A Multi-Scale Focus Pseudo Omni-directional Robot Vision System with Intelligent Image Grabbers

Qingrui ZHOU[1], Kui YUAN[1], Wei ZOU[1], Peng LU[1], Huosheng Hu[2] , *Senior Member, IEEE*

1: Institute of Automation, Chinese Academy of Sciences, Beijing, 100080, P.R.China
{qrzhou ,yuankui, wzou, plu}@hitic.ia.ac.cn

2: the Department Computer Science, University of Essex, Colchester CO4 3SQ, United Kingdom
hhu@essex.ac.uk

***Abstract*—In this paper, the development of an intelligent image grabber and its application to a multi-scale focus pseudo omni-directional robot vision system is presented. The new developed intelligent image grabber is designed using DSP and FPGA technology, which can do both the task of image grabbing and the task of image processing. A pseudo omni-directional robot vision system, which can "see" the four directions simultaneously using 4 sets of intelligent image grabbers and cameras, is realized and a multi-scale focus strategy which can improve the efficiency of this pseudo omni-direction robot vision system is also proposed. Experimental results have shown that this pseudo omni-directional robot vision system can work quite well.**

I. Introduction

In a lot of cases, real time environment sensing is very important to a mobile robot [1]. For example, when a robot is moving fast in an unstructured environment with a lot of static or moving objects, it is vital for the robot to get the information around it as quick as possible to achieve fast self-localization and object tracking. Otherwise the object it is tracking will be lost or a collision with the environment will happen.

Using an omni-directional vision system is a good way to increase the environment sensing speed of the mobile robot since it can provide global information of the environment at any moment [2]. But since the image obtained by an omni-directional vision system is distorted from the original image, it is necessary to make use of an image restoration algorithm to restore the original image from the distorted image before further processing in a lot of cases. The execution of the restoration algorithm will cost computation time and some detailed information will also be lost in the restoration process. Therefore, an omni-directional robot vision system is not always the best solution for a mobile robot.

It is also possible to get a pseudo omni-directional vision system making use of multi cameras and set them to cover the entire environment of the robot. But in these cases, it is very difficult to process the images came from these cameras in real time because of the computing ability limitation of the host computer.

To solve the problem discussed above, we propose a novel pseudo omni-directional vision system which uses the intelligent image-grabber developed in our lab recently. This so-called "intelligent image grabber" is designed using DSP and FPGA technology and can do both the task of image grabbing and the tasks of low-level image processing according to the command from its host computer. A special data transfer interface is also designed which enable 4 image grabbers can be used in parallel. A pseudo omni-directional robot vision system is realized which can "see" the four directions simultaneously using 4 sets of intelligent image grabbers and cameras. A multi-scale focus strategy, which can improve the efficiency of the pseudo omni-direction robot vision system, is also proposed.

The rest of this paper is organized as follows. Section II describes the design of the intelligent image grabber. Section III presents the development of the pseudo omni-direction robot vision system. In section IV, a multi-scale focus strategy and its application to the pseudo omni-direction vision system is described. Finally, conclusions and future work are given in section V.

II. Design of the intelligent image grabber

The main aim of the design of the intelligent image grabber is as follows: (i) It can complete the work of image grabbing; (ii) it can do the work of low-level image processing according the command from host computer and can send the results to the host computer in a high speed. (iii) Several intelligent image grabbers should be able to be used in parallel to increase the efficiency of the robot vision system.

The proposed intelligent image grabber consists of two parts: an image data acquisition and processing module (IDAPM) and a multi-channel communication card (MCC). In the following part of this section, the design of the IDAPM and MCC will be described respectively.

A. Design of IDAPM

The IDAPM is designed using DSP and FPGA techniques [3][4]. The block diagram of IDAPM is shown in Fig. 1a.

In the IDAPM, The FPGA is responsible to the implement of image acquisition and the control of the communication interface. A DSP chip TMS320C5416 (from TI Corp.) is used for low-level image data processing and to control the timing of image data acquisition. The flexible programming ability of FPGA makes it possible for the hardware architecture can be customized freely by the commands of the host computer.

