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Research on Intelligent Recognition and Verification System of Football Offside Penalty Based on Artificial Intelligence

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Abstract: - An automatic recognition method for ball trajectory and penalty is extensively studied, leveraging computer vision technology. The core hardware components of this system are designed to effectively filter out noise and extract crucial information from the moving track. This enables the system to accurately identify the speed and position of the ball in real-time. To enhance the precision of image segmentation, a novel approach is introduced that utilizes the threshold vector in high-resolution color spaces. This method determines the color of each pixel through bitwise "and" operations between pixel points and subsets. Additionally, a moving window image filtering algorithm is proposed, incorporating trajectory prediction theory. Experimental results demonstrate that this approach significantly reduces recognition errors, resulting in a notably higher accuracy level, making it a promising solution for enhancing the performance of soccer robot systems.

Keywords: Football; Curveball; Motion Trajectory; Image Segmentation; Threshold Value; Image Filtering; Intelligent Identification System.

I. INTRODUCTION

The world of soccer robotics has indeed become a vibrant frontier for new research and development. The soccer robot, a multi-faceted research direction with immense potential for application, stands as an excellent example of multi-disciplinary collaboration. Comprising a diverse array of subsystems, the soccer robot can be broadly categorized into four key components: robotics, vision, decision-making, and communication. Among these, the role of vision is paramount, as it serves as the linchpin for quickly and precisely identifying information sources that are crucial to ensuring the accuracy and stability of the entire system. The RoboCup micro-group system, for instance, relies heavily on the vision subsystem [1]. It analyzes the images captured by cameras positioned on the ground, transforming them into instructions that are then relayed to the decision-making subsystem. This, in turn, enables precise operations related to the position, number, and moving speed of players, as well as the position and moving direction of the ball. One significant challenge faced by the soccer robot system is the accurate identification of individual robots based on color. To address this, intelligent classification methods rooted in color identification have been proposed. However, as the field area expands, traditional image processing systems encounter new challenges in terms of recognition accuracy, speed, and precision. Currently, motion trajectory detection methods primarily rely on the gray features of the image [2]. While this approach has its merits, it falls short when it comes to recognizing curve balls, as it disregards the original color information. This can lead to significant errors and slower recognition speeds. To overcome these limitations, a set of automatic recognition and penalty systems based on computer vision technology is being designed. This system promises to enhance recognition accuracy and speed by leveraging advanced algorithms that take into account both gray features and color information. By doing so, it stands to revolutionize the soccer robot system, making it more robust, efficient, and accurate in its operations.

II. ANALYSIS OF FACTORS CAUSING FOUL OFFSIDE

A. Subjective negligence of the referee

a) Reasons for service level

Due to the difference of professional quality, there are the following reasons for the offside error in football matches. 1) In major international events, because the players of various countries are composed of different nationalities, there are certain differences in their understanding and understanding of this provision. 2) The

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choice of the vice referee, that is, when a "split second" is passed between teammates, the vice referee is not on a parallel line with the last second player, or is not parallel to the football. In the competition, if you do not have the ability to sprint and move quickly, it is likely to lose parallel positions, resulting in misjudgments and missed judgments. 3) Determine the "moment" required for players on the same team to kick or touch the ball, when the team moves forward quickly, in high-speed attack, in high-speed movement, in the case of fast speed, in a high-speed game, in the game, because the opponent's speed is faster, so that the referee is caught off guard, resulting in this "moment" decision error. 4) During the match, the attacker's "involvement" resulted in gains. Therefore, due to the subjective factors of the assistant referee, the two skills of "waiting" and "watching" were introduced into the "Assistant referee Code", and the relevant definitions of "interfering with the match", "interfering with the other side" and "gaining benefits" were deeply interpreted [3]. The auxiliary referee must observe the game carefully during the game, make the right judgment quickly, and closely link the spirit of the clause with the actual situation of the actual game, so as to make the right decision.

b) The mental condition of the vice referee on the field is poor

On the pitch, a poor mentality due to a lack of concentration. The concentration of referees is an essential and important guarantee to assist referees in judging offside. 2) Anxiety in the work of vice judges. Sources of stress can be results of important matches, intense matches, intense atmospheres, screaming fans, live television, and so on.

B. Objective facts that are inevitably wrong

a) Measurement deviation caused by excessive observation Angle

For a game, assistant referees typically employ two visual search mechanisms: 1) Attention migration, which follows a similar path to the movement of a spotlight light, taking 25 milliseconds each; 2) Swordshop, which is also the most basic eye movement activity, is divided into exogenous and endogenous two parts by scholars such as Professor Javal of the University of Paris. A single swordshop consists of two parts: planning and implementation, which only takes tens of milliseconds to hundreds of milliseconds. When an assistant is at his peak, if his observation is in the form of a spotlight, with a 60-degree view, it takes 1.5 seconds, when a player passes the ball to another player, assuming his first action is 9 m/s, consider the foul by the top defensive back, from the time he finds the ball to his action, His movement will have a deviation of more than 13.5 meters, which is how incredible things [4]. Therefore, in the decision of the referee, most of the use of the introverted eye leap, this introverted eye leap appears between the passer and the receiver.

