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Vision based AGV (mobile robot) using multiprocessor controller with RTOS

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ABSTRACT

Vision based AGV (Automatic Guided Vehicle) with RTOS (uC/OS-II) is designed and developed for controlling two wheeled differential servo motor drive. In order to meet the demand of function, reliability, cost and real time performance compared to its commercial counterpart of general purpose computer the system is implemented with RTOS. The multi-processor embedded system with distributed architecture consists of a main-controller of vehicle management based on the ARM LPC2378, and a sub-controller of vision navigation based on the DSP BF533. The embedded RTOS uC/OS-II is used to construct a software development platform, on which different functions needed are described as several tasks, and a number of system services facilitate software realization. In the practical application of device reformation, a commercial AGV product is upgraded by the embedded vehicular controller we develop, on which a sophisticated algorithm of path tracking is implemented successfully and efficiently. The experimental result demonstrates the effectivity and advantages of the embedded multi-processor controller with the RTOS uC/OS-II presented in this paper versus its commercial competitor.

Introduction

Automated Guided Vehicle (AGV) is one intelligent kind of Wheeled Mobile Robot (WMR) used widely for logistics automation in many fields. A number of commercial AGV Products have appeared in the market. Their hardware system usually adopts general purpose computer as host computer, and uses several kinds of function cards as extended module. The software system is generally based on Windows/ Linux operating system. It is convenient to construct control system by selecting different function cards for an industrial computer, and easy to get driver for various devices under Windows/Linux OS. However, there are also some unavoidable disadvantages for this universal solution. Unnecessary functions in the system charge additional payment from users. Power dissipation is another problem because real time execution in universal system requires CPU with high performance. Besides, it is difficult for Windows system to achieve real time completely.

With the advent of VLSI system level integration, embedded systems, such as ARM, DSP and FPGA, become the centre of gravity of the computer industry, and the first choice when vehicular controller is designed for WMR. The DSP TMS320F2812 is used widely to accomplish motor Control and sometimes also applied for higher level algorithm, such as image processing and path planning. The DSP BF-533/537 is also proposed for computer vision and image processing, which is designed for video/imaging application specially. ARM is another excellent microcontroller, which excels in event management in virtue of comprehensive supports from many matured RTOS. Real time control of AGV movements requires not only a computation-effective hardware system, but also an advanced control algorithms. For AGV that is a nonlinear system with time delay and non-holonomic constraints, traditional PID algorithm can only realize simple movement control at low speed when linear path is tracked. So a variety of advanced algorithms are proposed for complex motion control of WMR, used to calculate and optimize the controlling variable of speed difference under the condition of the fixed feedback gain and given speed.

Predictive control has advantages that optimization process is considered in a global and long-term view. An intelligent control imitating the preview driving behavior of human which combines human driving experiences with a PID algorithm. A steering control imitating human driving which conceives a series of steering control rules by a qualitative analysis on position and orientation of a guideline.

This paper conceives and constructs a multi-processor control system with master-slave distributed architecture for a two-wheel differential driven Automated Guided Vehicle by Visual guideline navigation (V-AGV), in order to implement a sophisticated hybrid algorithm of path tracking for real time control of AGV movements.

It is an advisable choice to integrate the capability of event management from ARM LPC2378 and image processing from DSP BF-533. This multi-processor controller consists of a main-controller of vehicle management based on ARM LPC2378, and a sub-controller of vision navigation based on DSP BF-533. All functions related to V-AGV can be classified as different tasks. Image processing for guideline acquisition are developed by the sub-controller of DSP BF-533, which can extract two path errors (distance and angle errors) according to a guideline on the ground. All other tasks are implemented by the main-controller of ARM. based on a series of steps, corresponding to the distinctions between problems, causes, and solutions. Step 1 is for identification of the number of disease in rice.

