches and categorized into different decision categories. A bias/confidence pattern may then be determined for the referee based at least in part on the categorization, and a profile may be determined for the referee based at least in part on the bias/confidence pattern.
Monitor over time a gaze of a referee officiating a sports match to generate gaze parameter data.

Identify a sports domain key performance indicator (KPI) associated with a sports domain to which the sports match corresponds.

Identify one or more sports domain rules associated with the sports domain KPI.

Determine a location/time series of the gaze parameter data that satisfies the one or more sports domain rules.

Translate the location/time series of the gaze parameter data into KPI data associated to the sports domain KPI.

Analyze the KPI data to determine a likelihood that referee bias influenced the officiating decision.
Obtain aggregate KPI data for a referee, the aggregate KPI data corresponding to a plurality of sports domain KPIs over a plurality of sports matches officiated by the referee

Categorize the aggregate KPI data into different decision categories

Determine, based at least in part on the categorization of the aggregate KPI data, a bias/confidence pattern for the referee with respect to different players, teams, and/or sports matches

Determine a profile for the referee based at least in part on the bias/confidence pattern

FIG. 5
ANALYZING AND INTERPRETING A REFEREE’S ACTIONS USING GAZE DATA
CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is related to co-pending application entitled “Determining Player Performance Statistics Using Gaze Data,” having attorney docket number YOR920160280US1, and to co-pending application entitled “Analyzing Team Game Play Interactions Using Gaze Data,” having attorney docket number YOR920160284US1.

BACKGROUND

[0002] A sports match (also referred to as a game, contest, or the like) is typically governed by a set of rules that determines the manner in which points/scores are allocated to participants in the match (or otherwise tabulated), the manner in which participants are permitted to interact, and so forth. The set of rules that governs a sports match is typically enforced by one or more referees (sometimes referred to as umpires). During a match, a referee may determine whether there has been an infraction of a rule, and if so, may assess a predetermined penalty against a participant in the match that the referee determines to be responsible for the infraction. Depending on the type of sports match, a participant may refer to an individual or a team of individuals. Further, as part of his/her officiating duties during a sports match, a referee may also determine whether a rule has been satisfied for allocating points to a particular individual or team or otherwise tabulating a score in a particular manner.

[0003] Oftentimes, a referee’s determination of whether an infraction of a rule has occurred or whether a rule has been satisfied for allocating points/tabulating a score involves, at least in part, a subjective judgment. As such, subsequent evaluation of a referee’s decision may reveal that the referee’s decision was not objectively reasonable. For example, video footage of a series of player interactions or events that caused a referee to determine that an infraction occurred may actually reveal that the infraction did not occur.

[0004] While review of video footage during a sporting match (as opposed to after the match has concluded) to confirm the accuracy of a referee’s decision (often referred to as “instant replay”) has become the norm for a number of different types of sports, it suffers from a number of drawbacks. For example, review of such footage fails to provide any quantitative assessment of behavioral characteristics of the referee that may have caused the referee to make a particular decision. In addition, conventional mechanisms for assessing the accuracy of a referee’s decision fail to provide any measure of potential bias of a referee towards a particular individual or team. Discussed herein are technical solutions that address at least some of the aforementioned drawbacks as well as other drawbacks associated with conventional mechanisms for assessing the accuracy of a referee’s decision.

SUMMARY

[0005] In one or more example embodiments of the disclosure, a computer-implemented method for assessing officiating behavior of a referee using gaze parameter data is disclosed. The method includes identifying, by an image sensor over a period of time, the gaze parameter data, where the gaze parameter data is associated with the referee during a sports match being officiated by the referee. The method further includes identifying, by a computer processor, a sports domain associated with the sports match, and identifying, by the computer processor, a key performance indicator (KPI) corresponding to the sports domain, the KPI being associated with an officiating decision made by the referee during the sports match. The method additionally includes identifying, by the computer processor, one or more sports domain rules associated with the KPI, and filtering, by the computer processor, the gaze parameter data to obtain a location/time series of the gaze parameter data that satisfies the one or more sports domain rules. The method further includes generating, by the computer processor, KPI data associated with the KPI based at least in part on the location/time series of the gaze parameter data, and determining, by the computer processor, whether the officiating decision was influenced by bias of the referee based at least in part on an analysis of the KPI data.

[0006] In one or more other example embodiments of the disclosure, a system for assessing officiating behavior of a referee using gaze parameter data is disclosed that includes at least one memory storing computer-executable instructions; and at least one processor configured to access the at least one memory and execute the computer-executable instructions to capture, by an image sensor over a period of time, the gaze parameter data, where the gaze parameter data is associated with the referee during a sports match being officiated by the referee. The at least one processor is further configured to identify a sports domain associated with the sports match, and identify a key performance indicator (KPI) corresponding to the sports domain, the KPI being associated with an officiating decision made by the referee during the sports match. The at least one processor is further configured to identify one or more sports domain rules associated with the KPI, and filter the gaze parameter data to obtain a location/time series of the gaze parameter data that satisfies the one or more sports domain rules. The at least one processor is further configured to generate KPI data associated with the KPI based at least in part on the location/time series of the gaze parameter data, and determine whether the officiating decision was influenced by bias of the referee based at least in part on an analysis of the KPI data.

[0007] In one or more other example embodiments of the disclosure, a computer program product for assessing officiating behavior of a referee using gaze parameter data is disclosed that comprises a non-transitory storage medium readable by a processing circuit, the storage medium storing instructions executable by the processing circuit to cause a method to be performed. The method includes capturing, by an image sensor over a period of time, the gaze parameter data, where the gaze parameter data is associated with the referee during a sports match being officiated by the referee. The method further includes identifying, by a computer processor, a sports domain associated with the sports match, and identifying, by the computer processor, a key performance indicator (KPI) corresponding to the sports domain, the KPI being associated with an officiating decision made by the referee during the sports match. The method additionally includes identifying, by the computer processor, one or more sports domain rules associated with the KPI, and filtering, by the computer processor, the gaze parameter data
to obtain a location/time series of the gaze parameter data that satisfies the one or more sports domain rules. The method further includes generating, by the computer processor, KPI data associated with the KPI based at least in part on the location/time series of the gaze parameter data, and determining, by the computer processor, whether the officiating decision was influenced by bias of the referee based at least in part on an analysis of the KPI data.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The detailed description is set forth with reference to the accompanying drawings. The drawings are provided for purposes of illustration only and merely depict example embodiments of the disclosure. The drawings are provided to facilitate understanding of the disclosure and shall not be deemed to limit the breadth, scope, or applicability of the disclosure. In the drawings, the left-most digit(s) of a reference numeral identifies the drawing in which the reference numeral first appears. The use of the same reference numerals indicates similar, but not necessarily the same or identical components. However, different reference numerals may be used to identify similar components as well. Various embodiments may utilize elements or components other than those illustrated in the drawings, and some elements and/or components may not be present in various embodiments. The use of singular terminology to describe a component or element may, depending on the context, encompass a plurality of such components or elements and vice versa.

[0009] FIG. 1 depicts a cloud computing environment in accordance with one or more example embodiments of the disclosure.

[0010] FIG. 2 depicts abstraction model layers in accordance with one or more example embodiments of the disclosure.

[0011] FIG. 3 is a schematic block diagram depicting illustrative components of a three-dimensional (3D) gaze-based referee analysis system in accordance with one or more example embodiments of the disclosure.

[0012] FIG. 4 is a process flow diagram of an illustrative method for generating key performance indicator (KPI) data associated with a sports domain KPI based at least in part on gaze parameter data and analyzing the KPI data to determine a likelihood that an officiating decision made by a referee is accurate and/or to determine a likelihood that potential referee bias influenced an officiating decision in accordance with one or more example embodiments of the disclosure.

[0013] FIG. 5 is a process flow diagram of an illustrative method for categorizing aggregate KPI data for a referee into different decision categories, determining a bias/confidence pattern for the referee based at least in part on the categorization, and determining a profile for the referee based at least in part on the bias/confidence pattern in accordance with one or more example embodiments of the disclosure.

