Design of Automatic Control System for Stage Following Spotlight Based on UWB Positioning Technology

Shu-qi NIU$^{1,2,3,*}$ and Shi-lei BAI$^{1,2,3}$

$^1$Faculty of Science and Technology, Communication University of China, Beijing, China
$^2$Key Laboratory of Acoustic Visual Technology and Intelligent Control System, Ministry of Culture, Beijing, China
$^3$Beijing Key Laboratory of Modern Entertainment Technology, Beijing, China

*Corresponding author

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Abstract. At present, the following spotlight on stage is performed manually. Then there are many disadvantages such as high labor intensity, unstable artistic effects, etc. With the improvement of the function of the intelligent lamps and the development of the intelligent control technology of the stage lighting, it is possible to realize the automatic control of the stage chasing lights. An automatic control system for stage following spotlight based on UWB (Ultra Wide Band) positioning technology is proposed in this paper. This system combines ultra wideband positioning technology with stage lighting control technology based on DMX512 protocol, and uses the moving head light to realize automatic chase. The stage target positioning technology and coordinate transformation are described in details, and C++ is adopted as the environmental tool for human-computer interaction design in this paper. The experiment result shows that system can achieve an automatic control system for stage following spotlight.

Introduction

Chasing light of stage is an important part of art light, which has the function of highlighting the theme, setting the mood of the actors, promoting the development of the plot, showing the transformation of time and space, and producing montage effect[1]. It is indispensable in many stage performances. Currently, the chase of light is performed manually, which not only increases the cost of performance, but also has the disadvantages of large labor intensity and unstable artistic effects. With the improvement of smart lighting function and the development of stage lighting intelligent control technology, it is possible to achieve the stage chase light automatic control[2]. Automatic tracking must meet the following three evaluation indicators: tracking accuracy, real-time follow-up, light-tracking stability.

At present, the BlackTrax system[3] can be used to automatically chasing light. BlackTrax is a vision-based target tracking system that enables real-time and accurate positioning of the infrared pulses emitted by the LED lights that are worn by the actors. But BlackTrax system is too expensive, so it is not popularized in the market. In China, Professor Wang Jun proposed an automatic spotlight system based on ultrasonic positioning [4], The principle is to place the spotlight on the steering gear with two degrees of freedom and obtain the three-dimensional coordinates of the stage actor through ultrasonic positioning, then adjust the direction of the steering gear to achieve light chase. Ultrasonic transmission is severely attenuated and susceptible to environmental interference. The effect of this solution is extremely unstable in a complicated arena environment.

Working Principle of the System and Architecture Design

An automatic stage chasing light control system based on ultra wide band positioning technology is proposed in this paper. The moving head light is used to replace the traditional manual chasing light to realize the automatic control of chasing light. The tracking control system is divided into two parts.
The first part is the target positioning subsystem, which includes four base stations and a wireless emission label. The second part is the signal transform subsystem, including coordinate conversion, DMX-512 signal conversion and human-computer interaction interface. The overall structure is shown in Figure 1:

![Overall structure of the system.](image)

So as to realize the effect of automatic light chasing. UWB technology is used to locate the tracking target in the performance space in real time, and then the primary base station transmits the positioning data to the PC through the USB interface, and the trilateration algorithm is used to perform coordinate calculation to obtain the three-dimensional coordinate sequence of the target position. Because the horizontal and vertical movements of the computer light are controlled by two motors respectively, the three-dimensional coordinates of the target position need to be converted into Pan and Tilt motion commands to control the rotation of the light. So a mathematical model of the stage space of computer lights and actors is constructed, the angle of rotation of the computer light in the horizontal direction and vertical direction are calculated by the system, Finally, this angle value is converted into a DMX512 signal through a USB-DMX512 controller and outputed to the computer light to control the movement of it.

**Tracking the Location Subsystem**

**Comparison of Wireless Location Technology at Home and Abroad**

Wireless positioning technology is a technology that uses wireless communication and suitable location algorithm to estimate the position of the label terminal relative to the location of the base station[5]. The current common positioning technologies and their features are shown in Table 1:

<table>
<thead>
<tr>
<th>Positioning Technology</th>
<th>Positioning accuracy</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS</td>
<td>10[m]</td>
<td>Universality</td>
<td>Signal easy to block</td>
</tr>
<tr>
<td>Infrared</td>
<td>5-10[m]</td>
<td>High accuracy</td>
<td>Short transmission distance</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>1-10[m]</td>
<td>Low cost</td>
<td>Multipath effect is high</td>
</tr>
<tr>
<td>WIFI</td>
<td>2-50[m]</td>
<td>Widespread network deployment</td>
<td>Poor stability</td>
</tr>
<tr>
<td>UWB</td>
<td>6-10[cm]</td>
<td>Strong penetrating ability, high positioning accuracy.</td>
<td>Slightly higher cost</td>
</tr>
<tr>
<td>Computer vision</td>
<td>1[cm]-1[m]</td>
<td>Not dependent on the external environment</td>
<td>Too high, Inconvenient</td>
</tr>
</tbody>
</table>

UWB is chosen as the positioning method of this system. It has the characteristics of large system capacity, high transmission speed, low transmission power, high multipath resolution, good system secrecy, strong penetration ability and high positioning accuracy. It is very suitable for stage tracking.
UWB technology, which directly modulates impulse pulses with steep rise and fall times, giving the signal a GHz-order bandwidth. The U.S. Federal Communications Commission (FCC) released the first UWB civil standard in 2002, assigning a bandwidth of 3.1-10.6 GHz to a total of 7.5 GHz, making it unobstructed among private enterprises.