Hardware description of the embedded vehicular controller

a. vehicle configuration

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The configuration of the V-AGV in this paper is shown in Fig. 1. Two wheels in middle of the V-AGV are driven wheels, which are actuated separately by a DC servomotor. Two optical encoders are mounted respectively to each driven wheel shaft to provide the position and speed feedback. Other two wheels are universal wheels only with support function. Therefore, there are two trajectories of line and arc for this kind of AGV. The center of linking line between two driven wheels is the kinematics origin of the V-AGV.

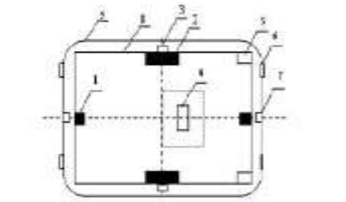

Fig. 1 Detailed configuration of V-AGV

One CCD camera is mounted in front of the linking line. Visual field covers path errors not only at current moment, but also at future moment. Two ultrasonic sensors are installed in front of the V-AGV to detect obstacles and measure the distances. Two photoelectric sensors are fixed both in front and back of it to find obstacles in a close distance. Four contact switches are distributed around it to monitor collision

B. A main-controller of vehicle management based on ARM

LPC2378 is based on a 16/32 bit ARM7TDMI-S CPU running up to 72 MHz with real-time emulation and embedded trace support. With its 100 pin package, low power consumption, various 32-bit timers, 8-channel 10-bit ADC, PWM channels and up to 4 external interrupt pins, this microcontroller is particularly suitable for industrial control. That is the evident reason why it is adopted as the main-controller of vehicle management for the V-AGV. Fig. 2 is a block diagram of LPC2378, which illustrates the specific use of peripheral resources in this chip.

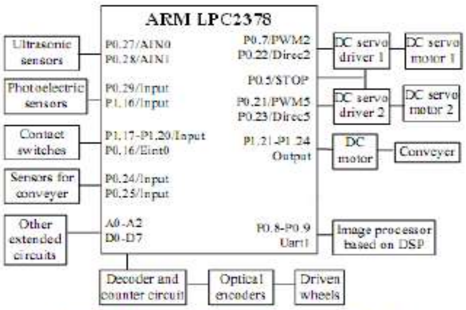

Fig. 2 Block diagram of the main-controller based on ARM

A modular structure is considered when the hardware of main-controller is designed. All functions needed to control the V-AGV are assigned to different microcontrollers and their peripheral devices. So the embedded vehicular controller as been classified to seven functional boards, as shown in Fig. 3. Connection board provides a mutual linking platform, and power board offers a common power supply for other boards. Kernel board is an ARM-based module with many accessible peripheral devices. Other boards are designed to assist ARM to control of the V-AGV. Image processing board is the sub-controller based on DSP, which is discussed later .

Kernel board is a platform with a minimum system of the ARM LPC2378, which provides various peripheral devices for other functional boards related to it. The memory system contains a 512kBflash SST39LF160 and a 56kB static RAM IS61LV 25616, which is able to satisfy capacity requirements of the sophisticated hybrid algorithm of path tracking based on this embedded platform. The interface for kernel board consists of address & data bus, analog inputs, PWM outputs, GPIO, and serial communication interfaces, such as UART, I2C, and SPI.

Fig 3 ARM LPC2378 kit with JTAG interface

Input board provides several analog signal interfaces for ultrasonic sensors, and two-state signal interfaces for photo-electric sensors, contact switches, and other sensors. The two-state signals from contact switches will cause an immediate response from ARM by using the external interruption pin when a collision happens. Other input signals are processed periodically in a small time slot due to their lower demand on real time.

