Research on spot location detection algorithm of embedded APT system

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Abstract: Due to the atmospheric laser communication aiming capture tracking system with FPGA device and HDL hardware description language to complete the spot capture and tracking function, it has high cost, difficult development, cannot change the design parameters, cannot adopt the disadvantage of replacing the sensor, and designs a single embedded the processor as the core aiming capture and tracking system, using the processor's own camera driver module and C wave gate centroid tracking algorithm is developed by CCD drive and spot capture alignment. The measured distance of the transceiver is 15.5km, the average precision is less than 5 pixels, and simple structure, low cost, which satisfies the needs of atmospheric laser communication.

Preface

Atmospheric laser communication is an important research direction in the field of communication. The aiming capture tracking (APT) system is an important part of the atmospheric laser communication system. The APT tracking system consists of beacon laser, CCD image sensor, processor and actuator. As the alignment tracking process is actually a process of spot closed-loop feedback detection and tracking to ensure real-time performance, most of the APT system processors are composed of FPGA devices, and the HDL hardware description language is used to complete the signal collection-processing-feedback. However, such systems need to have auxiliary FPGAs, MCUs, DSPs, etc., so there are high cost, difficult development, no change in design parameters, and no replacement of sensors, etc.[1,2]. In recent years, with the rapid progress of semiconductor technology and functional integration technologies, many new processors have powerful computing power and high functional integration[3,4]. Based on the above reasons, this paper uses S3C6410 processor to design a CCD information processing system integrating observation image and beacon spot detection algorithm. The system has the characteristics of low cost, fast response and quick adaptation.

General Design

The CCD imaging and spot tracking image processing system based on S3C6410 processor is composed of three parts: the CCD image sensor OV9650 part; image spot coordinate position detection and processing part, the data output and display part, and the overall hardware design is shown in figure 1.

Alignment tracking process: First, the transmitter sends the beacon laser, and the receiver opens the CCD camera field scan; If no beacon light spot is received, then beacon laser visual axis skip signal is sent to receive the next scan, and the process is repeated until the beacon light spot is received. In the alignment tracking phase, the APT controller adjusts the azimuth and pitch position of the
two-dimensional tracking turntable in real time according to the amount of spot missed on the target surface of the image sensor, the beacon spot gradually approaches the CCD view center, until completely aligned. When both ends of the transceiver are aligned, then laser data communication is performed. The software flow is shown in Figure 2.

**Image sensor drive design**

Since the S3C6410 provides the camera interface bus SCCB (serial camera control bus), to realize the CCD driver, it is necessary to configure the corresponding register of the S3C6410 according to the OV9650 parameter\(^{[5,6]}\).

First set the video resolution, and write the original resolutions 480 and 640 to the corresponding bits of the source format register.

The two values of the target resolutions 1080 and 1920 are respectively written to the corresponding bits of the preview DMA target image format register. In addition, the product of these two values (1080 × 1920) needs to be written into the preview zoom target area register.

Secondly, set the offset. Since the original resolution and the target resolution are inconsistent, the horizontal offset and the vertical offset are respectively written into the corresponding bits of the window offset register.

Then, set the address of the display memory. The S3C6410 needs to open four ping-pong storage areas in the memory as display memory, and write the address data into the ping-pong memory area register respectively.

Finally, set the DMA transfer mode, that is, the number of bytes per transfer and the way the interrupt is triggered.
Research and measurement of spot position detection algorithm

Laser transmission in space channel is greatly influenced by environment, especially atmospheric turbulence. Atmospheric turbulence is a phenomenon in which the refractive index changes randomly due to random changes in local temperature and pressure in the atmosphere. Experiments show that atmospheric turbulence causes spot flicker, power fluctuations, etc. on the photodetector at the receiving end, and increases with distance. This effect is increasing and becomes a major factor affecting the accuracy of CCD tracking.

Spot position detection algorithm Design

Atmospheric laser communication CCD receiving spot position detection algorithm mainly uses the wave gate tracking centroid algorithm. The size of the gate in the gate tracking is determined according to the size of the target image. The tracking system only processes the image information in the wave gate, which reduces the information processing time.

The centroid algorithm is the most important algorithm in the gate tracking. The centroid tracking algorithm uses the difference between the target image and the background in gray scale, and regards the image in the gate as two types of regions of different gray levels (target and background) combined. The combination of backgrounds selects an appropriate value to determine whether each pixel in the image should belong to the target or background area, resulting in a corresponding binary image.

An original image \( f(x, y) \) takes a single threshold \( T \)-divided binarized image is defined as.

\[
g(x, y) = \begin{cases} 
0, & f(x, y) < T \\ 
1, & f(x, y) \geq T 
\end{cases} 
\]  

(1)

The target centroid coordinates are calculated from the binarized image of the target area and its row and column coordinates.

\[
\begin{align*}
X &= \sum_{i=1}^{m} \sum_{j=1}^{n} P(x_i, y_j) x_i / \sum_{i=1}^{m} \sum_{j=1}^{n} P(x_i, y_j) \\
Y &= \sum_{i=1}^{m} \sum_{j=1}^{n} P(x_i, y_j) y_j / \sum_{i=1}^{m} \sum_{j=1}^{n} P(x_i, y_j)
\end{align*}
\]  

(2)

Where \( P(x_i, y_i) \) is the gray value of the image at position \((x_i, y_i)\), and \( x_i \) and \( y_i \) are the horizontal and vertical coordinates of the pixel in the window, respectively.

In the algorithm design, the relative position measurement of the spot adopts the gray projection method, that is, the pixels of the whole image are projected in the X and Y directions, and a one-dimensional gray scale array along the X direction and along the Y direction is obtained, and the X direction and the Y direction are found. The array number of the gray level peak point in the gray scale array in the direction determines the corresponding position coordinates of the spot in the X and Y directions. The processing flow of the light spot position detection algorithm is shown in Figures 3.
Due to the existence of atmospheric turbulence, the spot received by the CCD sensor surface is broken. Therefore, the center of the spot is not necessarily the coordinate position where the gray extreme value is located. It is necessary to calculate the center coordinate of the spot in the range of the wave gate by the centroid algorithm.

**System measurement**

The developed CCD imaging and spot position detection system is applied to the simulated atmospheric laser communication test. The tracking system observation platform is shown in Figure 4.

The beacon laser wavelength of the system is 800nm, and the distance between the receiver and the transmitter is 15.5km, and the average accuracy of the test results is less than 5 pixels. The CCD imaging and spot miss distance are recorded as shown in Figures 5 and 6. The general APT control system needs to meet less than 15 pixels, basic requirements.
Fig. 5 image sequence

(a) Miss-distance abscissa measurement record

(b) Miss-distance ordinate measurement record

Fig. 6 Spot miss measurement record

Conclusion

It can be seen from the actual measurement that the CCD image driving and spot position detection system with a single embedded processor as the core meets the requirements of atmospheric laser communication APT tracking, and has the characteristics of simple structure and low cost. At the same time, the general program of the system can be adapting to different camera systems further enhances its practicability. If the captured images can be supplemented with identification technology and dedicated GPU acceleration calculations, better results can be achieved.

References