[0014] FIG. 6 is a schematic diagram of an illustrative computing device that is configured to implement processes in accordance with one or more example embodiments of the disclosure.

DETAILED DESCRIPTION

[0015] Example embodiments of the disclosure include, among other things, systems, methods, computer-readable media, techniques, and methodologies for capturing gaze data for a referee over the course of a sports match, identifying a key performance indicator (KPI) corresponding to a sports domain with which the sports match is associated, and generating KPI data corresponding to the KPI. The KPI data may then be analyzed to assess a likelihood that an officiating decision made by the referee during the sports match is accurate as well as to assess the likelihood that referee bias contributed to the officiating decision. In certain example embodiments, KPI data for a referee may be aggregated across multiple sports domain KPIs and multiple sports matches and categorized into different decision categories. A bias/confidence pattern may then be determined for the referee based at least in part on the categorization, and a profile may be determined for the referee based at least in part on the bias/confidence pattern. The bias/confidence pattern may indicate whether the referee has exhibited a pattern of bias against an individual sports participant or a particular team. The referee profile may be used to determine whether a referee should be permitted to officiate a particular sports match depending on whether the referee has exhibited a pattern of bias against one or more participants of the sports match.

[0016] It is to be understood that although this disclosure includes a detailed description on cloud computing, implementation of the teachings recited herein are not limited to a cloud computing environment. Rather, embodiments of the present invention are capable of being implemented in conjunction with any other type of computing environment now known or later developed.

[0017] Cloud computing is a model of service delivery for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, network bandwidth, servers, processing, memory, storage, applications, virtual machines, and services) that can be rapidly provisioned and released with minimal management effort or interaction with a provider of the service. This cloud model may include at least five characteristics, at least three service models, and at least four deployment models.

[0018] Characteristics are as follows:

[0019] On-demand self-service: a cloud consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with the service’s provider.

[0020] Broad network access: capabilities are available over a network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and PDAs).

[0021] Resource pooling: the provider’s computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to demand. There is a sense of location independence in that the consumer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter).

[0022] Rapid elasticity: capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time.
[0023] Measured service: cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.

[0024] Service Models are as follows:

[0025] Software as a Service (SaaS): the capability provided to the consumer is to use the provider’s applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based e-mail). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

[0026] Platform as a Service (PaaS): the capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including networks, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations.

[0027] Infrastructure as a Service (IaaS): the capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

[0028] Deployment Models are as follows:

[0029] Private cloud: the cloud infrastructure is operated solely for an organization. It may be managed by the organization or a third party and may exist on-premises or off-premises.

[0030] Community cloud: the cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on-premises or off-premises.

[0031] Public cloud: the cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services.

[0032] Hybrid cloud: the cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds).

[0033] A cloud computing environment is service oriented with a focus on statelessness, low coupling, modularity, and semantic interoperability. At the heart of cloud computing is an infrastructure that includes a network of interconnected nodes.

[0034] Referring now to FIG. 1, illustrative cloud computing environment 50 is depicted. As shown, cloud computing environment 50 includes one or more cloud computing nodes 10 with which local computing devices used by cloud consumers, such as, for example, personal digital assistant (PDA) or cellular telephone 54A, desktop computer 54B, laptop computer 54C, and/or automobile computer system 54N may communicate. Nodes 10 may communicate with one another. They may be grouped (not shown) physically or virtually, in one or more networks, such as Private, Community, Public, or Hybrid clouds as described hereinabove, or a combination thereof. This allows cloud computing environment 50 to offer infrastructure, platforms and/or software as services for which a cloud consumer does not need to maintain resources on a local computing device. It is understood that the types of computing devices 54A-N shown in FIG. 1 are intended to be illustrative only and that computing nodes 10 and cloud computing environment 50 can communicate with any type of computerized device over any type of network and/or network addressable connection (e.g., using a web browser).

[0035] Referring now to FIG. 2, a set of functional abstraction layers provided by cloud computing environment 50 (FIG. 1) is shown. It should be understood in advance that the components, layers, and functions shown in FIG. 2 are intended to be illustrative only and embodiments of the invention are not limited thereto. As depicted, the following layers and corresponding functions are provided:

[0036] Hardware and software layer 60 includes hardware and software components. Examples of hardware components include: mainframes 61; RISC (Reduced Instruction Set Computer) architecture based servers 62; servers 63; blade servers 64; storage devices 65; and networks and networking components 66. In some embodiments, software components include network application server software 67 and database software 68.

[0037] Virtualization layer 70 provides an abstraction layer from which the following examples of virtual entities may be provided: virtual servers 71; virtual storage 72; virtual networks 73, including virtual private networks; virtual applications and operating systems 74; and virtual clients 75.

[0038] In one example, management layer 80 may provide the functions described below. Resource provisioning 81 provides dynamic procurement of computing resources and other resources that are utilized to perform tasks within the cloud computing environment. Metering and Pricing 82 provide cost tracking as resources are utilized within the cloud computing environment, and billing or invoicing for consumption of these resources. In one example, these resources may include application software licenses. Security provides identity verification for cloud consumers and tasks, as well as protection for data and other resources. User portal 83 provides access to the cloud computing environment for consumers and system administrators. Service level management 84 provides cloud computing resource allocation and management such that required service levels are met. Service Level Agreement (SLA) planning and fulfillment 85 provide pre-arrangement for, and procurement of, cloud computing resources for which a future requirement is anticipated in accordance with an SLA.

[0039] Workloads layer 90 provides examples of functionality for which the cloud computing environment may be utilized. Examples of workloads and functions which may be provided from this layer include: mapping and navigation 91; software development and lifecycle management 92;
virtual classroom education delivery 93; data analytics processing 94; transaction processing 95; and photograph sharing 96.

[0040] FIG. 3 is a schematic block diagram depicting illustrative components of a three-dimensional (3D) gaze-based referee analysis system in accordance with one or more example embodiments of the disclosure. FIG. 4 is a process flow diagram of an illustrative method 200 for generating key performance indicator (KPI) data associated with a sports domain KPI based at least in part on gaze parameter data and analyzing the KPI data to determine a likelihood that an officiating decision made by a referee is accurate and/or determine a likelihood that potential referee bias influenced an officiating decision in accordance with one or more example embodiments of the disclosure. FIG. 5 is a process flow diagram of an illustrative method 300 for categorizing aggregate KPI data for a referee into different decision categories, determining a bias/confidence pattern for the referee based at least in part on the categorization, and determining a profile for the referee based at least in part on the bias/confidence pattern in accordance with one or more example embodiments of the disclosure. FIG. 3 will be described in conjunction with FIG. 4 and FIG. 5, respectively, hereinafter.

[0041] One or more operations of the methods 200 and 300 may be performed by one or more engines, or more specifically, by one or more program modules or sub-modules forming part of such engine(s). A module, which may contain or be a collection of one or more sub-modules, may include computer-executable instructions that when executed by a processing circuit may cause one or more operations to be performed. A processing circuit may include one or more processing units or nodes. Computer-executable instructions may include computer-executable program code that when executed by a processing unit may cause input data contained in or referenced by the computer-executable program code to be accessed and processed to yield output data. Any module described herein may be implemented in any combination of software, hardware, and/or firmware. Depending on the implementation, any module described herein may form part of a larger collection of modules that together may constitute an engine, an application, or the like.

[0042] Referring first to FIG. 3, a 3D gaze-based referee analysis system in accordance with one or more example embodiments of the disclosure may include an eye gaze tracking engine 104, a sports match tracking and analysis engine 106, a referee analysis engine 108, and a sports domain rules/sports KPI loading engine 110. Each such engine may include computer-executable instructions configured to be executed by a processing circuit to perform one or more corresponding operations.

