Design of Character Recognition Robot Based on FPGA

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Abstract: As the inspection tour targeted at disarranged parking phenomenon conducted by specially assigned security personnel to parking lots in neighborhoods makes it more difficult for parking management, this paper proposes an FPGA-based character recognition robot design. The camera was controlled by the master controller EP4CE115F29C7N to acquire the license plate information, the improved character recognition algorithm based on YCbCr color space was put forward to identify the license plates, and the robot walking was controlled by combining IR control with increment-type PID. The experimental results show that this robot is of certain practical value as it is capable of effective recognition and displaying the characters on the license plates.

1. Introduction
With the rapid development of computer science and artificial intelligence, intelligent robots have gradually become a research hotspot in the modern field of robotics. Targeted at specialized security personnel assigned to inspect the disarranged parking phenomenon in parking lots, which makes it more difficult for parking management, an FPGA-based character recognition robot design was proposed, and this robot could considerably relieve the management pressure of unattended parking lots.

This character recognition robot controls the camera to collect the surrounding environmental information via the master controller FPGA. After being processed, the acquired images are used to identify the license plates to help the robot judge if disarranged parking takes place. Then a signal is transmitted by the IR remote control module to control the chassis motor to rotate so that the robot will move to the target position.

2. General System Design
The FPGA-based character recognition robot system is composed of two parts: hardware circuit and software part, where the first part mainly includes main control chip EP4CE115F29C7N and its peripheral circuit, image acquisition module, rotary steering gear of robot camera, chassis drive circuit and motor of robot, and IR remote control module. The block diagram of the hardware system is shown in Figure 1.
3. Hardware Design

This robot is of a double-layer structure, where the upper-layer boundless design can help build the FPGA control end better, and the lower layer, which has an excellent spatial capability, can be used to design and forward various module terminals. The overall mechanical structure is made of metal, with high stability and strong bearing capacity. Moreover, the space design can be made based on the installation needs of the circuit board and sensor, thus making the vehicle body artistic and compact.

3.1 Master controller and peripheral circuit

FPGA is used as the master controller in this system. As a pattern of manifestation for programmable gate array, FPGA can reduce the load burden of the system on other components and parts by virtue of broad functional area, fast product forming and strong editability, etc. The FPGA transmits the pulse signal through pulse width modulation (PWM), and completes the control of the analog circuit based on the data information processing results of the microprocessor. FPGA owns abundant hardware resources and strong parallel computing power. The hardware was developed using Cyclone IT series FPGA-EP4CE115F29C7N chip produced by Altera Corporation. With 30 global clock networks and 8 PLLs, this chip supports programmable bus-hold, programmable pull-up resistor, programmable delay, programmable driving force and programmable slew rate control. Besides, this chip satisfies the system’s performance requirements to support online real-time system upgrading [5]. Other peripheral circuits are designed with display modules such as Nixie tube and liquid crystal display (LCD), as well as input modules like keys.

3.2 Camera module

OV5640 camera was selected for the image acquisition. This camera adopts OV5640 module, CMOS production process, and 5 megapixel fixed/automatic focusing module. The camera shows excellent performance under normal conditions, low noisiness and in dark state. With COB packaging process, this camera can narrow the focus to the designated scope of focal length.

Through the control of the steering engine rotation, the operating voltage of the camera is 6 V, operating torque reaches 13 KG/cm, reaction speed is 53-62 R/M, and the maximum rotation angle is 180°, all of which are sufficient for the camera to rotate leftward and rightward flexibly.

3.3 Drive motor module

The chassis Mecanum wheel of the robot was designed in the sequence of ABAB, aiming to realize its flexible movement in any direction from any angle, and simultaneous rotation during translation. 25GA370 DC gear motor (totally 4 of them) was selected to conduct independent drive control of the robot’s Mecanum wheel. Each DC motor outputs two-way PWM pulse signals via the FPGA to realize various combined actions of the robot, such as move forward and backward, turn left, turn right and rotate in situ. This DC motor was supplied by a 6V power source to guarantee normal motor operation.
3.4 IR module
The IR control module instantiates three submodules: IR driver module resolving IR signal, motion module conducting PWM control of motor and steering gear, and signal light control module. In this IR control system, the IR driver module outputs the resolved control code to the motion module, and repeats the effective code before outputs to the LED control module. The motion module assigns different status signals to the motor and steering gear according to the received control code, and thus realize the collaboration of the motor and steering gear with the robot.

4. Software Design
The software design of this robot mainly consists of an IR remote control module, a robot motion control module, an image processing module, a character recognition module, a camera rotation control module and a display module.

4.1 Main program design
The main flow chart is shown in Figure 2. The drive is configured for I2C to initialize the camera, the data acquired by the OV5640 camera is written into SDRAM via the FIFO write module, the FIFO data is read and transmitted to vip module for image processing, and the feature matching between the extracted character feature set and feature recognition module is conducted to recognize the characters in the images. The identified numbers are sent to the Nixie tube for display, and the boundary between images is binarized and displayed on the LCD display.