The working procedure of the IDAPM is as follows:

(i) The DSP sends out the image data acquisition command to the ADC via FPGA.

(ii) The FPGA assembles the image data from ADC into image frame and pre-processes these frames. The pre-processed raw frame is saved into the Image RAM. The FPGA will send out an interrupt signal to the DSP when one image frame is ready in RAM.

(iii) The DSP will process the image data of this frame and then send the result to the host computer.

When the DSP is processing the image data, the FPGA will begin the data acquisition again.

Fig. 1b shows the architecture of the FPGA. It is a bridge between the DSP and the ADC, which can transfer the command from the DSP to the ADC and prepare the image from the ADC for the DSP. In addition, the FPGA can adjust the parameters such as image resolution, image size, the proportion of each component of YUV, under the control of the host computer. It is also the basis of our multi-scale focus robot vision system which will be described in section IV.

The image pre-processing by the FPGA includes digital filter, image assembling, etc. The DSP data bus interface connects the DSP and the image RAM, and the center control module coordinates the synchronizing signals of each module in the FPGA.

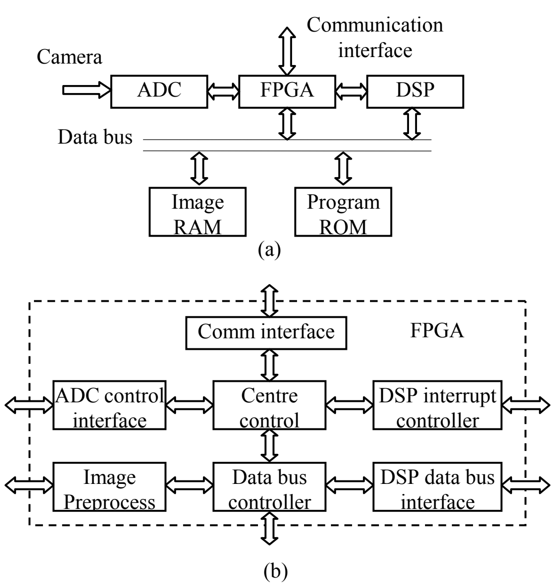


Fig. 1 Structure of IDAPM

The main task of the DSP is low-level image processing and provide desired processing results to the host computer. The major functions of this DSP include: color-based image segmentation, edge detection, object recognition, etc. The host computer can choose one or several of the functions by sending the corresponding command to the DSP.

The Image RAM is the image buffer to save the image data temporally for the FPGA and the DSP. It is a key component for the parallel image acquisition and data processing. The program of the DSP is stored in the Program ROM.

B. Design of MCC

The communication module in the host computer is a PCI-based multi-channel communication card that integrates four channels totally. The PCI bus is the most popular bus for PC [5]. It has a fast data transfer rate (up to 528Mbytes/s), supports the burst data transfer in DMA mode, and does not occupy the CPU of the host computer during the data transfer (An USB based image grabber will occupy the CPU of the host computer during the data transfer).

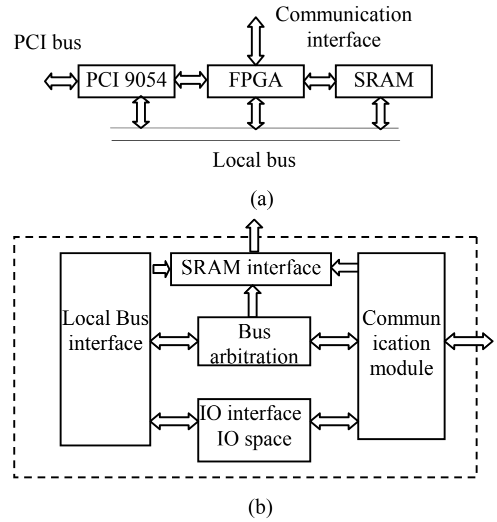


Fig. 2 Structure of MCC card

Fig. 2a shows the schematic structure of the MCC. A PCI 9054 chip is used as the PCI bus interface, which is a 32-bits PCI interface chip compatible with PCI Specification v2.2. This chip supports the master-slave communication mode and can be used in full speed data transfer for burst transfer situation by two bi-direction DMA channels. The Local Bus in the PCI9054 chip serves as the interface between the user devices and PCI bus.