[0043] The eye gaze tracking engine 104 may include one or more 3D gaze tracking module(s) 112 which, in turn, may include one or more gaze direction determination module(s) 114, one or more fixation duration determination module(s) 116, and one or more distance determination module(s) 118. The 3D gaze tracking module(s) 112 may be configured to monitor various gaze parameters associated with a referee 102 of a sports match. The sports match may be any suitable game, match, or contest including, without limitation, a team-based game or match in which two opposing teams compete; each team including a plurality of players (e.g., a soccer match, a baseball game, a cricket match, a basketball game, a football game, etc.; a game or match in which two individuals compete against one another (e.g., a tennis match, a table tennis match, etc.); a game in which an individual competes with one or more other individuals but does not directly interact with the other individual(s) (e.g., a golf tournament); and so forth.

[0044] Referring now to FIGS. 3 and 4 in conjunction with one another, at block 202, the 3D gaze tracking module(s) 112 may be executed to monitor various gaze parameters associated with the referee 102 during a sports match and generate gaze parameter data 120 continuously or at periodic intervals of a specified granularity. The gaze parameter data 120 may include, for example, gaze direction data, gaze fixation duration data, and gaze distance data. The gaze parameter data 120 may be stored in a gaze parameter data repository 122. The gaze parameter data 120 may be captured in real-time during the sports match, or alternatively, may be captured (potentially post-match) based at least in part on an image analysis performed on a video of the sports match.

[0045] For instance, the gaze direction determination module(s) 114 may be executed to monitor a gaze direction of the referee 102 to generate the gaze direction data, which may indicate how the direction of the referee’s 102 gaze changes over time. This may be achieved using a camera that captures images of the referee’s 102 head over time at a particular frame rate. For each image frame, the gaze direction determination module(s) 114 may determine the angle of the referee’s 102 head with respect to the camera, and may further determine the position of the referee’s 102 eyes with respect to the referee’s head 102. The gaze direction determination module(s) 114 may then perform this determination repeatedly across all image frames to determine a scan path that indicates how the direction of the referee’s 102 gaze changes over time.

[0046] The fixation duration determination module(s) 116 may be executed to determine a respective duration of time that the referee’s 102 gaze remains in each particular gaze direction. The fixation duration determination module(s) 116 may output gaze fixation duration data that includes a series of time durations, where each time duration represents an amount of time that the referee’s 102 gaze remains in a particular gaze direction.

[0047] The distance determination module(s) 118 may be executed to determine distances between points of gaze of the referee 102 and objects of interest. Depending on the particular sports domain KPI that is being evaluated, an object of interest may be a ball, bat, racket, shuttlecock, or other object that a participant interacts with during the sports match. The object of interest may also be a participant himself. The distance determination module(s) 118 may determine a three-dimensional distance between the referee 102 and an object of interest for each gaze direction of the referee 102 and may generate gaze distance data indicative thereof.

[0048] As previously noted, the 3D gaze-based referee analysis system may include a referee analysis engine 108 that may include computer-executable instructions that when executed by a processing circuit may cause operations to be performed to generate an analysis model for interpreting the gaze parameter data 120 within a sports domain by translating a location/time series 124 of the gaze parameter data 120 into KPI data 144 associated with KPIs 140 that are relevant to the sports domain. More specifically, the referee
analysis engine 108 may include one or more gazo to sports domain KPI mapping modules 130 (hereinafter “mapping module(s) 130”) that may include computer-executable instructions that when executed by a processing circuit may determine gaze-based KPIs from the location/time series gaze parameter data 124 and translate the gaze-based KPIs into KPI data 144 that is relevant to a particular sports domain. The gaze-based KPIs may include, for example, any of the gaze parameters previously described including, but not limited to, the referee’s 102 gaze direction, the referee’s 102 gaze duration for a gaze direction, a distance between the referee 102 and an object of interest for a particular gazo direction (e.g., a sports participant), etc.

[0049] Each sports domain may define a plurality of different sports domain KPIs 140 and associated sports domain rules 138. The KPIs 140 and associated domain rules 138 may be loaded into a data repository 142 by the sports domain rules/sports KPI loading engine 110, and retrieved therefrom by mapping module(s) 130. Each sports domain may correspond to a particular type of sport, and the mapping module(s) 130 may be configured to translate gazo KPIs into sports domain KPIs for any number of sports domains.

[0050] Each sports domain KPI 140 for a given sports domain may be a particular type of performance indicator and may correspond to a particular event that may occur within that sports domain. Each sports domain KPI 140 may further be associated with a particular location or set of locations defined within a playing environment. In addition, each sports domain KPI 140 may be associated with a set of one or more sports domain rules 138 that define condition(s) based on which the gazo parameter data 120 may be filtered to obtain the location/time series gazo parameter data 124 that satisfies the sports domain rule(s) 138.

[0051] In addition to accessing the repository 142 to obtain the sports domain KPIs 140 and associated sports domain rules 138, the referee analysis engine 108 may also receive sports match data 126 as input from the sports match tracking and analysis engine 106. More specifically, the sports match data 126 may be input to the sports match tracking and analysis engine 106 via a user interface 128, and the engine 106 may provide the data 126 as input to the referee analysis engine 108. The sports match data 126 may include data indicative of a time of a sports match, a location of the sports match, environmental conditions present at the location of the sports match (e.g., temperature, precipitation, wind speed, etc.), participants (individuals or teams) in the sports match, etc. The sports match data 126 may be used by the referee analysis engine 108 to determine, for example, how the sports KPIs 140 for the referee 102 are impacted by different sports match locations, different times of day at which the sports matches take place, different sports participants, and/or different environmental conditions in which the sports matches occur.

[0052] The process performed by the mapping module(s) 130 for translating the location/time series gazo parameter data 124 into KPI data 144 associated with KPIs 140 that are relevant to a sports domain will be described hereinafter in reference to a particular referee (e.g., the referee 102) and a particular sports domain KPI 140 associated with a particular sports domain. It should be appreciated, however, that the process may be performed for any number of number referees and any number of KPIs 140 associated with any number of sports domains.

[0053] Referring again to FIGS. 3 and 4 in conjunction with one another, at block 204, computer-executable instructions of the mapping module(s) 130 may be executed to identify a sports domain KPI 140 associated with a sports domain to which the sports match corresponds. The sports domain KPI 140 identified at block 204 may include, for example, a reaction time of a referee (e.g., the amount of time it takes for the referee 102 to detect an object of interest such as a ball or another player, potentially as part of an event that requires an officiating decision); a response time of a referee (e.g., the amount of time that elapses between when an event corresponding to the sports domain KPI 140 occurs and when the referee 102 provides an indication of an officiating decision such as the amount of time that elapses between when a pitched ball strikes a catcher’s mitt and when an umpire makes a strike or ball call); a metric indicating a degree of attentiveness of a referee (e.g., a gazo direction of the referee 102 when an event corresponding to the sports domain KPI occurs); or the like.

[0054] As previously described, each sports domain KPI 140 may be defined with respect to a corresponding type of event that may occur during the sports match. Taking the sport of soccer as an example, the events may include, without limitation, a foul, a throw-in, a center, an indirect free kick, a direct free kick, a penalty kick, a header, a corner kick, and so forth. As another example, in tennis, the events may include, without limitation, a serve, a volley, a baseline shot, a forehand, a backhand, a cross-court shot, a down-the-line shot, a passing shot, an overhead smash, an approach, and so forth.

[0055] Further, each sports domain KPI 140 may be defined with respect to one or more locations. Referring again to soccer as an example, the locations may include, without limitation, an out-of-bounds line, a penalty box, a mid-field line, a goal-line, a particular portion of a soccer field (e.g., midfield), and so forth. As another example, in tennis, the locations may include, without limitation, the baselines, the sidelines, the line separating the deuce and advantage courts, the net, and so forth.

[0056] At block 206, the mapping module(s) 130 may identify one or more sports domain rules 138 associated with the sports domain KPI 140 identified at block 204. The sports domain rule(s) 138 associated with a given sports domain KPI 140 may include one or more conditions that the gazo parameter data 120 must satisfy in order to be eligible for translation into the KPI data 144 corresponding to the sports domain KPI 140 for that sports domain. For instance, for a sports domain KPI 140 corresponding to a foul in soccer, an associated sports domain rule 138 may specify that the mapping module(s) 130 must analyze gazo parameter data 120 for the referee 102 obtained during the time period that is X seconds prior to the time the foul occurs as well as the moment the foul occurs.