**Stage Target Positioning**

The UWB mini3 positioning kit is used in this paper, whose positioning method is the two-way time-of-flight (TW-TOF) method. Two parties exchange time-stamp information without requiring accurate synchronization, and thus the distance between each module can be obtained. Then the trilateration algorithm is used to obtain the specific location of the label. As shown in Figure 2. Setting the coordinates of the four base stations A, B, C, D as \((X_i, Y_i, Z_i)\) and the tag T \((X, Y, Z)\), assuming that the distance from the base station \((A, B, C, D)\) to the tag T is \(S_i\) \((i=1, 2, 3, 4)\).

![Figure 2. Trilateration schematic.](image)

From the spherical coordinate equation and the distance formula:

\[
\begin{align*}
(X - X_i)^2 + (Y - Y_i)^2 + (Z - Z_i)^2 &= S_i^2 \\
(X - X_j)^2 + (Y - Y_j)^2 + (Z - Z_j)^2 &= S_j^2 \\
(X - X_k)^2 + (Y - Y_k)^2 + (Z - Z_k)^2 &= S_k^2 \\
(X - X_l)^2 + (Y - Y_l)^2 + (Z - Z_l)^2 &= S_l^2
\end{align*}
\]

Solving equations to get the coordinates of the label \(T(X, Y, Z)\).

**Motion Control Subsystem**

**Coordinate Conversion**

After obtaining the 3d coordinates of the label on the PC side, the mathematical model needs to be established according to the space position of the label and the computer light to calculate the Angle of rotation of the computer light. The specific model is shown in the figure below:

![Figure 3. Coordinate transformation mathematical model.](image)

A is a computer light whose coordinates are \((X_1, Y_1, Z_1)\), B is the tracking target, its coordinates are \((X, Y, Z)\), \(\angle \alpha\) is the vertical rotation angle of the scanner, and \(\angle \beta\) is the horizontal rotation angle of the scanner. From the knowledge of solid geometry:
\[ \angle \beta = \arctan \left( \frac{X - X_i}{Y - Y_i} \right) \]

(2)

\[ \angle \alpha = \arctan \left( \frac{\sqrt{(X - X_i)^2 + (Y - Y_i)^2}}{Z - Z_i} \right) \]

(3)

Horizontal rotation angle of computer light \( \angle \beta \):

1) When \( X - X_i > 0, Y - Y_i > 0 \), \( \angle \beta > 0 \), that is, the computer light rotates \( \angle \beta \) in the clockwise direction, the actor is on the right side of the computer light.

2) When \( X - X_i < 0, Y - Y_i > 0 \), \( \angle \beta < 0 \), that is, the computer light rotates \( \angle \beta \) in the counterclockwise direction, and the actor is on the left side of the computer light.

3) When \( X - X_i > 0, Y - Y_i = 0 \), the computer light rotates \( 90^\circ \) in the clockwise direction, \( \angle \beta = 90^\circ \).

4) When \( X - X_i < 0, Y - Y_i = 0 \), the computer light rotates \( 90^\circ \) in the counterclockwise direction, \( \angle \beta = -90^\circ \).

Vertical rotation angle of computer light \( \angle \alpha \):

1) When \( Z_i - Z > 0 \), \( \angle \alpha > 0 \), the computer light rotates \( \angle \alpha \) in the clockwise direction.

2) When \( Z_i - Z = 0 \), the computer light rotates \( 90^\circ \) in the clockwise direction, \( \angle \alpha = 90^\circ \).

3) When \( Z_i - Z < 0 \), the computer light rotates \( 90^\circ - \angle \alpha \) in the clockwise direction.