From the above discussion, in this case, if the assistant referee can achieve a very perfect degree of subjectivity, then, in this case, the Angle between the passer and the receiver on the field is about 80 degrees. In a conservative estimate, when the player is running forward, when the player touches the ball, the Angle he is looking at, the saccade takes 100 ms to occur [5]. In such a case, how many meters of error did the deputy referee see? Assuming that at the moment of passing, the attacking player and the second defender are parallel, and the vice referee is also on this parallel line, the time required from the referee's observation of the player's pass to the observation of the player's position is 100 milliseconds, that is, 0.1 seconds, and the relative speed when the first player and the second player face each other is 9 m/s +2 m/s =11 m/s, so, When, 0.1 seconds after the first pass, the second player is 11m/s×0.1s =1.1m closer to the goal line than the second player, the referee will mistakenly think that the opponent is offside from the moment his teammate passes the ball to him.

b) Noise caused by sound wave transmission

The author conducted interviews with players at different levels, and the results show that some assistant referees, when calling offside, will only focus their full attention on the second defender, and this will not happen, they will only judge the timing of the pass based on the player's "bang". In rugby players, the long ball is 30 to 50 meters or more [6]. For example, at a distance of 40 meters, the transmission rate of sound waves in the air is about 340 meters/second, and the time taken from the beginning of the ball to the referee hearing the "bang" is 40 meters ×340 meters/second =0.12 seconds. The results show that the measurement of 0.12s is better than that of 0.1s under normal conditions. Thus, it can be seen that hearing alone to determine the timing of the pass is not very reliable.

c) Error caused by the speed of the ball or the speed of the player in the court

Football is a quick attack and defense of the sport, the explosive power of the attacking athletes is very strong, the speed is very fast, and the number of sprints is also a lot, so in this case, the physical quality of the referee is much worse than that of the professional athletes, in this case, when making a quick counterattack, it is difficult for the referee to ensure that the position of the second defender is 100% consistent. Although the assistant referee's game experience can make up for the lack of physical fitness to a large extent, but many times, the key game, mainly rely on the initiative to run, to establish a good position [7]. For example, when a player has control of the ball near the halfway line, and the defender is in a small area battle, the receiver moves forward quickly from the halfway line, the second defender immediately drops back to defend, and the referee has to run after him. However, when the receiver moves forward to a certain point, his teammates will pass the ball to him, at this time, the referee will be thrown far behind, which clearly does not meet the conditions of parallel observation of offside, and therefore produces an objective error.

III. The technical feasibility of electronic adjudication

A. Hawk-Eye system

Engineers at Manor Research developed the Hawk-Eye system, which is already used in sports such as cricket, tennis and snooker. The method utilizes visual images and real-time information captured by high-speed cameras located in various areas of the site. The device requires six cameras, with a total value of £250,000. The disadvantage of this method is that it is statistically incorrect, and both Federer and Nadal have criticized this method in the past, but Federer himself believes that it can be used in football [8].