[0057] In certain example embodiments, a sports domain rule 138 may also specify criteria that must be met in order to determine a likelihood that an officiating decision made by the referee 102 is accurate. For example, a sports domain rule 138 may specify that the referee’s 102 attention (as determined from the gazo parameter data 120) must be within a circle centered at the location of a foul and having a diameter of at least Y % of the X seconds prior to the foul referenced earlier. If this sports domain rule 138 is satisfied, the foul may be confirmed, whereas if this
sports domain rule 138 is not satisfied, the referee’s decision to call the foul may be overturned or at least called into question.

[0058] At block 208, the mapping module(s) 130 may determine the location/time series gaze parameter data 124 that satisfies the sports domain rule(s) 138 identified at block 206. As an example, if the sports domain KPI 140 identified at block 204 is the focus/attentiveness of the referee 102 with respect to a player’s service in a tennis match, and an associated sports domain rule 138 identified at block 206 specifies that a time period beginning 2 seconds before the service and ending when the ball hits the opposing player’s side of the court should be monitored, the location/time series gaze parameter data 124 that satisfies the sports domain rule 138 may include the gaze direction data, gaze duration data, and gaze distance data for the referee 102 that is captured during that time period.

[0059] At block 210, the mapping module(s) 130 may translate the location/time series gaze parameter data 124 determined to satisfy the sports domain rule(s) 138 into the KPI data 144 associated with the sports KPI 140 identified at block 206. The KPI data 144 may be stored in the data repository 142. Taking the sports domain of soccer as an example again, the mapping module(s) 130 may translate the location/time series gaze parameter data 124 into the KPI data 144 for a focus/attentiveness KPI 140 relating to a foul event in the following manner. The mapping module(s) 130 may obtain data relating to an event (e.g., a foul) associated with the focus/attentiveness KPI 140. The data relating to the event may include time data comprising, for example, a timestamp of when the foul occurred or a time period over which the foul occurred. The data relating to the event may include location data indicating a location of the foul within a playing environment (e.g., grid coordinates indicative of a location of the foul within a Cartesian plane representing the playing environment) and expected zone data indicative of a region surrounding the location of the foul (e.g., a circle having as its center the location of the foul) in which the referee’s 102 gaze direction is expected to fall for at least a threshold amount of time over a time period beginning x units of time (e.g., seconds) prior to the time of the foul and ending at the time of the foul or y units after the time of the foul, where such a time period may be specified by a sports domain rule 138 associated with the sports KPI 140. As previously described, the mapping module(s) 130 may utilize the time data to filter the gaze parameter data 120 for the referee 102 at block 208 to identify location/time series gaze parameter data 124 that satisfies the sports domain rule(s) 138 associated with the sports KPI 140. The mapping module(s) 130 may then compare the location/time series gaze parameter data 124 to the expected zone data to determine whether and to what extent the referee’s 102 gaze direction deviates from the region indicated by the expected zone data during the time period specified by the sports domain rule(s) 138. The extent of this deviation (or lack thereof) may be reflected in the KPI data 144.

[0060] At block 212, computer-executable instructions of the referee bias/confidence determination module(s) 134 may be executed by a processing circuit to analyze the KPI data 144 to determine a likelihood that referee bias influenced the officiating decision. Referring again to the soccer example discussed earlier, the referee bias/confidence determination module(s) 134 may analyze the KPI data 144 relating to a focus/attentiveness sports KPI 140 to determine a number of gaze directions (e.g., gaze vectors) of the referee 102 that coincided with the region around the location of the foul specified in the expected zone data during the time period specified by the sports domain rule associated with the sports KPI 140. If this number of gaze directions fails to satisfy a threshold value, the referee bias/confidence determination module(s) 134 may infer that the referee 102 made the officiating decision that a foul occurred without actually observing the location where the foul allegedly occurred or a surrounding region, and thus, may determine that the referee’s 102 officiating decision to call a foul was more likely than not motivated by the referee’s bias. For example, the referee 102 is determined to have more likely than not been biased against the player who was cited (e.g., issued a yellow card) for the foul (or the team of which the cited player is a member).

[0061] As another example, the referee bias/confidence determination module(s) 134 may analyze the KPI data 144 relating to a focus/attentiveness sports KPI 140 to determine a percentage of time that the gaze directions (e.g., gaze vectors) of the referee 102 coincide with the region around the location of the foul in relation to the time period specified by the sports domain rule associated with the sports KPI 140. If this percentage fails to satisfy a threshold value, the referee bias/confidence determination module(s) 134 may determine that the referee’s officiating decision to call a foul was more likely than not motivated by the referee’s bias.

[0062] It should be appreciated that a threshold value described above may be zero, in which case, a determination of likely referee bias only occurs if the referee’s gaze direction never coincides with the region around the location of the foul. In other example embodiments, a threshold value may be some value greater than zero but small enough that any value that does not satisfy the threshold value indicates that the referee’s gaze directions during the relevant time period did not sufficiently coincide with the location of the foul to deem the referee’s officiating decision objectively reasonable. It should be appreciated that, depending on the implementation, a first value may satisfy a second value if the first value is greater than or equal to the second value or if the first value is less than or equal to the second value.

[0063] In certain example embodiments, if the referee bias/confidence determination module(s) 134 determine, based at least in part on an analysis of the KPI data 144, that the referee’s 102 officiating decision (e.g., decision to call a foul) is not more likely than not indicative of referee bias, the referee decision accuracy assessment module(s) 132 may be executed to assess an accuracy strength of the officiating decision. For example, if the referee bias/confidence determination module(s) 134 determine that a metric calculated from the KPI data 144 (e.g., a number of gaze directions of the referee 102 that fall within the region associated with the location of a foul during a soccer match; a duration/percentage of time that the referee’s gaze directions fall within the region, etc.) satisfies a corresponding threshold value, the referee decision accuracy assessment module(s) 132 may compare the metric against set of criteria to determine an accuracy strength of the officiating decision.

[0064] Referring to the example of a foul during a soccer match again, assume that the referee decision accuracy assessment module(s) 132 determine that the referee’s 102 gaze direction coincided with the location of the foul at the time of the foul (potentially taking into account an accept-
able tolerance). Further assume that the referee decision accuracy module(s) 132 determine that less than a threshold number of gaze directions of the referee 102 coincided with the region surrounding the location of the foul or with the location of the ball during the monitoring period prior to the time of the foul (as specified by a sports domain rule 138), or that less than a threshold amount of time or percentage of the monitoring period prior to the time of the foul included gaze directions for the referee 102 that coincided with the region or location of the foul. In this example scenario, the referee decision accuracy assessment module(s) 132 may classify the officiating decision to call the foul as a weak decision because the referee’s 102 gaze direction data and/or gaze duration data associated with the monitoring period prior to the time of the foul indicates that the referee 102 had failed to adequately observe events leading up to the time of the alleged foul and in the vicinity of the location of the foul, and thus, lacked a sufficient evidentiary basis for the officiating decision to call the foul.

[0065] As another example, assume that the referee decision accuracy assessment module(s) 132 determine that the referee’s 102 gaze direction did not coincide with the location of the foul at the time of the foul, but that more than a threshold number of gaze directions of the referee 102 coincided with the region surrounding the location of the foul or with the location of the ball during the monitoring period prior to the time of the foul (as specified by a sports domain rule 138), or that more than a threshold amount of time or percentage of the monitoring period prior to the time of the foul included gaze directions for the referee 102 that coincided with the region or location of the foul. In this example scenario, the referee decision accuracy assessment module(s) 132 may also classify the officiating decision to call the foul as a weak decision because while the referee’s 102 gaze direction data and/or gaze duration data associated with the monitoring period prior to the time of the foul indicates adequate observation of events leading up to the time of the alleged foul and in the vicinity of the location of the foul, the referee’s 102 gaze direction did not coincide with the actual location of the foul at the time of the foul.