Fig. 2b shows the inside structure of the FPGA in the MCC. The main functions of this FPGA include: build local bus interface, control the SRAM interface, implement the multi-channel communication, and manage the IO interface and the IO space for the local bus.

The user device of PCI9054 only needs to communicate with the local bus via the interface logic provided by the Local Bus interface module of the FPGA. In addition, the FPGA also supplies the control logic for the SRAM, IO space and the Communication module. The FPGA has many RAM units and some of these RAM are separated as IO space for the register of the status control and data buffer. However, there is still a bus traffic problem because all of the data of each channel uses the same SRAM. Making use of a Bus Arbitration module that works in the token-ring mode solves this problem. The channel or the local bus that is holding the token can access the SRAM.

The high speed SRAM in the MCC works as a buffer to save the raw image from the FPGA and the process results from the DSP. Its storage is 512K x 32bits.

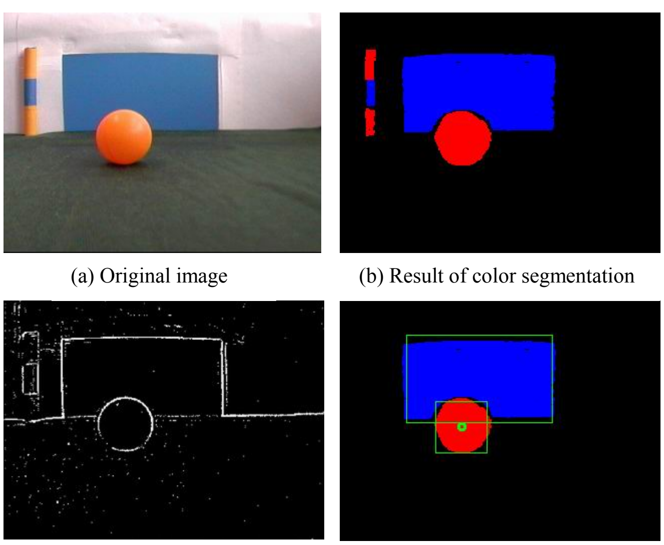
C. *Implementation of Communication*

To realize the communication between the IDAPM and the MCC, a new kind of Remote Host Port Interface (RHPI) is proposed, which based on the Low Voltage Differential Signal (LVDS) technology. The data transfer media used for the RHPI is the UTP-CAT5 cable which is widely used in the Ethernet network. The use of LVDS technology makes it possible to transfer the data in the rate of hundreds mega bits per second under low power consumption and high noise proof ability.

Since both the IDAPM and the MCC uses the LVDS-supported FPGA, the implement of the communication is quite simple. The data transfer rate obtained by our method reaches 100Mbps. This is sufficient not only for the transfer of the results of low-level image processing, but can even transfer the original image data with a size of 720x576 in a rate of 15 frames per second.

Experimental results have shown that the proposed RHPI runs reliably and stably for a 4-channel vision system. The reliable data transfer distance can reach 15m, which means that the designer of the robot system can put the cameras in any parts of his robot and need not to be bothered by how to connect the cameras to its host computer.

Fig.3 shows some of the results obtained by the intelligent image grabber. The original images are shown in Fig. 3(a) and the results after low-level image processing are shown in Fig.3(b), Fig.3(c), and Fig.3(d). The whole process of image grabbing and low-level image processing from 4 sets of intelligent image grabber is completed in about 10ms using a PC with a P4 2.4G CPU.