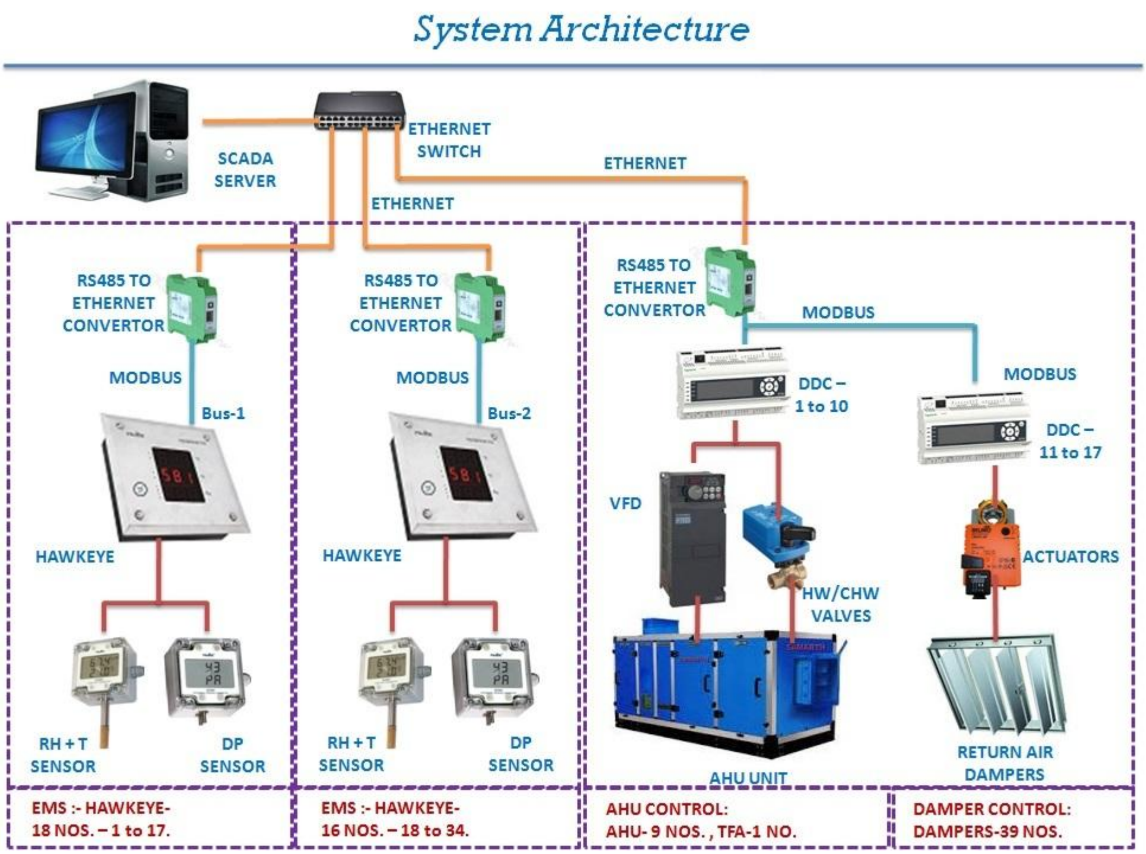

Fig. 1 Hawkeye system architecture

Another drawback is that when the football is completely blocked, the system does not work properly. If this system were to be applied to rugby, it would have to take into account the number of attacks each team made against the Hawkeyes, the number of interruptions and the duration of the interruptions. Fig. 1 shows the architecture of Hawkeye (image cited in Building Management System in Pharmaceutical Industry).

B. Cairos GLT system

CairosGLT is a joint development between Adidas and Cairos Technologies. The device consists of a thin cable installed under a football field. Electricity from the cable creates a magnetic field that can be sensed by sensors in the player and his body. Sensors in the player's body can detect the magnetic field in this area and transmit messages from this area to a receiver near the stadium and then to a central computer. At the moment of shooting, the computer calculates whether the offensive and defensive sides are in the offside state, if the offside is confirmed, then the computer will send a goal signal to a vice referee wearing a special watch, and the vice referee will decide to raise the flag according to the "involvement" of the attack party in the actual game to gain benefits, thus greatly increasing the judgment of offside [9]. The shortcoming of this system is that the speed and accuracy are not high. If this system can be improved, it can make timely feedback on whether the athlete is in the offside state, rather than stopping because there is no pause, and the final decision must be made by the assistant referee, which is also very beneficial for the continuity of the game. Fig. 2 shows the architecture of Cairos GLT (image cited in Life Cycle Cost Analysis of Nearly-Zero Energy Buildings: An Introduction to the Methodologies).