[0066] In yet another example scenario, if the referee decision accuracy assessment module(s) 132 determine that the referee’s 102 gaze direction coincided with the location of the foul at the time of the foul (potentially taking into account an acceptable tolerance), and that more than a threshold number of gaze directions of the referee 102 coincided with the region surrounding the location of the foul or with the location of the ball during the monitoring period prior to the time of the foul (as specified by a sports domain rule 138), or that more than a threshold amount of time or percentage of the monitoring period prior to the time of the foul included gaze directions for the referee 102 that coincided with the region or location of the foul, then the referee decision accuracy assessment module(s) 132 may classify the officiating decision as a strong decision. In other words, the officiating decision may be classified as one that is very likely to be accurate.

[0067] It should be appreciated that the referee decision accuracy assessment module(s) 132 may be configured to assign a score or other metric to an officiating decision to indicate a degree of accuracy of an officiating decision. The score assigned to any given officiating decision may be determined as a function of the relationship between one or more metrics derived from the KPI data 144 and corresponding threshold value(s). For example, a weighted linear combination of the differences KPI data 144 metrics and corresponding threshold values may be computed to determine a score to assign to an officiating decision. A range of potential scores may be segmented into tiers. A first set of one or more tiers may include scores indicative of an officiating decision having low accuracy (e.g., a weak officiating decision), a second set of one or more tiers may include scores indicative of an officiating decision having intermediate accuracy, and a third set of one or more tiers may include scores indicative of an officiating decision having high accuracy (e.g., a strong officiating decision).

[0068] The assessment of the accuracy of officiating decisions by the referee 102 and the assessment of whether low-accuracy officiating decisions may be motivated by referee bias, as described in connection with the method 200 of FIG. 4, may be performed in real-time during the sports match. In certain scenarios, these real-time assessments may be used to determine whether an officiating decision should be allowed to stand or overruled during the sports match. These assessments may additionally or alternatively be made after completion of the sports match. Data indicative of these assessments may be stored as referee decision data in a data repository 146. In certain example embodiments, referee decision data may be aggregated across multiple sports matches and analyzed to determine a bias/confidence pattern for the referee 102.

[0069] Referring now to FIGS. 3 and 4 in conjunction with one another, at block 302 of the method 300, the referee bias/confidence determination module(s) 134 may be executed by a processing circuit to obtain aggregate KPI data for the referee 102. The aggregate KPI data corresponding to a plurality of sports domain KPIs over a plurality of sports matches officiated by the referee 102.

[0070] At block 304, the referee bias/confidence determination module(s) 134 may categorize the aggregate KPI data in different decision categories. The various decision categories may represent different officiating decision scenarios with respect to different sport KPIs 140 and different gazing behavior of the referee 102. The aggregate KPI data may be grouped into the different decision categories based at least in part on the referee’s 102 gaze parameter data reflected in the aggregate KPI data.

[0071] The officiating decision categories may include, for example, a category that corresponds to scenarios in which a referee makes an officiating decision without having observed a relevant object of interest (e.g., the referee 102 calls goaltending during a basketball game without having observed the ball at the time of the alleged violation); a category that corresponds to scenarios in which a referee makes an officiating decision having observed the object of interest (e.g., the referee 102 calls a foul on a soccer player having observed the location of the foul (or the player alleged to have committed the foul) at the time of the foul); a category that corresponds to scenarios in which a referee makes an officiating decision having observed the object of interest at the time of an alleged violation but without having observed the object of interest or a region associated with the location of the alleged violation during a monitoring time period prior to the time of the violation (e.g., the referee 102 makes an out-of-bounds call having observed the ball bounce off a player and cross an out-of-bounds boundary but not having observed, during a prior monitoring period, the feet of an opposing player who caused the ball to bounce off
the player in relation to the out-of-bounds boundary; a category that corresponds to scenarios in which a referee makes an officiating decision not having observed the object of interest at the time of an alleged violation but having observed the object of interest or a region associated with the location of the alleged violation during a monitoring time period prior to the time of the violation; a category that corresponds to scenarios in which a referee makes an officiating decision having observed the object of interest at the time of an alleged violation and having observed the object of interest or a region associated with the location of the alleged violation during a monitoring time period prior to the time of the violation; and so forth. It should be appreciated that the above examples of decision categories are merely illustrative and not exhaustive.

[0072] At block 306, the referee bias/confidence determination module(s) 134 may be executed to determine, based at least in part on the categorization of the aggregate KPI data, a bias/confidence pattern for the referee 102 with respect to different players, teams, and/or sports matches. For example, if a significantly larger portion of the aggregate KPI data is categorized into decision categories that indicate that the referee 102 made corresponding officiating decisions having gazed attentively at an object of interest, a location of an alleged violation, etc. (regardless of the individual or team involved) as opposed to categories that indicate otherwise, it may be determined that the referee 102 exhibits no pattern of bias with respect to any particular individual or team. On the other hand, if a portion of the aggregate KPI data associated with officiating decisions relating to a first team is more heavily categorized into decision categories indicative of bias as compared to a portion of the aggregate KPI data associated with officiating decisions relating to a second team, it may be determined that the referee 102 exhibits a pattern of bias towards the first team.

[0073] At block 308, computer-executable instructions of the referee labeler module(s) 136 may be executed by a processing circuit to generate a profile for the referee 102 based at least in part on the bias/confidence pattern. The profile may include a label assigned to the referee 102 indicative of the bias/confidence pattern corresponding to the referee 102. For example, if the bias/confidence pattern indicates that the referee 102 exhibits bias towards or against a particular individual or team, a label indicative of this bias may be assigned to the referee 102 as part of his profile and may be used to determine which sports matches the referee 102 should and should not be assigned to. For example, the referee 102 may be excluded from officiating any sports matches that involve an individual or team towards which and against which the referee 102 is biased. Conversely, if the bias/confidence pattern indicates a high level of confidence in the referee's 102 officiating decisions, the label assigned to the referee 102 may be indicative of her neutrality.

[0074] Taking the domain of soccer again as an example, assume that the referee 102 has officiated four matches between Team 1 and Team 2 and has made the officiating decisions outlined in the table below. Further assume that the aggregate KPI data for the referee 102 has been analyzed to categorize those decisions as outlined in the table below.

<table>
<thead>
<tr>
<th></th>
<th># Decisions Against Team 1</th>
<th># Decisions Against Team 2</th>
<th>Decisions Made in Favor of (Gazing Attentively)</th>
<th>Decisions Made in Favor of (Not Gazing Attentively)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match 1</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Match 2</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Match 3</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Match 4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

[0075] Based on the categorization of the aggregate KPI data outlined in the table on the previous page, the referee bias/confidence determination module(s) 134 may determine that the referee 102, when not exhibiting attentive gazing behavior, makes a considerably larger number of officiating decisions that are favorable to Team 1 than officiating decisions that are favorable to Team 2. Based on this determination, the referee bias/confidence determination module(s) 134 may determine that the referee 102 exhibits a bias towards Team 1 and no particular bias towards or against Team 2. After aggregate KPI data corresponding to a threshold number of matches involving Team 1 has been categorized, if the bias pattern for the referee 102 continues to exhibit a bias towards Team 1, a label indicative of this bias may be assigned to the referee 102 by the referee labeler module(s) 136, and subsequent officiating assignments of the referee 102 may be made accordingly.

[0076] One or more illustrative embodiments of the disclosure are described herein. Such embodiments are merely illustrative of the scope of this disclosure and are not intended to be limiting in any way. Accordingly, variations, modifications, and equivalents of embodiments disclosed herein are also within the scope of this disclosure.

