[Claim 1]

A ball tracking apparatus comprising:

a capturing control part capturing a ball with a camera;

a detection control part detecting a launch of the ball;

a calculation control part calculating a three-dimensional position and a three-dimensional velocity of a world coordinate system of a flying ball at an initial time when the launch of the ball is detected as an initial position and an initial velocity;

a prediction control part predicting a three-dimensional position and a three-dimensional velocity of the world coordinate system of the flying ball at a specific time after the initial time as a predicted position and a predicted velocity based on the calculated initial position and the calculated initial velocity of the flying ball, and an equation (8) in-dicating a parabolic shape of the flying ball;

a conversion control part converting the predicted position of the flying ball into a two-dimensional position of a camera coordinate system in a captured image captured at the specific time as a temporary position;

an acquisition control part specifying a flying ball image indicating the flying ball in the captured image at the specific time based on the converted temporary position in the captured image, and acquiring a two-dimensional position of camera coordinate system of the specified flying ball image as an observation position;

a correction control part correcting the predicted position and the predicted velocity of the flying ball as a corrected position and a corrected velocity based on the predicted position and the predicted velocity of the flying ball, the observation position of the flying ball image, and a Kalman filter of an equation (11) of a state model and an equation (12) of an observation model;

a repetition control part calculating a trajectory of the flying ball by repeating the prediction, the conversion, the acquisition, and the correction with using the correction position and the correction velocity of the flying ball at the specific time;

wherein:

the equation (8) is

[Math. 1]

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ z(k+1) \\ Vx(k+1) \\ Vy(k+1) \\ Vz(k+1) \end{bmatrix} = \begin{bmatrix} x(k) \\ y(k) \\ z(k) \\ Vx(k) \\ Vy(k) \\ Vz(k) \end{bmatrix} + \begin{bmatrix} Vx(k) \\ Vy(k) \\ Vz(k) \\ -k_d\|V(k)\|Vx(k) + k_m\{\omega yVz(k) - \omega zVy(k)\} \\ -k_d\|V(k)\|Vy(k) + k_m\{\omega zVx(k) - \omega xVz(k)\} \\ -k_d\|V(k)\|Vz(k) + k_m\{\omega xVy(k) - \omega yVx(k)\} - g \end{bmatrix} T \cdots (8)$$

, kd is (-1 / 2m) CdρA, km is (1 / 2m) CmρAr, T is a capturing time interval, m (kg) is a weight of the flying ball , Cd is a coefficient of air resistance, ρ is a density of air, A is a front projected area of the flying ball, V = (Vxr, Vyr, Vzr) is a three-dimensional velocity of the flying ball, Cm is a coefficient of Magnus force, r (m) is a radius of the flying ball, ω = (ωx, ωy, ωz) is a three-dimensional spin velocity of the flying ball, ω = (ωx, ωy, ωz) = (0, 0, 0) in the initial state, and g is a gravity acceleration;

the equation (11) is

x (k + 1) = F (k) * x (k) + w (k) ... (11)
, k is a time coefficient, F (k) corresponds to the equation (8) indicating
a parabolic shape at k, x (k) corresponds to the three-dimensional position and the three-dimensional velocity at k, w (k) is a process
noise at k, and x (k + 1) corresponds to the predicted position and predicted velocity at k + 1;

the equation (12) is
y (k) = H (k) * x (k) + v (k) ... (12)
, H (k) corresponds to the equation for converting the three-dimensional position of the world coordinate system into the two-dimensional position of the camera coordinate system, v (k) is a process noise at k, and y (k) corresponds to the observation position at k,

the acquisition control part determines a search range centered on the converted temporary position in the captured image at the specific time, detects an edge image from the determined search range by using a method such as an edge enhancement processing or an edge detection processing, calculates a minimum circle image including the detected edge image, calculates a division value by dividing a minimum occupied area occupied by the minimum circle image from an occupied area occupied by the edge image, and specifies an edge image in which the division value is within a range of a flying ball reference value and is closest to a circle reference value indicating a circle as a flying ball image,

the flying ball reference value is set in a range of 0.9 (-) to 1.1 (-), and the circle reference value is set to 1.0 (-), and

the acquisition control part acquires a two-dimensional center position of the specified flying ball image as the observation position.

[Claim 2]

The ball tracking apparatus according to claim 1, wherein:

the detection control part detects the launch of the ball by detecting a disappearance of a stop ball image after detecting the stop ball image showing the ball stopped for a predetermined time, or

the detection control part receives a Doppler signal corresponding to the launch of the ball by using a microwave detection device, and detects the launch of the stop ball based on a fluctuation of the Doppler signal.

