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Multi-sensor Data Acquisition of Machine Vision in Agricultural Application

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Abstract: With the continuous development of precision agriculture technology, the research and application of machine vision technology in planting, fertilizing, plant protection and other agricultural fields has made rapid progress. In this study, a data acquisition system based on multi-sensor machine vision is developed. With DSP processing technology and multi-bus architecture, this system can acquire the multi-sensor data from digital camera, infrared sensor, laser range finder and optical fiber gyroscope, and achieve rapid transmission of information by CPCI bus technology plus dual-port memory (dual-port RAM), thereby providing reliable data for the servo control system. In this paper, the design concept and working principle of the data acquisition system is introduced, while the control mode and interface design of each sensor in the system is the research priority, and the modes of information transmission among the systems are described.

Keywords-component: data acquisition, multi-sensor, machine vision, DSP; multi-bus

1. Introduction

Modern precision agriculture aims at economizing investment, increasing output, improving efficiency and reducing environmental pollution. With the advantages of no destructiveness, high precision, high efficiency, large information capacity and excellent flexibility, the machine vision technology has been widely applied in precision agriculture [1][2], So far, the research and application of machine vision technology in planting, fertilization, vegetable and fruit picking, plant protection and other agricultural fields has enjoyed a raid development [3][4]. Improving the efficiency of agricultural production and raising the degree of agricultural automation is a fundamental requirement of the agricultural modernization, while the achievement of any agricultural automation technology is based on the correct identification and positioning for the agricultural objects [5][6], and acquiring agricultural information quickly and precisely as well as monitoring the agricultural objects effectively is the basis to implement precision agriculture. However, in view of the huge data size, great variety, randomness and strong variability of agricultural objects, the monitoring on agricultural objects are carried out using various sensors [7][8]. In this design, the problem that the traditional agricultural machine is largely dependent on visual sensors is changed, and acceleration sensors, fiber optic gyroscopes and multiple resolver are employed to acquire the data of acceleration, angular velocity and angle, thus enhancing the accuracy of target positioning.

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To quickly collect the data from every sensor, a new high-speed DSP TMS320C6416 is used in this design for data computing and processing. Especially, with a new type of CPCI bus, the universal property, hot plug, expansibility and high reliability of the DSP TMS320C6416 are quite suitable for the data acquisition & processing system. Moreover, as a result of the introduction of a special CAN bus for data connectivity, the real-time data communication and storage is ensured.

A complete machine vision system consists of various information detection modules, acquisition system, image digitization and processing module, intelligent decision-making module, and control & implementation module [9]. After sending the target image data that is acquired by the digital camera and infrared thermal imager to the video tracker, the system will extract and process the target information, work out the deviation of the direction and pitch angle between the target and the central position, and then send the processed data to the control and identification system, which will move the whole system towards the direction of reducing errors. During the process of tracking, the distance to the target is determined by the laser rangefinder [10]. The data of acceleration, angular rate and angle is acquired by the acceleration sensor, fiber optic gyroscope and multiple resolver, and then it will be processed and sent to the control system for stable tracking and control to the target [11]. The speed and accuracy of target tracking rests with the precision and real-time property of every sensor in data acquisition, while how to timely and accurately collect and send the information that is acquired by the sensors to the control system is a key problem. In this paper, in addition to the application of DSP processing technology, many acquisition and transmission circuits are designed in accordance with the data transmission modes of every sensor and the information transfer rate, thus ensuring the accuracy and real-time property of data acquisition.

2. Design of the Data Acquisition System

2.1. Overall design of the data acquisition system

To enhance the machine vision system's rapid identification and processing to the agricultural objects, the data acquisition system must be able to collect and process the data from each sensor in real time and then send it to the control system. In the overall design, by introducing a new generation of high-speed DSP processor and making use of the speediness & scalability of DSP processor, rich internal resources and the design of programmable CPLD logic circuit, the multi-sensor connection and control based on CAN bus and RS422 bus is realized, the 2-way multiple resolver decoding circuitry and dual-port RAM are extended, the collection of data from digital camera channel, infrared channel, laser range finder, acceleration sensors, fiber optic gyroscopes and multiple resolver is achieved respectively, and the data can be quickly transferred to the control computer through CPCI bus. The structure diagram shown in Figure 1.