[0077] FIG. 6 is a schematic diagram of an illustrative computing device 400 that is configured to implement processes in accordance with one or more example embodiments of the disclosure in accordance with one or more example embodiments of the disclosure. While the computing device 400 may be described herein in the singular, it should be appreciated that multiple instances of the computing device 400 may be provided, and functionality described in connection with the computing device 400 may be distributed across such multiple instances.

[0078] In an illustrative configuration, the computing device 400 may include one or more processors (processor(s) 402, one or more memory devices 404 (generically referred to herein as memory 404), one or more input/output ("I/O") interfaces 406, one or more network interfaces 408, one or more sensors or sensor interface(s) 410, and data storage 412. The computing device 400 may further include
one or more buses 414 that functionally couple various components of the computing device 400. The bus(es) 414 may include at least one of a system bus, a memory bus, an address bus, or a message bus, and may permit exchange of information (e.g., data, including computer-executable code, signaling, etc.) between various components of the computing device 800. The bus(es) 414 may include, without limitation, a memory bus or a memory controller, a peripheral bus, an accelerated graphics port, and so forth. The bus(es) 414 may be associated with any suitable bus architecture including, without limitation, an Industry Standard Architecture (ISA), a Micro Channel Architecture (MCA), an Enhanced ISA (EISA), a Video Electronics Standards Association (VESA) architecture, an Accelerated Graphics Port (AGP) architecture, a Peripheral Component Interconnects (PCI) architecture, a PCI-Express architecture, a Personal Computer Memory Card International Association (PCMCIA) architecture, a Universal Serial Bus (USB) architecture, and so forth.

The memory 404 of the computing device 400 may include volatile memory (memory that maintains its state when supplied with power) such as random access memory (RAM) and/or non-volatile memory (memory that maintains its state even when not supplied with power) such as read-only memory (ROM), flash memory, ferroelectric RAM (FRAM), and so forth. Persistent data storage, as that term is used herein, may include non-volatile memory. In certain example embodiments, volatile memory may enable faster read/write access than non-volatile memory. However, in certain other example embodiments, certain types of non-volatile memory (e.g., FRAM) may enable faster read/write access than certain types of volatile memory.

In various implementations, the memory 404 may include multiple different types of memory such as various types of static random access memory (SRAM), various types of dynamic random access memory (DRAM), various types of unalterable ROM, and/or writeable variants of ROM such as electrically erasable programmable read-only memory (EEROM), flash memory, and so forth. The memory 404 may include main memory as well as various forms of cache memory such as instruction cache(s), data cache(s), translation lookaside buffer(s) (TLBs), and so forth. Further, cache memory such as a data cache may be a multi-level cache organized as a hierarchy of one or more cache levels (L1, L2, etc.).

The data storage 412 may include removable storage and/or non-removable storage including, but not limited to, magnetic storage, optical disk storage, and/or tape storage. The data storage 412 may provide non-volatile storage of computer-executable instructions and other data. The memory 404 and the data storage 412, removable and/or non-removable, are examples of computer-readable storage media (CRSM) as that term is used herein.

The data storage 412 may store computer-executable code, instructions, or the like that may be loadable into the memory 404 and executable by the processor(s) 402 to cause the processor(s) 402 to perform or initiate various operations. The data storage 412 may additionally store data that may be copied to memory 404 for use by the processor(s) 402 during the execution of the computer-executable instructions. Moreover, output data generated as a result of execution of the computer-executable instructions by the processor(s) 402 may be stored initially in memory 404 and may ultimately be copied to data storage 412 for non-volatile storage.

More specifically, the data storage 412 may store one or more operating systems (O/S) 416; one or more database management systems (DBMS) 418 configured to access the memory 404 and/or one or more external data repositories 444; and one or more program modules, applications, engines, computer-executable code, scripts, or the like such as, for example, an eye gaze tracking engine 420, a referee analysis engine 422, a sports match tracking and analysis engine 424, and a sports domain rules/sports KPI loading engine 426. The eye gaze tracking engine 420 may include one or more 3D gaze tracking modules 428, which in turn, may include one or more sub-modules such as, for example, one or more gaze direction determination modules 430, one or more fixation determination duration modules 432, and one or more distance determination modules. The referee analysis engine 422 may further include one or more gaze to sports domain KPI mapping modules 436, one or more referee decision accuracy assessment modules 438, one or more referee bias/confidence determination modules 440, and one or more referee labeler modules 442. Any of the components depicted as being stored in data storage 412 may include any combination of software, firmware, and/or hardware. The software and/or firmware may include computer-executable instructions (e.g., computer-executable program code) that may be loaded into the memory 404 for execution by one or more of the processor(s) 402 to perform any of the operations described earlier in connection with correspondingly named engines or modules.

Although not depicted in FIG. 6, the data storage 412 may further store various types of data utilized by components of the computing device 400 (e.g., the gaze parameter data 120, data indicative of sports domain rules 138, data indicative of sports KPIs 140, KPI data 144, sports match data 126, referee decision data, referee profile/label data, etc.). Any data stored in the data storage 412 may be loaded into the memory 404 for use by the processor(s) 402 in executing computer-executable instructions. In addition, any data stored in the data storage 412 may potentially be stored in one or more of the data repositories 444 and may be accessed via the DBMS 418 and loaded in the memory 404 for use by the processor(s) 402 in executing computer-executable instructions.

The processor(s) 402 may be configured to access the memory 404 and execute computer-executable instructions loaded therein. For example, the processor(s) 402 may be configured to execute computer-executable instructions of the various program modules, applications, engines, or the like of the computing device 400 to cause or facilitate various operations to be performed in accordance with one or more embodiments of the disclosure. The processor(s) 402 may include any suitable processing unit capable of accepting data as input, processing the input data in accordance with stored computer-executable instructions, and generating output data. The processor(s) 402 may include any type of suitable processing unit including, but not limited to, a central processing unit, a microprocessor, a Reduced Instruction Set Computer (RISC) microprocessor, a Complex Instruction Set Computer (CISC) microprocessor, a microcontroller, an Application Specific Integrated Circuit (ASIC), a Field-Programmable Gate Array (FPGA), a System-on-a-Chip (SoC), a digital signal processor (DSP),
and so forth. Further, the processor(s) 402 may have any suitable microarchitecture design that includes any number of constituent components such as, for example, registers, multiplexers, arithmetic logic units, cache controllers for controlling read/write operations to cache memory, branch predictors, or the like. The microarchitecture design of the processor(s) 402 may be capable of supporting any of a variety of instruction sets.

[0087] Referring now to other illustrative components depicted as being stored in the data storage 412, the OS 416 may be loaded from the data storage 412 into the memory 404 and may provide an interface between other application software executing on the computing device 400 and hardware resources of the computing device 400. More specifically, the OS 416 may include a set of computer-executable instructions for managing hardware resources of the computing device 400 and for providing common services to other application programs (e.g., managing memory allocation among various application programs). In certain example embodiments, the OS 416 may control execution of one or more of the program modules depicted as being stored in the data storage 412. The OS 416 may include any operating system now known or which may be developed in the future including, but not limited to, any server operating system, any mainframe operating system, or any other proprietary or non-proprietary operating system.

[0088] The DBMS 418 may be loaded into the memory 404 and may support functionality for accessing, retrieving, storing, and/or manipulating data stored in the memory 404, data stored in the data storage 412, and/or data stored in the data repositories 444. The DBMS 418 may use any of a variety of database models (e.g., relational model, object model, etc.) and may support any of a variety of query languages. The DBMS 418 may access data represented in one or more data schemas and stored in any suitable data repository. The data repositories 444 may be accessible by the computing device 400 via the DBMS 418 may include, but are not limited to, databases (e.g., relational, object-oriented, etc.), file systems, flat files, distributed datastores in which data is stored on more than one node of a computer network, peer-to-peer network datastores, or the like. The data repositories 444 may include the repository 122, the repository 142, and the repository 146, and may store various types of data including, without limitation, the gaze parameter data 120, data indicative of sports domain rules 138, data indicative of sports KPIs 140, KPI data 144, sports match data 126, referee decision data, referee profile/label data, etc. It should be appreciated that, in certain example embodiments, any of the data repositories 444 and/or any of the data residing thereon may additionally, or alternatively, be stored locally in the data storage 412.