(a) Original image (b) Result of color segmentation

(c) Result of edge detect (d) Result of object recognition

Fig. 3 Experiment results of intelligent image grabber

III. Development of the Pseudo Omni-Direction Robot Vision System

Using the intelligent image grabber described in section II, it becomes possible to realize a high performance pseudo omni-direction robot vision system. In this section, the development of the pseudo omni-direction robot vision system will be described.

A. *Basic Configuration*

Fig.4 shows the basic configuration of a pseudo omni-directional vision system.

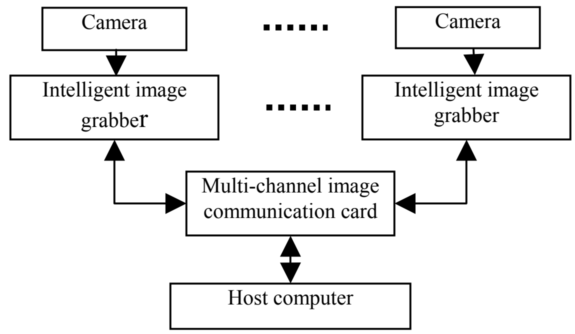


Fig.4 Configuration of pseudo omni-direction vision

When 4 sets of intelligent image grabbers and cameras are used and the angle between any two adjacent cameras is 90 degree, the robot will be able to cover all of the directions at the same time, just as an omni-direction vision system do.

Because the intelligent image grabbers can do the works of low-level image processing in parallel and send the results to the host computer simultaneously, this pseudo omni-direction vision system is much faster than an ordinary multi-camera vision system. Therefore, the host computer will have more time to do the tasks of high-level image processing, image understanding, etc.

B. *Other Applications*

Although to put all of the 4 cameras of the pseudo omni-direction vision system in the same plane can get a good cover of all directions (Fig. 8 shows an example), it is not the only way to use it. The cameras of the pseudo omni-direction vision system can also be set at any parts of the robots, according to the requirement of the application.

Fig. 5 Experimental Platform: Aim Robot

Fig. 5 is a picture of our experimental platform. In this mobile robot platform, the pseudo omni-directional vision system is used in the following way.

3 cameras are set on a base with the angle between any two adjacent cameras is 120 degree. The 4th camera is set in the lower front part of the robot. This alignment of the cameras enables the robot to get a large view field and can see the detailed scene at the same time when it moves ahead.

IV. MULTI-SCALE FOCUS STRATEGY AND ITS APPLICATION TO THE PSEUDO OMNI-DIRECTION VISION SYSTEM

One of the advantages of the intelligent image grabber is that its resolution can be changed easily by the command of the host computer. Making use of this advantage and inspired by the bionics research of human vision, we have proposed a multi-scale focus strategy for the mobile robot vision system and applied it to a soccer robot.

A. Multi-scale focus strategy for robot vision system

There are two kinds of photosensitive cells in our eyes: cone cells and rod cells. Most of the cone cells lie in the fovea area, and each cone cell connects with a nerve fibre. Contractively, rod cells locate diffusely on the retina and several rod cells connect with one nerve fibre. Since one optic nerve only receives the average light stimulation come from these rod cells, the vision resolution is decreased remarkably. The fact described above means that our human eye is a multi-resolution system, with the center fovea area has the highest resolution and the resolution decreases with the increasing of its distance from the center fovea area. When we look around, we do not always see everything clearly at the same moment. Only the objects which interest us most can be seen clearly because they are chosen to be projected to the center fovea area of our eyes.

Because the resolution of the intelligent image grabber can be changed online by the command of the host computer, it is possible to realize a multi-scale focus robot vision system whose working mechanism is similar to our eyes.

This multi-scale focus strategy for the robot vision system is as follows.

(i) In most time, all intelligent image grabbers of the robot vision system work in the low-resolution mode so that the robot can get a large searching area and a fast searching speed.

(ii) Once the robot finds an interested object by one of its cameras, this object will be focused. That means that the corresponding image grabber will be set to work in the high-resolution mode and the image size to be processed will be adjusted too.