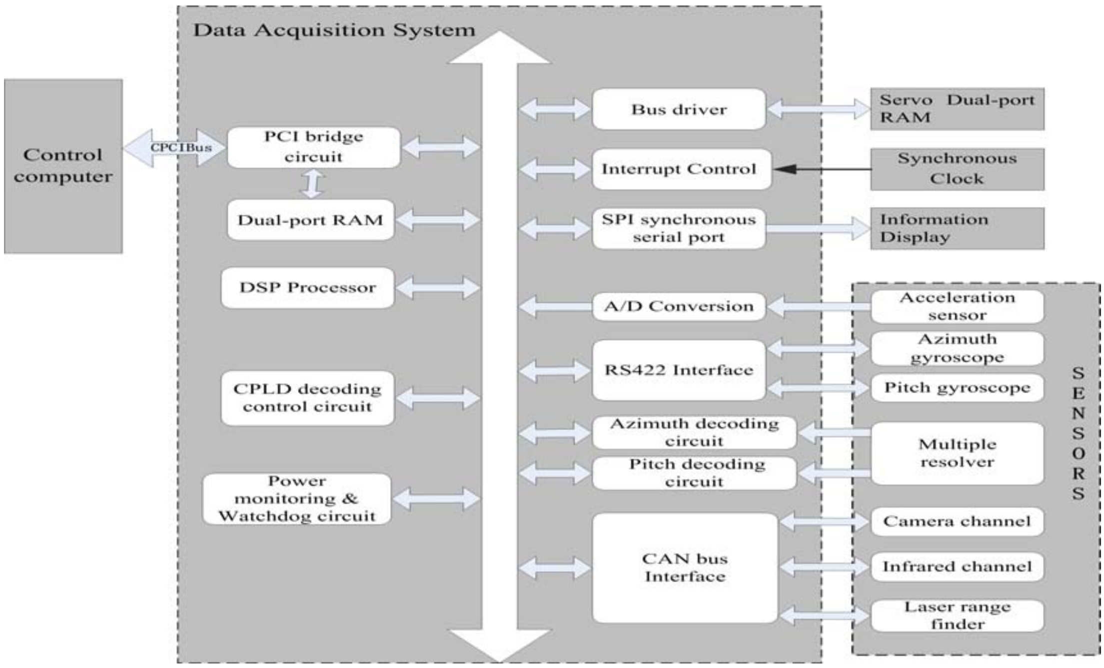

Fig.1.Structure diagram of data acquisition system

2.2. Working principle

In the machine vision system, the DSP processor generates 500μs timed interrupts by an internal timer, collects the angular rate data from azimuth/pitch gyroscope through RS422 bus, and collects the angle data from azimuth/pitch multiple resolver through the decoding circuit. In the 20 *ms* interrupts, the data from cameral channel, infrared channel and laser range finder is collected through CAN bus and then stored in the dual-port RAM, thus achieving information sharing. The control computer reads the data in dual-port RAM through the CPCI bus interface circuit, while the servo control system reads the data in dual-port servo RAM and, at the same time, displays the data collection through SPI interface.

2.3. Design of the data controller system

Regarding the centralized control and processing of the multi-sensor machine vision system, the processing speed of the processor must be high due to the restriction of the sampling rate and time, so a high-performance DSP device (TMS320C6416) made by TI Corporation is equipped in this system as the core controller. With 1GHz main frequency, 600MHz clock frequency and the maximum processing capacity of 4800MIPS, this processor has an excellent real-time property in data acquisition and can shorten the processing time . Plus, with the data lines for external data, address and control, this processor has perfectly scalable data memory and I/O peripherals. There are rich available resources including 2 extended memory interfaces (EMIF) and the PCI interface, SCI asynchronous serial port, SPI synchronous serial interface, CAN bus interface and timer, thereby facilitating the design and control of the multi-bus interfaces in the system, reducing the number of the peripheral circuits and enhancing the reliability of the system. By the resources of the DSP processor, the system is competent in controlling the sensors and collecting data from them without extra extension of the control circuit.

2.4. Acquisition of the acceleration data

MMA7260, a single-chip high-sensitivity three-axis acceleration sensor, is equipped in this system. Based on the surface micro-mechanical structure, such acceleration sensor has 4 modes of sensitivity selection. Integrating the data conditioning, monopole low-pass filter and temperature compensation technology, it has 4 ranges of acceleration measurement. The acceleration at the three mutually perpendicular directions X, Y and Z is captured by G-Cell sensing unit, and then the information will be outputted as voltage data after going through capacitance- voltage converter, gain amplification, filter and temperature compensation. However, due to the occurrence of clock noise, RC filters should be installed at the 3 outputting ends of MMA7260.