[Claim 3]

The ball tracking apparatus according to claim 1, wherein:

the calculation control part sets a three-dimensional center position of a stop ball image showing the ball stopped at the initial time, or the
flying ball image at a specific time after the initial time as the initial position, extracts a flight ball candidate image being a possibility of the flying ball from a captured image at each time after the initial time, specifies flying ball candidates image existing on or near a straight line over time in the flying ball candidate images extracted at each time as flying ball images, and calculates the initial velocity based on the specified flight ball images based on the specified flying ball
candidates, or

the calculation control part receives a Doppler signal after the ball launches immediately by using the microwave detection device, detects an initial velocity of the flying ball based on the Doppler signal, and calculates the initial position of the flying ball by analyze images with the camera.

[Claim 4]

A ball tracking method comprising:

a capturing control step for capturing a ball with a camera;

a detection control step for detecting a launch of the ball;

a calculation control step for calculating a three-dimensional position and a three-dimensional velocity of a world coordinate system of a flying ball at an initial time when the launch of the ball is detected as an initial position and an initial velocity;

a prediction control step for predicting a three-dimensional position and a three-dimensional velocity of the world coordinate system of the
flying ball at a specific time after the initial time as a predicted position and a predicted velocity based on the calculated initial position and the calculated initial velocity of the flying ball, and an equation (8) in-dicating a parabolic shape of the flying ball;

a conversion control step for converting the predicted position of the flying ball into a two-dimensional position of a camera coordinate system in a captured image captured at the specific time as a temporary position;

an acquisition control step for specifying a flying ball image indicating the flying ball in the captured image at the specific time based on the converted temporary position in the captured image, and acquiring a two-dimensional position of camera coordinate system of the specified flying ball image as an observation position;

a correction control step for correcting the predicted position and the predicted velocity of the flying ball as a corrected position and a corrected velocity based on the predicted position and the predicted velocity of the flying ball, the observation position of the flying ball image, and a Kalman filter of an equation (11) of a state model and an equation (12) of an observation model;

a repetition control step for calculating a trajectory of the flying ball by repeating the prediction, the conversion, the acquisition, and the correction with using the correction position and the correction velocity of the flying ball at the specific time;

wherein:

the equation (8) is

[Math. 2]

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ z(k+1) \\ Vx(k+1) \\ Vy(k+1) \\ Vz(k+1) \end{bmatrix} = \begin{bmatrix} x(k) \\ y(k) \\ z(k) \\ Vx(k) \\ Vy(k) \\ Vz(k) \end{bmatrix} + \begin{bmatrix} Vx(k) \\ Vy(k) \\ Vz(k) \\ -k_d \|V(k)\| Vx(k) + k_m \{\omega y Vz(k) - \omega z Vy(k)\} \\ -k_d \|V(k)\| Vy(k) + k_m \{\omega z Vx(k) - \omega x Vz(k)\} \\ -k_d \|V(k)\| Vz(k) + k_m \{\omega x Vy(k) - \omega y Vx(k)\} - g \end{bmatrix} T \cdots (8)$$

, kd is (-1 / 2m) CdρA, km is (1 / 2m) CmρAr, T is a capturing time interval, m (kg) is a weight of the flying ball , Cd is a coefficient of air resistance, ρ is a density of air, A is a front

projected area of the flying ball, V = (Vxr, Vyr, Vzr) is a three-dimensional velocity of the flying ball, Cm is a coefficient of Magnus force, r (m) is a radius of the flying ball, ω = (ωx, ωy, ωz) is a three-dimensional spin velocity of the flying ball, ω = (ωx, ωy, ωz) = (0, 0, 0) in the initial state, and g is a gravity acceleration;

the equation (11) is

x (k + 1) = F (k) * x (k) + w (k) ... (11)

, k is a time coefficient, F (k) corresponds to the equation (8) indicating a parabolic shape at k, x (k) corresponds to the three-dimensional position and the three-dimensional velocity at k, w (k) is a process noise at k, and x (k + 1) corresponds to the predicted position and predicted velocity at k + 1;

the equation (12) is

y (k) = H (k) * x (k) + v (k) ... (12)

, H (k) corresponds to the equation for converting the three-dimensional position of the world coordinate system into the two-dimensional position of the camera coordinate system, v (k) is a process noise at k, and y (k) corresponds to the observation position at k,

the acquisition control step determines a search range centered on the converted temporary position in the captured image at the specific time, detects an edge image from the determined search range by using a method such as an edge enhancement processing or an edge detection processing, calculates a minimum circle image including the detected edge image, calculates a division value by dividing a minimum occupied area occupied by the minimum circle image from an occupied area occupied by the edge image, and specifies an edge image in which the division value is within a range of a flying ball reference value and is closest to a circle reference value indicating a circle as a flying ball image,

the flying ball reference value is set in a range of 0.9 (-) to 1.1 (-), and the circle reference value is set to 1.0 (-), and

the acquisition control step acquires a two-dimensional center position of the specified flying ball image as the observation position.