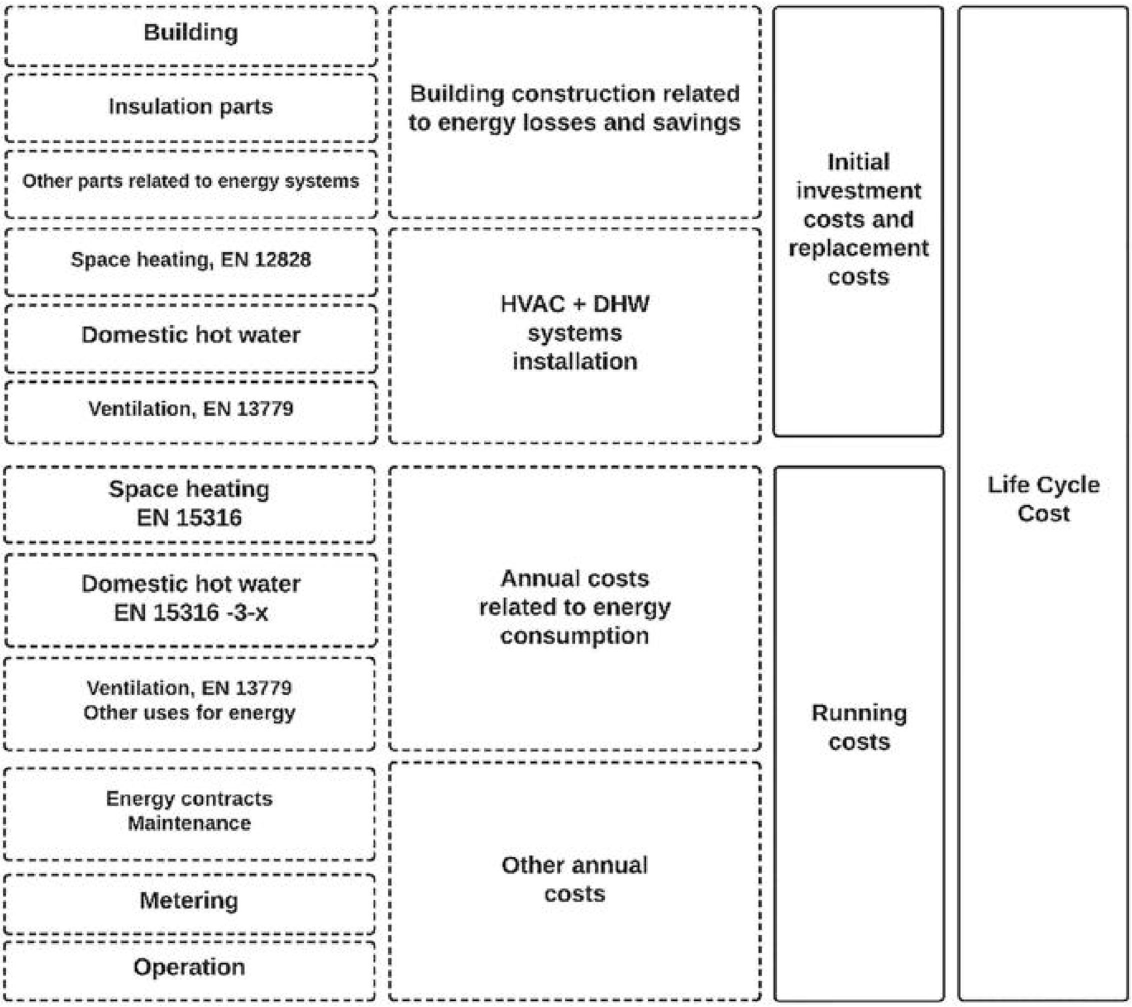

Fig. 2 Cairos GLT system architecture

IV. Hardware design of football electronic referee system

With the expansion of the venue area, the obtained color label and the sphere contain less information, which is difficult to meet the identification needs of the target. Therefore, the system uses two camera acquisition methods (Fig. 3 cited in ICT Reference Architecture Design Based on Requirements for Future Energy Marketplaces), As can be seen from Fig. 3, the image acquisition area overlaps. The traditional multi-layer image segmentation technique based on image Mosaic has some disadvantages such as complicated operation and complex operation [10]. This project intends to use two different visual systems to recognize objects in the scene, and extract the corresponding objects from the local coordinate system of the corresponding image acquisition device. Digital information is passed to the fusion component, which fuses multiple objects in overlapping positions and transmits that object to the decision subsystem.

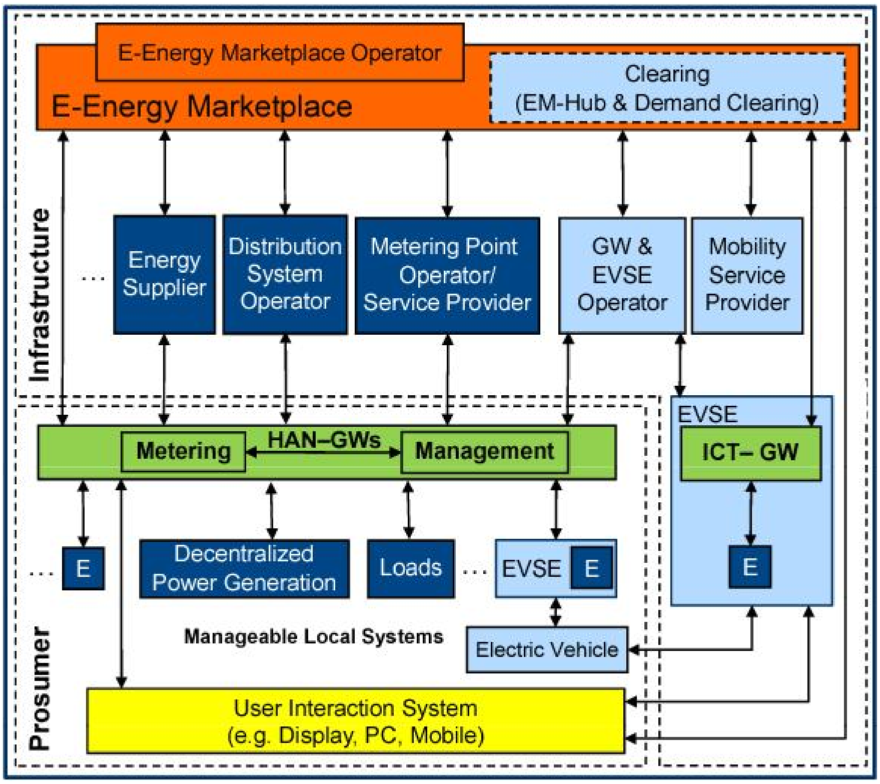

Fig. 3 Architecture of football electronic referee system

A. Acceleration sensor selection

Because football is a kind of sports object with spatial movement characteristics, there are often players in the game, so its movement area is very narrow. The KSD-2563 accelerometer is selected as the research object [11]. The supply voltage of the KSD-2563 sensor is 2.54-2.84V, the voltage of the digital signal conversion is 1.5-2.5V, and the measuring range is ±2kg. The measurement accuracy is 12 bit 2 g /0.2 degree, 8 bit 8 g /0.55 degree. The acceleration element of the model KSD-2563 is shown in Fig. 4 (image cited in Biosensors, Volume 12, Issue 11 (November 2022)-148 articles).