[0089] Referring now to other illustrative components of the computing device 400, the input/output (I/O) interface(s) 406 may facilitate the receipt of input information by the computing device 400 from one or more I/O devices as well as the output of information from the computing device 400 to the one or more I/O devices. The I/O devices may include any of a variety of components such as a display or display screen having a touch surface or touchscreen; an audio output device for producing sound, such as a speaker; an audio capture device, such as a microphone; an image and/or video capture device, such as a camera; a haptic unit; and so forth. Any of these components may be integrated into the computing device 400 or may be separate. The I/O devices may further include, for example, any number of peripheral devices such as data storage devices, printing devices, and so forth.

[0090] The I/O interface(s) 406 may also include an interface for an external peripheral device connection such as universal serial bus (USB), FireWire, Thunderbolt, Ethernet port or other connection protocol that may connect to one or more networks. The I/O interface(s) 406 may also include a connection to one or more antennas to connect to one or more networks via a wireless local area network (WLAN) (such as Wi-Fi) radio, Bluetooth, and/or a wireless network radio, such as a radio capable of communication with a wireless communication network such as a Long Term Evolution (LTE) network, WiMAX network, 3G network, etc.

[0091] The computing device 400 may further include one or more network interfaces 408 via which the computing device 400 may communicate with any of a variety of other systems, platforms, networks, devices, and so forth. The network interface(s) 408 may enable communication, for example, with one or more other devices via one or more networks. Such network(s) may include, but are not limited to, any one or more different types of communications networks such as, for example, cable networks, public networks (e.g., the Internet), private networks (e.g., frame relay networks), wireless networks, cellular networks, telephone networks (e.g., a public switched telephone network), or any other suitable private or public packet-switched or circuit-switched networks. Such network(s) may have any suitable communication range associated therewith and may include, for example, global networks (e.g., the Internet), metropolitan area networks (MANs), wide area networks (WANs), local area networks (LANs), or personal area networks (PANs). In addition, such network(s) may include communication links and associated networking devices (e.g., link-layer switches, routers, etc.) for transmitting network traffic over any suitable type of medium including, but not limited to, coaxial cable, twisted-pair wire (e.g., twisted-pair copper wire), optical fiber, a hybrid fiber-coaxial (HFC) medium, a microwave medium, a radio frequency communication medium, a satellite communication medium, or any combination thereof.

[0092] The sensor(s)/sensor interface(s) 410 may include or may be capable of interfacing with any suitable type of sensing device such as, for example, ambient light sensors, inertial sensors, force sensors, thermal sensors, image sensors, magnetometers, and so forth. Example types of inertial sensors may include accelerometers (e.g., MEMS-based accelerometers), gyroscopes, and so forth.

[0093] It should be appreciated that the engines and program modules depicted in FIG. 6 as being stored in the data storage 412 are merely illustrative and not exhaustive and that processing described as being supported by any particular engine or module may alternatively be distributed across multiple engines, modules, or the like, or performed by a different engine, module, or the like. In addition, various program module(s), script(s), plug-in(s), Application Programming Interface(s) (API(s)), or any other suitable computer-executable code hosted locally on the computing device 400 and/or hosted on other computing device(s) accessible via one or more networks, may be provided to support functionality provided by the engines or modules depicted in FIG. 6 and/or additional or alternate functionality. Further, functionality may be modularized differently.
such that processing described as being supported collectively by a collection of modules depicted in FIG. 6 may be performed by a fewer or greater number of program modules, or functionality described as being supported by any particular module may be supported, at least in part, by another program module. In addition, engines or program modules that support the functionality described herein may form part of one or more applications executable across any number of computing devices 400 in accordance with any suitable computing model such as, for example, a client-server model, a peer-to-peer model, and so forth. In addition, any of the functionality described as being supported by any of the engines or program modules depicted in FIG. 6 may be implemented, at least partially, in hardware and/or firmware across any number of devices.

[0094] It should further be appreciated that the computing device 400 may include alternate and/or additional hardware, software, or firmware components beyond those described or depicted without departing from the scope of the disclosure. More particularly, it should be appreciated that software, firmware, or hardware components depicted as forming part of the computing device 400 are merely illustrative and that some components may not be present or additional components may be provided in various embodiments. While various illustrative engines and program modules have been depicted and described as software modules stored in data storage 412, it should be appreciated that functionality described as being supported by the engines or modules may be enabled by any combination of hardware, software, and/or firmware. It should further be appreciated that each of the above-mentioned engines or modules may, in various embodiments, represent a logical partitioning of supported functionality. This logical partitioning is depicted for ease of explanation of the functionality and may not be representative of the structure of software, hardware, and/or firmware for implementing the functionality. Accordingly, it should be appreciated that functionality described as being provided by a particular engine or module may, in various embodiments, be provided at least in part by one or more other engines or modules. Further, one or more depicted engines or modules may not be present in certain embodiments, while in other embodiments, additional engines or modules not depicted may be present and may support at least a portion of the described functionality and/or additional functionality. Moreover, while certain modules may be depicted or described as sub-modules of another module, in certain embodiments, such modules may be provided as independent modules or as sub-modules of other modules.

[0095] One or more operations of the methods 200 and 300 may be performed by a computing device 400 having the illustrative configuration depicted in FIG. 6, or more specifically, by one or more program modules, engines, applications, or the like executable on such a device. It should be appreciated, however, that such operations may be implemented in connection with numerous other device configurations.

[0096] The operations described and depicted in the illustrative methods of FIGS. 4 and 5 may be carried out or performed in any suitable order as desired in various example embodiments of the disclosure. Additionally, in certain example embodiments, at least a portion of the operations may be carried out in parallel. Furthermore, in certain example embodiments, less, more, or different operations than those depicted in FIGS. 4 and 5 may be performed.

[0097] Although specific embodiments of the disclosure have been described, one of ordinary skill in the art will recognize that numerous other modifications and alternative embodiments are within the scope of the disclosure. For example, any of the functionality and/or processing capabilities described with respect to a particular system, system component, device, or device component may be performed by any other system, device, or component. Further, while various illustrative implementations and architectures have been described in accordance with embodiments of the disclosure, one of ordinary skill in the art will appreciate that numerous other modifications to the illustrative implementations and architectures described herein are also within the scope of this disclosure. In addition, it should be appreciated that any operation, element, component, data, or the like described herein as being based on another operation, element, component, data, or the like may be additionally based on one or more other operations, elements, components, data, or the like. Accordingly, the phrase “based on,” or variants thereof, should be interpreted as “based at least in part on.”

[0098] The present disclosure may be a system, a method, and/or a computer program product. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present disclosure.

[0099] The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

[0100] Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter
card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

[0101] Computer readable program instructions for carrying out operations of the present disclosure may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++ or the like, and conventional procedural programming languages, such as the “C” programming language or similar programming languages. The computer readable program instructions may execute entirely on the user’s computer, partly on the user’s computer, as a stand-alone software package, partly on the user’s computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user’s computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present disclosure.

[0102] Aspects of the present disclosure are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

[0103] These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

[0104] The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, and/or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0105] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

What is claimed is:

1. A computer-implemented method for assessing officiating behavior of a referee using gaze parameter data, the method comprising:
   - capturing, by an image sensor over a period of time, the gaze parameter data, wherein the gaze parameter data is associated with actions of the referee during a sports match being officiated by the referee;
   - identifying, by a computer processor, a sports domain associated with the sports match;
   - identifying, by the computer processor, a key performance indicator (KPI) corresponding to the sports domain, the KPI being associated with an officiating decision made by the referee during the sports match;
   - identifying, by the computer processor, one or more sports domain rules associated with the KPI;
   - filtering, by the computer processor, the gaze parameter data to obtain a location/time series of the gaze parameter data that satisfies the one or more sports domain rules;
   - generating, by the computer processor, KPI data associated with the KPI based at least in part on the location/time series of the gaze parameter data; and
   - determining, by the computer processor, whether the officiating decision was influenced by bias of the referee based at least in part on an analysis of the KPI data.