2.5. Acquisition of the angular rate and angular data

As the pitch/azimuth angular rate sensor of the machine vision system, the fiber-optic gyroscope is equipped with standard RS422 interfaces and connected though bus. To meet the requirements of the fiber-optic gyroscope’s interface, the RS422 interface is designed by externally connecting the SCI asynchronous serial ports in the DSP processor with differential transceiver driver, thereby achieving the acquisition of angular rate data. The requirements of baud rate in data transfer can be met by setting the baud rate register.

As the pitch/azimuth angular sensor of the machine vision system, the multiple resolver can output coarse/fine-level sine and cosine analog data, which will be sent to the DSP processor after being received and converted into angular digital quantity by the decoding circuit of the data acquisition system. There are 2 resolver–digital converter switchers (coarse/fine) and a two-speed processor (speed ratio: 1/64; 20-bit resolution; accuracy: $\pm 5''$) for combination and error correction of coarse and fine code. The design of the decoding circuit is shown in Fig.2. The decoding module has 20-bit data lines, 3 enable data ($\overline{ENL}$, $\overline{ENM}$ and $\overline{ENH}$), and 1 inhibit data ($\overline{INH}$). In design, $\overline{INH}$ is controlled by the I/0 data of DSP, the CPLD address codes are connected to $\overline{ENL}$, $\overline{ENM}$ and $\overline{ENH}$ respectively, and the data lines are correspondingly connected with the data lines of DSP processor, thereby implementing the measurement of angular metric.

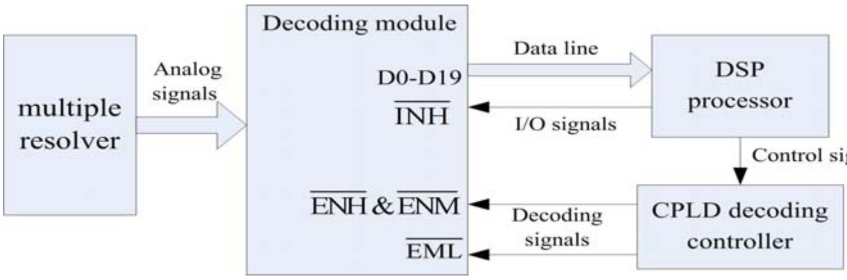

Fig.2. Principle diagram of decoding circuit

2.6. Data acquisition of angular error and distance

By processing the video data from the digital camera and infrared thermal imager with a tracker, the target angle error is calculated and then sent to the data acquisition system. The standard CAN bus interface is used for data transmission between the data acquisition system and the camera tracker, infrared tracker or laser rangefinder, thus achieving the multi-node fast communication, simplifying the design of the machine vision system [12], reducing the number of data lines for communications, and enhancing the reliability, speediness and flexibility of the system.

The CAN bus interface of the data acquisition system is designed by connecting a CAN controller in DSP processor and a driver, and its basic parameters are: CAN 2.0B protocol, PelicCAN model, 1 Mbps baud rate, 8-byte data packets, and the time to receive and send one-channel data packets is less than 100μs, So achieving the requirements of the rapid date collection in the each node. The connection mode is shown in Figure.3

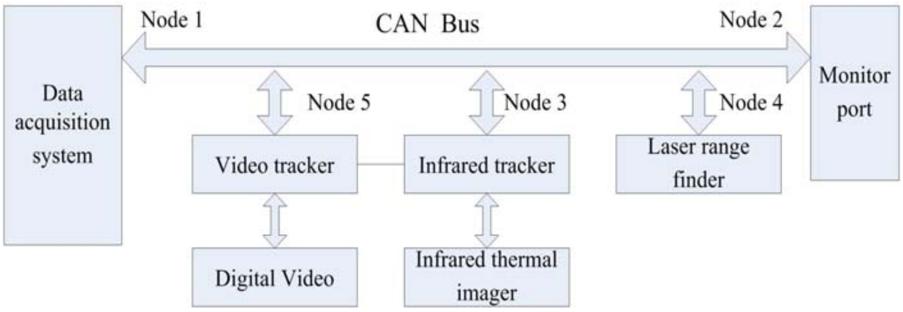

Fig.3**.** Design for multi-node data acquisition of CAN bus

In addition, the identifiers, acceptance codes and acceptance shielding codes of each node in the network are different from each other. As the main controller, the data acquisition system (Node 1) sends control codes to the video tracker (Node 2) in the 20*ms* clock interrupts, while the video tracker will feed back the current computing results and status to the data acquisition system after receiving the control codes. In the same way, the system gets access to the infrared tracker and laser range finder to acquire the azimuth/pitch angle deviation and distance of the target. The Node 5 in the following figure is a monitor port that can check the status of the bus and whether the instructions & data of nodes are normal or not, but it is only used when debugging.