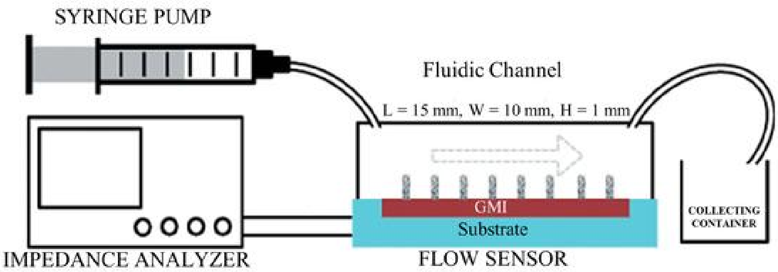

Fig. 4 Acceleration sensor of the KSD-2563 model

B. Selection of angular motion detection device

SJDA-25542 horn action detection equipment can output adjustable digital signals to the system through a simple serial port, and can also detect Angle action detection equipment, temperature, power supply voltage, etc. SJDA-25542 horn displacement detection equipment, its displacement stability is about 0.018 degrees/second, random walk 5.2 degrees/hour, its characteristic frequency band width 0.48 KHz, noise amplitude in 0.002 degrees/second/second, the maximum current 35 mA. According to the vibration coupling of the driving mode, the displacement or corresponding change of the detecting mode, and then the Angle size and angular velocity of the motion of the ball are obtained.

C. Power circuit design

In the operation of the wireless communication system, the mobile phone is usually equipped with a 4.0 volt (V) round battery as its energy source, while the base station terminal relies on a 4C external power supply. During system operation, the operating voltage standard of the acceleration sensor is 3.5 volts (V), while the required operating voltage of the angular motion detection device is increased to 4.5 volts (V) under dynamic monitoring conditions. In view of the specific needs of the system application, we built a regulated power supply model to ensure that the operating voltage requirements of different hardware components can be met. The model is designed to provide a stable and compatible power supply so that all parts of the system work together at their best. Fig. 5 shows the connection diagram of the power supply circuit of the system in this paper (the picture is quoted in Sequence Controls for Motor Starters). The acceleration signal acquisition and reception part is also designed. The function of the system is to collect and transmit the information of the acceleration of the motion of the curve ball in space [12]. The receiving part of the signal is to receive various types of football arc ball action information from the acquisition loop, and the information is transmitted to the PC in a serial manner.

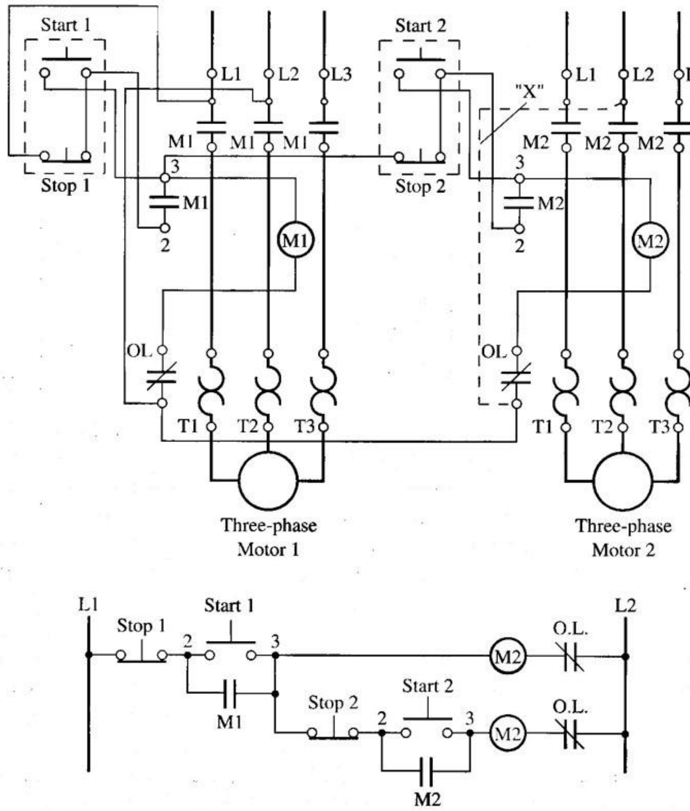

Fig. 5 Schematic diagram of the system power circuit connection

V. System software design

A. Motion trajectory data filtering processing

Kalman filter model is introduced to filter and process the motion trajectory data collected and extracted by the hardware of the above system. The model can be expressed by formula (1):

$$f_m = \phi_m f_m + \zeta_m \tag{1}$$

f_m represents the system state matrix, ϕ_m represents the system state transition matrix, and ζ_m represents the system noise. The trajectory information is input into the Kalman filter, and then the new motion state information is iterated to obtain the dynamics curve after noise reduction [13]. Then the estimation is revised based on the observation results, noise variation and prediction are performed at the same time, and then back to the Kalman filter, and so on, until the movement of the circular ball is finished, all the updated values are 0, then all the data is the trajectory data after noise elimination. The flow of the mobile tracking data filtering algorithm is shown in Fig. 6 (image cited in Appl.Sci.2022, 12(3), 1319).