(iii) The robot will continue to focus on this object and adjust the resolution and image size of other image grabbers according to the requirements of the task.

(iv) Low-level image processing of the focused object will be done by the corresponding image grabber and the results will be sent to the host computer.

Obviously, the efficiency of object searching will be improved using in this way because only the corresponding image grabber need to work in the resolution mode whereas all of the other image grabbers can still work in the low-resolution mode. In this way, the robot can both obtain the detailed information about the interested objects and can also have a large searching area and fast searching speed.

B. Design of a multi-scale focus pseudo omni-direction robot vision system

The robot soccer competition is a good experimental platform aimed at the research of the robotics, artificial intelligence, pattern recognition, intelligent control, etc, and is interested by a lot of researchers [6].

To test the effectiveness of our pseudo omni-direction robot vision system and the multi-scale focus strategy, a soccer robot developed in our lab is used as the test bed.

Fig. 6 A scene of robot soccer competition

Due to the technology limitation of robot vision systems, color information is used as the basis of object recognition in the robot soccer competition. Different colors are assigned to different objects so that the robot can recognize them using color and shape information in real time. Fig 6 is one scene of the RoboCup robot soccer competition.

In the RoboCup robot soccer competition, the static objects, such as the goal, the pole for the corner, the sideline, is relatively large compared with the ball and can be found easily even in the low-resolution mode. On the contrary, the ball is relatively small and is always moving about in fast speed. This makes it difficult for the robot to find the ball and keep tracking on it. Therefore, the ball must be treated in the high-resolution mode and should be kept "focused" when it is found.

Fig. 7 shows the working procedure of our multi-scale focus pseudo omni-direction robot vision system. It works in the following way:

(i) Initialization

The host computer initializes itself and calibrates each camera by obtaining one frame of unprocessed high-resolution image from them and run the initializing algorithms. Since the robot mainly uses the color information of the interested objects, the calibration for the color of each interested object is done through the host computer. At this period, each image grabber works in the low-resolution mode so that the robot can have a fast processing speed. When all of the 4 image grabbers work in the PAL mode, the data processing speed can reach to 50 frames per second.

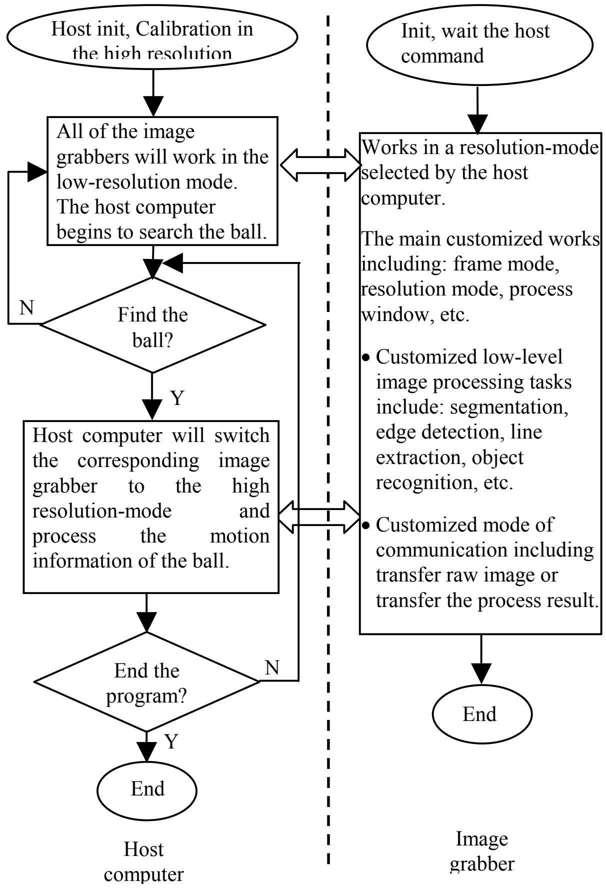


Fig. 7 The process chart of the vision system

(ii) Low-level image processing

The host computer sends commands to the image grabbers which are working in the low-resolution mode and customize their image processing algorithm accordingly. The intelligent image grabber will acquire image data through the camera connected with it and complete assigned works of low-level image processing. In the robot soccer competition, the works of the low-level image processing of the intelligent image grabber include segmentation of the ball, the goal, the goalpost, the corner pole, the sideline, etc, based on the color and shape information [7] [8].