2.7. G. Data transmission

After acquiring the target's azimuth/pitch angle deviation and distance as well as the acceleration, angular rate and angle data of the machine vision system relative to the target, the data acquisition system must timely and accurately send the data to the servo control systems and identification system[16]. For this reason, 2 dual-port RAMs are installed in this system to conduct information transmission with the control computer and servo system.

2.8. H. The dual-port RAM communication

With dual-port RAM, the information transmission in the system will be much faster and easier with a lower bit error rate. As the shared resource for the both sides of communication, the dual-port RAM can provide information freely. Using the external data lines, address lines and control lines of the DSP processor, the data acquisition system extends 2 dual-port RAM partitions for data transmission as the shared memory of the data acquisition system, vision system and servo control system.

2.9. I. Design of the CPCI bus interface

The data acquisition system is encased in the machine vision system's control computer, where the currently popular CPCI bus structure is used, so the data transmission to the control computer needs to be implemented by PCI bridge circuit (as shown in Figure.1). In this system, the PCI9054 interface chip, a proprietary chip of PLX Corporation, is sued to simplify the design of the bus interface circuit. With 30-bit data bus, 33MHz bus clock frequency and 132 MB/s transmission speed, this device uses the non-multiplexed data & address bus mode and support PCI2.2 Protocol. The data sharing and transmission between the data acquisition systems and control computer is implemented by the dual-port RAM, which, as the extended memory of the control computer, is directly connected with the dual-port RAM IDT7133 though the local bus of the PCI9054 interface chip, thus achieving the resource & information sharing and rapid communication.

3. Experiment and Discussion

In the machine vision system, the acquired data from the sensors will be sent to the control system through dual-port RAM in real time, and then the data will be taken as the input of the digital servo control through the digital controller of the position loop and stabilizing loop of the rate gyroscope. Also, in this system, the digital filter with optical variable parameters, regenerative feedback, the compound control of video-channel image fusion, nonlinear compensation, digital adaptive control, and other technologies are applied, thereby achieving stable and fast tracking and identification of the targets [17][18].

Such data acquisition system has been applied into agricultural machine vision systems and works stably and reliably. According to the results of the system test, the sampling time of acceleration, angular rate and angle, and angular error is 98μs, 97μs and 91μs respectively, which can meet the general parameter requirements of the system.

In our experiment, a tracking and identification test on agricultural targets was conducted through the data acquisition system within the machine vision system.

The machine trolley platform can be adjust the height in the range of the 1 meter to 2 meter and the platform can be move within the speed scope 0.5 meters per second to 1.5 meters per second. The video camera on the platform can take images up or down.

In actual tests, the watermelons and oranges in farmland were tracked and identified at the height of 0.8 m and 1.2 m, respectively. The machine trolley platform's speed is 0.7 meters per second in order to ensure the accuracy. The test results are shown in Table 1. and Table 2.

TABLE 1. THE RESULTS OF TEST ON WATERMELON

Parameter	Azimuth	Pitch
System error/*mrad*	0.0263	0.0136
Random error/*mrad*	0.0591	0.0312
Maximum angular velocity/$(^o)/s$	337.8	101.7
Maximum angular acceleration/$(^o)/s$	93.1	89.3

TABLE 2. THE RESULTS OF TEST ON ORANGE

Parameter	Azimuth	Pitch
System error/*mrad*	0.0472	0.0287
Random error/*mrad*	0.106	0.0595
Maximum angular velocity/$(^o)/s$	235.6	123.5
Maximum angular acceleration/$(^o)/s$	91.7	87.6

It’s demonstrated by the data in the table that the improvement in the performance of the data acquisition system has enhanced the speed of servo control, shortened the system response time, and improved the performance of the control system.

4. Conclusions

By applying a variety of sensors, the multi-bus control technology, the DSP & CPLD control technology and CPCI bus interface technology, the data acquisition system can acquire the multi-sensor data from digital camera, infrared sensor, laser range finder and optical fiber gyroscope, and achieve rapid transmission of information by CPCI bus technology plus dual-port memory, and enabled to collect the multi-sensor data in real time and provide timely & accurate data for the composite control of the machine vision system, which has been demonstrated in practice. With the advantages of high data acquisition speed, stability, reliability and versatility as well as low cost, the multi-sensor data acquisition system has a bright prospect of application in agriculture.

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