2. The computer-implemented method of claim 1, wherein determining whether the officiating decision was influenced by bias of the referee comprises:
   - determining, by the computer processor, a metric indicative of a gazing behavior of the referee in connection with the officiating decision;
   - determining, by the computer processor, that the metric fails to satisfy a threshold value; and
   - determining, by the computer processor, that the officiating decision was influenced by bias of the referee.

3. The computer-implemented method of claim 2, wherein the KPI corresponds to a type of event to which the officiating decision relates, wherein the one or more sports
domain rules comprise a first rule specifying a predeter-
mined period of time prior to the occurrence of the event that
the gazing behavior of the referee is to be monitored and a
second rule that specifies that a predetermined physical
region encompassing a physical location of the event is to be
monitored during the predetermined time period.
4. The computer-implemented method of claim 3, wherein the metric is a number of gazing directions of the
referee that coincide with the predetermined physical region
during the predetermined time period, and wherein deter-
mining that the metric fails to satisfy a threshold value
comprises determining that the number of gazing directions
is less than a threshold number of gazing directions.
5. The computer-implemented method of claim 3, wherein the metric is a total duration of time or a percentage
of the predetermined time period associated with gazing
directions of the referee that coincide with the predeter-
mined physical region, and wherein determining that the
metric fails to satisfy a threshold value comprises deter-
mining that the duration of time or the percentage of
the predetermined time period is less than a threshold duration
of time or a threshold percentage.
6. The computer-implemented method of claim 1, further
comprising:
- determining, by the computer processor, a first metric
  indicative of a gazing behavior of the referee in con-
  nection with the officiating decision;
- determining, by the computer processor, that the metric
  satisfies a threshold value; and
- determining, by the computer processor, a second metric
  indicative of an accuracy of the officiating decision.
7. The computer-implemented method of claim 6, wherein the second metric is determined based at least in
part on a deviation between the first metric and the threshold
value.
8. The computer-implemented method of claim 1, wherein the KPI data is first KPI data and the sports match
is a first sports match, the method further comprising:
- aggregating, by the computer processor, the first KPI data
  with second KPI data corresponding to a second sports
  match officiated by the referee to obtain aggregated
  KPI data;
- partitioning, by the computer processor, the aggregated
  KPI data into a plurality of decision categories; and
- determining, by the computer processor and based at least
  in part on the partitioning, a bias pattern associated with
  the referee.
9. A system for assessing officiating behavior of a referee
using gaze parameter data, the system comprising:
- at least one memory storing computer-executable instruc-
tions; and
- at least one processor configured to access the at least one
memory and execute the computer-executable instruc-
tions to:
  - capture the gaze parameter data via an image sensor
    over a period of time, wherein the gaze parameter
data is associated with actions of the referee during
a sports match being officiated by the referee;
  - identify a sports domain associated with the sports
    match;
  - identify a key performance indicator (KPI) correspond-
ing to the sports domain, the KPI being associated
with an officiating decision made by the referee
during the sports match;
  - identify one or more sports domain rules associated
with the KPI;
  - filter the gaze parameter data to obtain a location/time
series of the gaze parameter data that satisfies the one
or more sports domain rules;
  - generate KPI data associated with the KPI based at
least in part on the location/time series of the gaze
parameter data; and
  - determine whether the officiating decision was influ-
enced by bias of the referee based at least in part on
an analysis of the KPI data.
10. The system of claim 9, wherein the at least one
processor is configured to determine whether the officiating
decision was influenced by bias of the referee by executing
the computer-executable instructions to:
  - determine a metric indicative of a gazing behavior of the
    referee in connection with the officiating decision;
  - determine that the metric fails to satisfy a threshold value;
  - and
  - determine that the officiating decision was influenced by
    bias of the referee.
11. The system of claim 10, wherein the KPI corresponds
to a type of event to which the officiating decision relates,
wherein the one or more sports domain rules comprise a first
rule specifying a predetermined period of time prior to the
occurrence of the event that the gazing behavior of the
referee is to be monitored and a second rule that specifies that a
predetermined physical region encompassing a physical location of the event is to be monitored during the
predetermined time period.
12. The system of claim 11, wherein the metric is a
number of gazing directions of the referee that coincide with
the predetermined physical region during the predetermined
time period, and wherein the at least one processor is
configured to determine that the metric fails to satisfy a
threshold value by executing the computer-executable instruc-
tions to determine that the number of gazing direc-
tions is less than a threshold number of gazing directions.
13. The system of claim 11, wherein the metric is a
total duration of time or a percentage of the predetermined
time period associated with gazing directions of the referee
that coincide with the predetermined physical region, and
wherein the at least one processor is configured to determine
that the metric fails to satisfy a threshold value by executing
the computer-executable instructions to determine that the
duration of time or the percentage of the predetermined
time period is less than a threshold duration of time or a threshold
percentage.
14. The system of claim 9, wherein the at least one
processor is further configured to execute the computer-
executable instructions to:
  - determining, by the computer processor, a first metric
    indicative of a gazing behavior of the referee in con-
    nection with the officiating decision;
  - determining, by the computer processor, that the metric
    satisfies a threshold value; and
  - determining, by the computer processor, a second metric
    indicative of an accuracy of the officiating decision.
15. The system of claim 9, wherein the KPI data is first
KPI data and the sports match is a first sports match, and
wherein the at least one processor is further configured to
execute the computer-executable instructions to:
aggregate the first KPI data with second KPI data corresponding to a second sports match officiated by the referee to obtain aggregated KPI data; partition the aggregated KPI data into a plurality of decision categories; and determine, based at least in part on the partitioning, a bias pattern associated with the referee.

16. A computer program product for assessing officiating behavior of a referee using gaze parameter data, the computer program product comprising a non-transitory storage medium readable by a processing circuit, the storage medium storing instructions executable by the processing circuit to cause a method to be performed, the method comprising:

retrieving the gaze parameter data, wherein the gaze parameter data is captured by an image sensor over a period of time, and wherein the gaze parameter data is associated with actions of the referee during a sports match being officiated by the referee;

identifying a sports domain associated with the sports match;

identifying a key performance indicator (KPI) corresponding to the sports domain, the KPI being associated with an officiating decision made by the referee during the sports match;

identifying one or more sports domain rules associated with the KPI;

filtering the gaze parameter data to obtain a location/time series of the gaze parameter data that satisfies the one or more sports domain rules;

generating KPI data associated with the KPI based at least in part on the location/time series of the gaze parameter data; and determining whether the officiating decision was influenced by bias of the referee based at least in part on an analysis of the KPI data.

17. The computer program product of claim 16, wherein determining whether the officiating decision was influenced by bias of the referee comprises:

determining a metric indicative of a gazing behavior of the referee in connection with the officiating decision;

determining that the metric fails to satisfy a threshold value; and

determining that the officiating decision was influenced by bias of the referee.

18. The computer program product of claim 17, wherein the KPI corresponds to a type of event to which the officiating decision relates, wherein the one or more sports domain rules comprise a first rule specifying a predetermined period of time prior to the occurrence of the event that the gazing behavior of the referee is to be monitored rule and a second rule that specifies that a predetermined physical region encompassing a physical location of the event is to be monitored during the predetermined time period.

19. The computer program product of claim 18, wherein the metric is a number of gazing directions of the referee that coincide with the predetermined physical region during the predetermined time period, and wherein determining that the metric fails to satisfy a threshold value comprises determining that the number of gazing directions is less than a threshold number of gazing directions.

20. The computer program product of claim 16, wherein the KPI data is first KPI data and the sports match is a first sports match, the method further comprising:

aggregating the first KPI data with second KPI data corresponding to a second sports match officiated by the referee to obtain aggregated KPI data; partitioning the aggregated KPI data into a plurality of decision categories; and determining, based at least in part on the partitioning, a bias pattern associated with the referee.

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