![Figure 2 Main Program Flow Chart](image)

4.2 Character recognition based on YCbCr color space
The character recognition algorithm used in this paper is based on YCbCr color space, where the Y component is the brightness component of color, Cb and Cr are concentration shift components of blue and red colors, and the algorithm steps are presented in Figure 3.
1) The color components in the RGB color space are converted into the YCbCr color space to obtain the image of the YCbCr color space.

2) The Cb color component in the YCbCr color space is extracted, the Cb color component of the license plate is the highlighted part in the image, and the brightness of the license plate can be enhanced through the contrast stretch to provide conditions for the binarization of the license plate images.

3) Otsu algorithm is used to binarize the license plates. Otsu algorithm, namely the maximum between-cluster variance method, has an ideal effect on processing the images without noise jamming and prominent double peaks in the histogram. The threshold value acquired through the Otsu algorithm-based binarization will have strong self-adaptability.

4) Dilation and closing operations of mathematical morphology are conducted on the post-binarization images. In mathematical morphology, the signal is processed using erosion, dilation, open operation and closing operation and their combinations as well as structural elements with different shapes and lengths. The license plate images obtained through the mathematical morphological processing will be of good noise immunity and continuity. The binary images of license plates are effectively filtered, which can improve the follow-up character segmentation accuracy.

5) The license plate characters are directly segmented. As the character interval is large, they will not adhere to each other. Blocks with continuous characters are directly sought in the binary images. If the length of one block is greater than a certain threshold value, this block is then considered to have two characters in need of segmentation.

6) The segmented character images are normalized. In order to eliminate the influence of character size and position on the character feature extraction and recognition, it is essential to normalize the character images. The acquired license plate images have varied sizes, which brings inconvenience to the border removal using the same parameters and the subsequent image segmentation, so the acquired license plate images should be normalized. In other words, they should be magnified to the same size. The size of character images segmented through normalization is 40*20, which matches the character image size in the template.

7) The normalized characters are matched with the template to realize character recognition. To be specific, the to-be-recognized characters are binarized, zoomed to the template size in the character database, and matched with all templates. The best match should be the recognition result. The main feature of template matching is its easiness to realize. When the characters are regular, they will show
a strong adaptability and high recognition rate to the defect and smear disturbance of the character images. During the template matching process, the characteristic quantities extracted from the to-be-recognized image or image region \( f(i,j) \) will be compared with the corresponding ones in the template \( T(i,j) \) one by one, the normalized mutual correlation quantities among them are calculated. The maximum mutual correlation quantity represents the highest level of similarity, and the images involved can be classified into the corresponding categories.

4.3 PID control algorithm for chassis motor

PID control means to compare the measured value with a given value and further calculate the deviation value \( e(t) \), based on which \( K_p, K_i \) and \( K_d \) are adjusted to reduce the errors, and meanwhile, dynamic system parameters like time and overshoot are also adjusted. According to the robot’s movement characteristics, the increment-type PID algorithm is used in this system. The increment PID algorithm takes the increment of position-type PID. The controller outputs the difference value between the position values calculated at two adjacent sampling time points. The PID controlled output is an increment, while the controlled quantity \( \Delta u(k) \) is the increment of recent position errors but not the deviation of actual position, and there is no error accumulation.

\[
\Delta u(k) = u(k) - u(k-1) = K_p[e(k) - e(k-1)] + K_i\Delta e(k) + K_d[e(k) - 2e(k-1) + e(k-2)]
\]

where \( K_p \) is proportionality coefficient; \( K_i \) is the integration coefficient; \( K_d \) is the differential coefficient; \( e(k) \) is the current error; \( e(k-1) \) is the last error; \( e(k-2) \) is the error before the last one.

During the increment PID parameter calibration, the parameters \( K_i \) and \( K_d \) are firstly set to zero, the parameter \( K_p \) is adjusted, the oscillation is conducted only two to three times on the precondition that the high-speed requirement is satisfied, and thus the adjustment of parameter P is completed. Although the pure P algorithm can satisfy the high-speed requirement, the output value could hardly reach the mobile voltage due to the overall resistance of the robot, and consequently, the robot will stay put. The parameter I is added to eliminate the static error, and in the meantime, the number of system oscillations is increased, and eventually the parameter D is added to eliminate the system oscillation.

5. Experimental Verification

The designed software program is downloaded into FPGA via JTAG. The system operation effect after character recognition is displayed in Figure 4. According to the experimental results, this robot can accurately segment, extract, recognize, and display the license plate characters. The repeated experiments are carried out on the robot walking. The results show the robot can flexibly rotate in situ, turn left, turn right and turn round, and keep stable straight running, without obvious slipping or shaking during the running and turning process.
6. Conclusions
The robot designed in this paper is capable of recognizing the license plate characters accurately, and realizing various functions like turning in situ and turning around. The actual operation process is stable, showing no phenomenon of slipping or shaking. Meanwhile, the robot maintains flexibility throughout the whole motion process. Furthermore, this robot is also applicable to the inspection tour to public places like airports and stations. Further research will be conducted to improve the robot’s autonomous walking and wireless communication with the management layer.

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