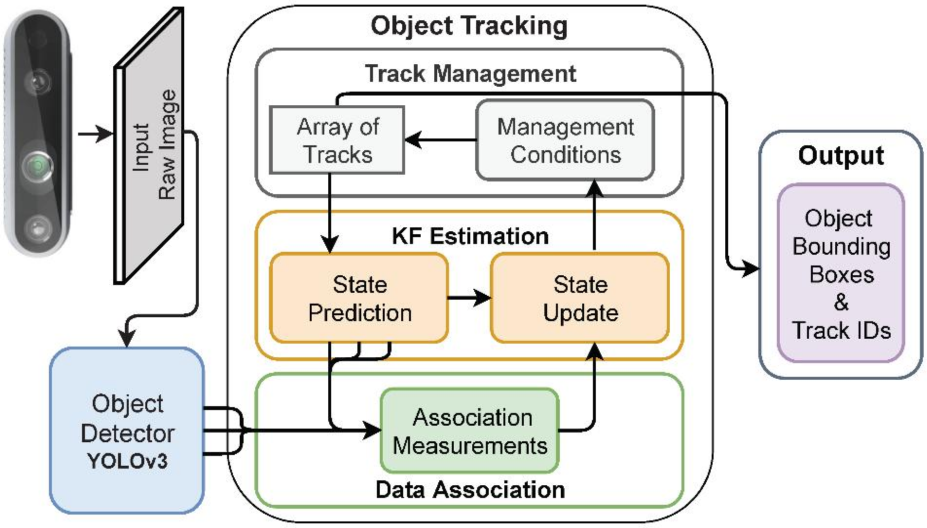

Fig. 6 Flow chart of mobile tracking data filtering algorithm

B. Football speed and position identification

This paper identifies the velocity and displacement results of the curveball movement, and points out that there are some errors in this method [14]. Polynomial method is used to identify the results of the motion rate and displacement of the football curve:

$$d = d(t) + \frac{\lambda_1}{3}t^2 + \frac{\lambda_2}{2}t^2 + \lambda_3 t \tag{2}$$

d represents the movement displacement of the curveball recognized by the system; $\lambda_1, \lambda_2, \lambda_3$ represents the offset component of the gravitational acceleration in each axis direction of the space coordinates during the motion of the curved ball. t represents the time from the time the ball leaves the ground to the time it first makes contact with the ground [15]. The trajectory model is established in MATLAB environment. The software flow of the system is shown in Fig. 7 (image cited in SoccER: Computer graphics meets sports analytics for soccer event recognition).

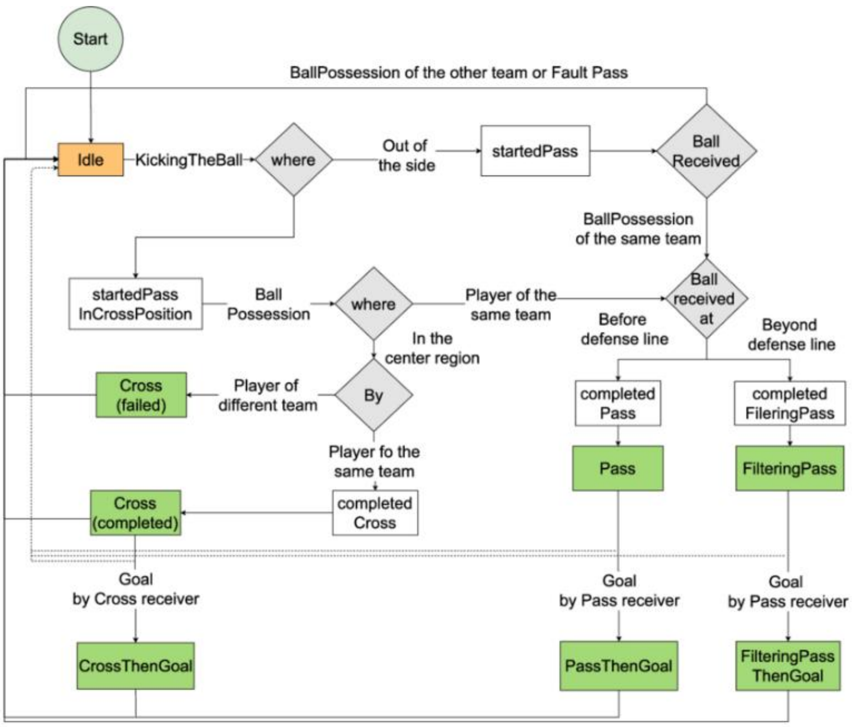

Fig. 7 Software flow of football track recognition system

VI. Field target recognition method

A. Color space transformation

There is a strong correlation between the three components of the RGB color space, so that the similarity between the colors cannot be measured by the distance between the two points [16]. In addition, the change in lighting brightness will also have a great impact on the size of the RGB three components, which is very inconvenient in practice. In contrast, HSI algorithm is more used in color image processing, it can separate brightness and chroma, reduce the impact of lighting conditions on the image. Where hue represents chroma, $saturat$ represents saturation, and $\text{int}\,ensit$ represents brightness. The hue component ranges from 0 to 360 and is the Angle value. The $saturat$ and $\text{int}\,ensit$ components range from 0 to 255.