To sum up, the angle of rotation of the computer light is obtained. Since the computer light can only recognize the DMX512 signal, it is converted into a recognizable instruction of the computer light, that is, the corresponding Pan and Tilt control channel parameters. The calculation formula is as follows:

\[
\text{Pan} = \begin{cases} 
\frac{\arctan(\frac{X - X_i}{Y - Y_i}) \times 180^\circ}{\pi} & \frac{255}{540} \quad Y - Y_i > 0, \begin{cases} X - X_i > 0 \\ X - X_i < 0 \end{cases} \\
\frac{90 \times 255}{540} & Y - Y_i = 0, X - X_i > 0 \\
\frac{90 \times 255}{540} & Y - Y_i = 0, X - X_i < 0 
\end{cases}
\]

(4)

\[
\text{Tilt} = \begin{cases} 
\frac{\arctan(\frac{\sqrt{(X - X_i)^2 + (Y - Y_i)^2}}{Z - Z_i}) \times 180^\circ}{\pi} & \frac{255}{270} \quad Z_i - Z > 0 \\
\frac{90 \times 255}{270} \quad & Z_i - Z = 0 \\
\frac{90 \times 255}{270} - \arctan(\frac{\sqrt{(X - X_i)^2 + (Y - Y_i)^2}}{Z - Z_i}) \times 180^\circ & \frac{255}{270} \quad Z_i - Z < 0 
\end{cases}
\]

(5)
The Design of Human-Computer Interaction Interface

C++ is used to develop friendly human-computer interaction interface, interface’s functions include: input the coordinates of the four base stations and computer light, set the computer light channel. Because different computer lights have different rotation angle range of X-axis and Y-axis, coordinate conversion algorithm is related to this range, so the range of rotation angle of X-axis and Y-axis is specially set to increase the universality of the equipment. This interface lets the user knowing the change of location coordinate and the update of data directly, which is convenient for the user to analyze and compare the location of real environment.

System Verification and Analysis

Experimental Environment

The experiment was conducted in a studio with 10m×6m×4m in volume. The base stations A0, A1 and A2 were set at a height of 1.65 meters. The base station A3 was 2.19 meters, and A0 was the origin of the coordinates. The edge where A0 and A1 are located is the X axis, and the edge where A0 and A2 are located is the Y axis. As shown below:

![Figure 4. Lab Environment Layout.](image)

The manually operate follow spotlight is generally placed in the chasing room opposite the stage. In this system, the computer light is hung on the suspender at the stage mouth. Taking Zhujiang pr3300's light as an example: its horizontal rotation angle is 540 degrees, scanning 360 degrees takes 2.2 seconds, vertical rotation angle is 270 degrees, and vertical scanning 270 degrees takes 1.5 seconds. This responding speed can fully meet the real-time requirements of chasing light. Because the computer light rotates clockwise in one direction, the left of the stage to be illuminated needs to rotate 180 degrees, does not meet the requirements for chasing light, giving an initial value to the light can solve this problem. Therefore, the initial value of 180 degrees is added to the calculation formula of the horizontal rotation angle, and the initial value of 135 degrees is added in the vertical direction to make the light head vertical down.

Static Light Chase Test

MSE (Mean Squared Error) can evaluate the degree of change of positioning coordinate data. The smaller the value of MSE is, the higher the positioning accuracy is [10]. The calculation formula can be expressed as:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} [(x_{i} - x)^2 + (y_{i} - y)^2 + (z_{i} - z)^2]$$

In the formula, \((x, y, z)\) is the actual coordinate of the label, \((x_i, y_i, z_i)\) is the estimated value of the positioning, and \(n\) is the number of base stations. In the experimental environment, we selected 20 positions to detect the tracking position of the static node. In the case of interference, the maximum positioning error is 12cm, the average error is 7.6cm; in the absence of interference, the maximum positioning error is 9.9cm, the average error is 4cm.
Dynamic Light Chase Test

In this test, there is no need to distinguish between interference and non-interference because the actor may have an obstruction between the label during the movement. When the actor started to move at a speed of 1m/s, the system did not respond in time, led to chasing light lagging actor 0.5 meters. The data refresh rate of USB-DMX512 is 25ms, which can achieve real-time tracking. UWB positioning data refreshed 12 times a second in the serial assistant, cannot meet the real-time tracking, in the main.c file of positioning subsystem, the refresh rate was increased to 33.3Hz by modified its sleep time, and allowed the actor to move at speed of 1m/s, 1.5m/s, and 2m/s. Those achieved stable tracking effect, but, when the tracking target suddenly accelerates at an acceleration of 6m/s$^2$, the system cannot respond instantaneously, resulting in a delay of about 0.5s.

Conclusion

The system has successfully solved the problem of automatic stage chasing. The results show that the system can meet the basic requirements of precision, real-time and stability, and can achieve high accuracy in the environment with obstacles, but there are still some further improvements:

The two subsystems need data lines to connect, which is very inconvenient to use. Nowadays, WIFI technology is developing rapidly, and wireless computer lights are also facing the market. In the future, the data can be transmitted through WIFI, which will greatly increase the universality. In the process of chasing, when the target accelerates suddenly with the acceleration of 6m/s$^2$, the system has a response time of about half a second. It is possible to increasing the data refresh frequency of DMX512 signal transmission to reduce delay. At present, the system can only realize single target tracking, how to realize the automatic tracking of multiple targets through multiple computer lights? These will be the contents of further study.

References