Output board has two kinds of control means: PWM and two-state switch outputs. The PWM outputs are utilized to control DC servo drivers, which amplify control signals from ARM, and actuate DC servomotors. The switch outputs are used to control two-state actuators and other output devices. In order to avoid power interference from the driving system to the control system, many photo coupler circuits are used to isolate control signals from the driving signals. Encoder & wireless communicator board contains data & address bus, Uart1 with modem interface, and SPI1. In order to estimate the position and speed of the V-AGV, a quadrature decoding and counting interface circuit is used to count pulses and discern direction, which is based on the decoder/counter interface IC HCTL2021. Then ARM can read the value of the counter by address & data bus. It is obvious that the resources of the chip LPC2378 are utilized wisely and the peripheral circuits are very concise. Other resources of the chip are also made available to users through kinds of interfaces and ports provided by ARM-based kernel board. It is convenient to extend new functions and integrate extra devices, such as a LCD screen and a keyboard to facilitate human-computer interaction on the V-AGV.

C. A sub-controller of vision navigation based on DSP(BF533)

The vehicular vision navigation system comprises a CCD camera and a sub-controller of image processing based on DSP BF533 which acts as a Slave control for ARM – Master controller. The CCD camera captures the images of a guideline on the ground, and provides a PAL analog video signal output. DSP first converts the video signal to a digital signal, and then executes several image processing algorithms to acquire two path errors (distance error and angle error) between the guideline and the origin of V-AGV in a local visual coordinate. Two path errors are inputs of ARM that runs a hybrid algorithm of path tracking. The processing steps of visual guideline information are shown in Fig. 4

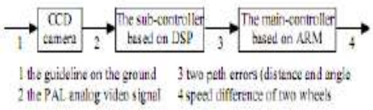

Fig 4 Transmission process of Visual Guideline information

Fig 5 Black fin BF533 Evaluation Board

The DSP BF533 is specially designed for signal and image processing applications. The board comprises of 128Mbit SDARM., 1Mbyte Flash., 256KB Spi Flash Program Memory, UART for Serial Communication, 27MHz On-Board crystal, 32.768 KHz RTC, Output Led's Timers and RTC, Programmable Flags (For External I/O), JTAG Connectors, Asynchronous Memory Connector for debugging

Implementation and results

A.Real Time Kernel µcos-II for ARM LPC2378

By the foundation of robot's attribute, a satisfied OS for robotic purpose needs a well management mechanism to deal with tasks and devices that can coordinate various tasks inside the robot to work fine. As well as offering real-time kernel to let the robot react quickly and operate smoothly, the OS kernel ought to have IPC methods which are dedicated to the convenient of robot's applications developing. Fig. 6 presents the structure of OS kernel. API provides the interface between OS and top-level applications

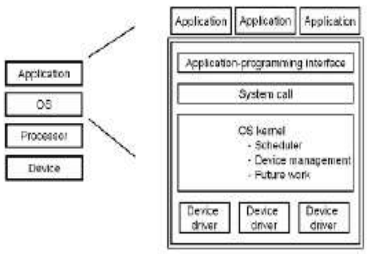

Fig 6 µcos-II Kernel Structure

Driver provides the interface between OS and low-level devices (e.g. actuator, sensor, etc.).

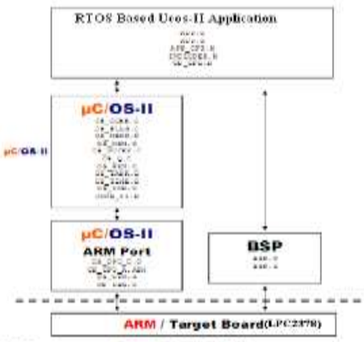

Fig 7 Porting µcos-II for ARM LPC2378

In this paper, we adopt uC/OS-II as an implementation example of robotic OS in IAR Embedded Workbench Platform-Kick start Edition 4.0. uC/OS-II is a RTOS which is open source and widely used especially for control system, and it has the advantages of high performance, small footprint, excellent real-time and scalable. In our design, inside OS layer which requires API, system call, kernel and driver. To meet the requirement of intelligent robot's behavior control, we rewrite API and driver.