The conversion formula is as follows:

$$\begin{aligned}
&hue = \cos^{-1}\left(\frac{(red-green)+(red-blue)}{2\times\sqrt{(red-green)^2+(red-blue)(green-blue)}}\right) red \neq green\, or\, red \neq blue \\
&if\ blue > green\ hue = 2\pi - hue \\
&saturat = 1 - \frac{3\times[\min(red, green, blue)]}{red+green+blue} \\
&\text{int}\,ensit = \frac{red+green+blue}{3}
\end{aligned} \tag{3}$$

B. Threshold determination and color judgment

Aiming at the high demand of real-time performance in RoboCup team football competition, a fast and low computational identification algorithm is adopted. Sets the pixel points in a particular color interval to the same region and splits them into corresponding subregions [17]. First, the upper and lower thresholds $hue_{ihue}, hue_{iC}, saturat_{ihue}, saturat_{iC}, \text{int}\,ensit_{ihue}, \text{int}\,ensit_{iC}$ of each color are determined in the HSI color space by sampling. In order to minimize the impact of lighting, the colors to be identified can be sampled in the brightest and darkest parts of the site. For a pixel Q to be identified, if:

$$\begin{aligned}
&hue_{iC} \leq hue_Q \leq hue_{ihue} \\
&saturat_{iC} \leq saturat_Q \leq saturat_{ihue} \\
&\text{int}\,ensit_{iC} \leq \text{int}\,ensit_Q \leq \text{int}\,ensit_{ihue}
\end{aligned} \tag{4}$$

Point Q is considered to belong to the color. However, the algorithm requires 6 criteria to determine a pixel value, and in the contest, there are 768x576 pixels in an image, so the computation is very large [18]. Use a sequence of 0,1 to represent the threshold range of each color, such as:

$$\begin{aligned}
&hue_i = \{0,0,0,0,0,0,0,1,...,1,0,0,0,...\} \\
&saturat_i = \{0,0,0,0,1,1,1,1,0,....\} \\
&\text{int}\,ensit_i = \{0,0,0,1,1,1,1,0,...\}
\end{aligned} \tag{5}$$

C. Dynamic window filtering

a) Algorithm proposal

Due to noise interference, there are discontinuity between the same image elements, and they are divided into several smaller areas by noise, resulting in image loss, so it is necessary to filter the image quickly and efficiently [19]. The average filter has the advantages of good de-noising effect and good de-noising effect, but in the process of de-noising, the image boundary will become fuzzy, and the object can not be accurately determined. A method of denoising based on weighted average is proposed. The experimental de-noise the original data, and provide high-quality data for the subsequent classification work.

b) Implementation of algorithm

In the HSI color space, the hue value represents chroma and has very good image recognition [20]. In order to improve the recognition speed, only the hue component is filtered. $h(\alpha,\beta)$ represents the original image, $g(\alpha,\beta)$ is the chromaticity value of the smoothed point (α,β), U represents the neighborhood centered on the point (α,β), which contains Z pixels, and n represents the chromaticity mean in the neighborhood U. Then:

$$g(\alpha,\beta)=\begin{cases} n+\lambda n_g & Z_g > \max(Z_l,Z_o) \\ n-\lambda n_l & Z_l > \max(Z_g,Z_o) \\ n & else \end{cases} \tag{6}$$

Where Z_g, Z_o, Z_l represents the number of pixels whose chroma value is greater than, equal to and less than n in U respectively; n_g is defined as the difference between the average chromaticity value of each pixel with a chromaticity value greater than the neighborhood mean n and n, and n_l is defined as the difference between the average chromaticity value of each pixel with a chromaticity value less than n. There is:

$$\begin{cases} n=\dfrac{1}{Z}\cdot\sum\limits_{(i,j)\in U} h(i,j) \\ n_g=\dfrac{1}{Z_g}\cdot\sum\limits_{\substack{(i,j)\in U \\ h(i,j)>n}} h(i,j)-n \\ n_l=n-\dfrac{1}{Z_l}\cdot\sum\limits_{\substack{(i,j)\in U \\ h(i,j)<n}} h(i,j) \end{cases} \tag{7}$$

λ is the correction factor, ranging from 0 to 1, and its magnitude reflects the edge condition in U. The definition is as follows:

$$\lambda=\begin{cases} 1-\left(\dfrac{Z_g}{Z_l}\right)^{\delta} & Z_l > \max(Z_g,Z_o) \\ 1-\left(\dfrac{Z_l}{Z_g}\right)^{\delta} & Z_g > \max(Z_l,Z_o) \\ 0 & else \end{cases} \tag{8}$$

Where $\delta > 0$. The size of δ directly affects the performance of the above formula. The smaller the δ, the stronger the smoothing effect on the noise; The larger δ is, the stronger its sharpening effect is. Generally, in the case of strong noise, the impact of noise interference on image quality is more prominent, so δ should be a smaller value; On the contrary, in the case of weak noise, a larger value should be taken [21]. So it can be adjusted before the game.