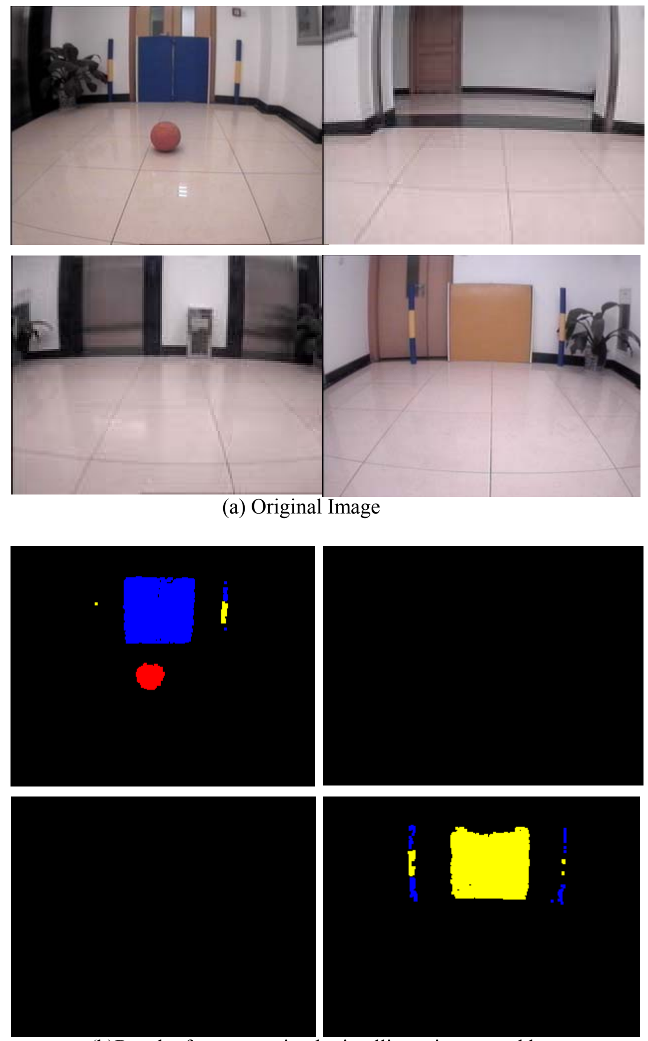
(iii) Ball searching and focusing

The results obtained by the intelligent image grabber will be sent back to the host computer and the host computer. If one of the intelligent image grabber finds the ball, the host computer will go into the third stage. It increases the image resolution of the corresponding image grabber and re-customizes its data processing and communication algorithms to get more accurate position of the ball. The position of the ball will also be memorized to obtain the motion information from its "historical data".

(iv) Other treatments

Since the goal and other objects in the ground can be recognized in the low-resolution mode, other image grabber which does not focus on the ball will still be left to work in the low-resolution mode.

The host computer also calculates the kinematics information of the ball and saves it to adjust the resolution of each client dynamically, i.e. to keep to "focus" on the ball. If all clients lost the ball, the host goes back to the second stage.



(a) Original Image

(b)Result after processing by intelligent image grabber

Fig. 8 An Example of pseudo omni-direction vision system

V. Conclusion

In this paper, the development of an intelligent image grabber and its application to a pseudo omni-direction robot vision system is presented. Experiments have shown that this multi-scale focus strategy and pseudo omni-direction vision system can remarkably increase the ability for the mobile robot to search and track an interested object. Although only the application to the RoboCup robot soccer competition is presented, the multi-scale focus strategy and the pseudo omni-direction vision system can also be used for other kinds of autonomous mobile robots.

Acknowledgments

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