Fig 8 IAR EMB IDE for ARM with µc/os-II

B. Task Transitions in µcos-ii

B. Task Transitions in µcos-ii

A number of system services are offered such as mailboxes, queues, semaphores, fixed-sized memory partitions, time related functions, and etc. The vehicle control and management software running on LPC2378 is designed and developed with the support of uC/OS-II.

Fig 9 Task Classification and communication based on µcos-II

Eight event control blocks (ECB), including semaphores, mailboxes, and a queue, provide inter-task communication and shared data protection. The initial task TaskStart is the first and only task created by the main function, which is used to initialize the objective hardware, set device parameters, and create other nine tasks. A queue ToCarMovQueue with fixed-sized memory partitions is designed for TaskCarMove. Four mailboxes are assigned to four tasks respectively for inter-task communication. Three semaphores are used to protect shared data for data integrality. An event that some obstacles approach will trigger a message sent to the mailbox of TaskFaultProcess. The Analog/Digital conversion task TaskADCDistance transforms periodically a 4-20mA current output of ultrasonic sensors to a 0-3.3V voltage that describes a distance between the V-AGV and a possible obstacle. The TaskEncoder reads the count number and direction of the pulse from optical Encoders. The vehicle speed is calculated according to the accumulated pulse number in the current interval.

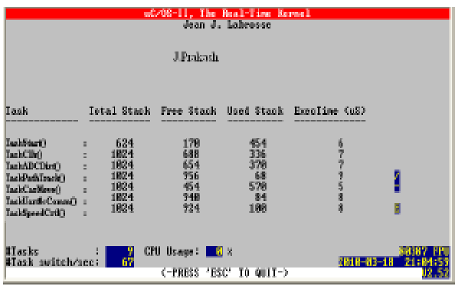

Fig 10 Task Execution & Preemption in µc/os-II for AGV

The TaskPathTrack implements the hybrid algorithm of path tracking control for the V-AGV. Speed difference for two driven wheels is calculated to adjust the V-AGV for eliminating two path errors when it moves along the guideline. The hybrid algorithm is carried out when path errors occur.

The driven wheel speed control task TaskSpeedControl converts the speed difference output to the voltage output, which controls the servomotor drivers directly. An expert PID algorithm is used for the wheels servo control in PWM way. The PWM number is sent to the mailbox of TaskCarMove.

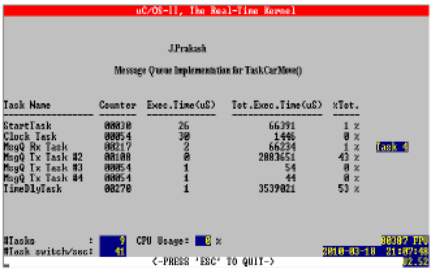

Fig 11 Message Queue Implementation for TaskCarMove()

The TaskCarMove provides a series of control functions for V-AGV movements, such as start, stop, speed change, etc. A queue is used to store temporarily the messages from other tasks in order to avoid possible information loss when a time delay occurs for smoothing sudden speed change. It shows that all control requirements for the V-AGV is divided to several functional units, including tasks, interrupts and ECBs. Modularization design idea is adopted not only in hardware construction but also in software development. A set of system services offered by uC/OS-II facilitate the software programming, and improve the real time performance.

Iv. Conclusion and future work

This paper presents a vision based Automatic guided vehicle (Mobile Robot) with uC/OS-II for a two-wheeled differential driven in order to provide a Real time solution, compared to the system of general purpose computer. The main-controller of vehicle management is based on the ARM LPC2378, which is distinguished for its excellent capability of event handling (Master) and real time control. The sub-controller of vision navigation is based on the DSP BF533, which excels in parallel calculations for the image processing.

In order to simplify the software programming and improve the real time response, an embedded RTOS uC/OS-II is transplanted to ARM LPC2378. An actual experiment of path tracking control is conducted in the industrial field to test the performance and reliability of the embedded controller, the result of which proves our work. Next task focuses mainly on extending the management and control functions to cooperate with their equipments in the field of Avionics & Automation research.

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