c) Selection of filter region

If all the pixels are judged the competition can not be achieved. The motion range between adjacent frames is limited, so it is not necessary to filter it globally, but only to filter its motion range in the maximum range [22]. According to the principle of trajectory prediction, the speed of the target is constant, so the target in the next frame can be predicted by estimating the positioning and speed of the next image. Set the current position of the target as (α_t, β_t), then the predicted position of the target in the next frame is:

$$\alpha_{t+1} = \alpha_t + v_{\alpha,t}\Delta T$$
$$\beta_{t+1} = \beta_t + v_{\beta,t}\Delta T \tag{9}$$

Since the speed of the robot cannot be directly obtained in actual decision-making, the above formula is rewritten as:

$$\begin{cases} \alpha_{t+1} = \alpha_t + \Delta\alpha = 2\alpha_t - \alpha_{t-1} \\ \beta_{t+1} = \beta_t + \Delta\beta = 2\beta_t - \beta_{t-1} \end{cases} \tag{10}$$

Where $v_{\alpha,t}, v_{\beta,t}$ is the predicted current frame α, β of the target. ΔT is the time interval between adjacent frames, and $\Delta\alpha, \Delta\beta$ is the increment in the α, β direction in the ΔT time[23]. $\alpha_{t-1}, \beta_{t-1}$ indicates the dynamic window with $(\alpha_{t+1}, \beta_{t+1})$ as the center and d as the distance extending outward is the filtering region.

VII. Experimental demonstration and analysis

A. Experimental process

This project chooses a 6.8GHz memory 16G system as the research object, and takes Windows2020 as the development environment. The acceleration information of X, Y and Z axes is selected to describe the football curve, and the acceleration information of each direction is 32 bits. Each data set has two 16-bit registers [24].The effect of the two methods on the football curveball in 3D environment, the identification effect of the two methods is compared from the initial point.

B. Experimental Results

All the calculated results are summarized and drawn into a comparison table of experimental results, as shown in Table 1 and Fig. 8 proposed system with that of the traditional system.

Table 1: Comparison of experimental results

ball trajectories	The system identifies the result offset /m	Traditional systems identify the result offset /m
Track 1	0.019	0.102
Track 2	0.017	0.113
Track 3	0.024	0.120
Track 4	0.015	0.125
Track 5	0.019	0.130

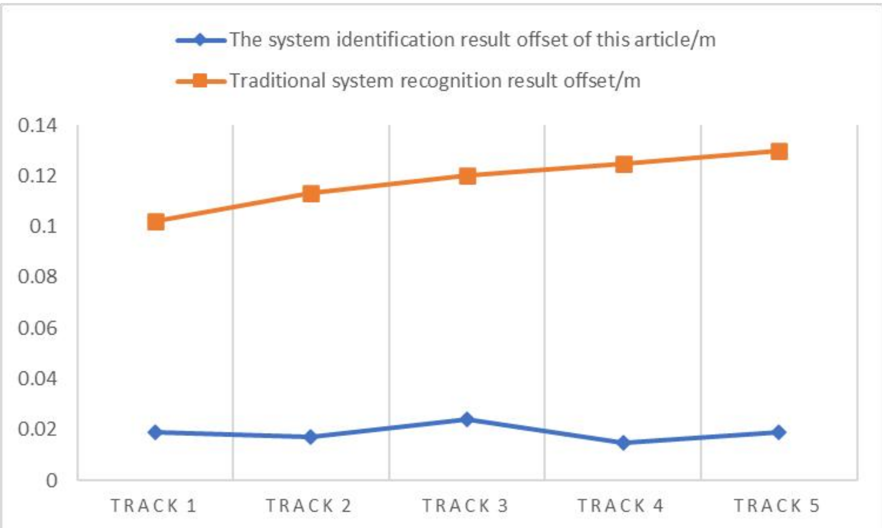

Fig. 8 Identifying the result offset

It can be seen from Table 1 compared with the conventional method, this method has higher precision. In the test, the conventional test method has a great error; Due to the strong interference of external factors, the nonlinear error caused by it cannot be completely eliminated. In practical application, the error is caused by the action of gravity field. However, in this method, the external reference frame can give more accurate position information, and it is not limited by the external frame, and the football trajectory can be detected freely at any position.

VIII. CONCLUSION

In this paper, the automatic detection technology of football trajectory is discussed in detail, and a concrete integrated design scheme of software and hardware is proposed. In order to verify the effectiveness of these schemes, a series of experiments are carried out, and the experimental results confirm their feasibility and accuracy. Looking forward to the future, this paper will continue to deepen the research in this field, and strive to achieve a higher accuracy of football motion trajectory prediction, that is, to reach a precision close to or equal to the millimeter level. Such progress will not only have a positive impact on the fair ruling of football matches, but also bring new breakthroughs in the development of sports science and technology as a whole. With the continuous improvement and innovation of technology, we have reason to expect a more intelligent era of football analysis.

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