3D Reconstruction Embedded System Based on Laser Scanner for Mobile Robot

Jianhua Wang Bing Li Weihai Chen Lixia Rong
School of Automation and Electrical Engineering
Beijing University of Aeronautics and Astronautics
Beijing 100083, China
libing2002@gmail.com whchenbuaa@126.com

***Abstract* - For 3D reconstruction technology based on laser ranging for mobile robot, this paper presents the design of real-time embedded system for 3D data processing. Firstly, this paper introduces the home and abroad research situation of laser ranging for mobile robot, and analysis the method of 3D data acquisition with 2D laser scanner and 1D driving motor module. Secondly, this paper introduces the hardware design and system building of multi-module embedded system, which consists of DSP data acquisition module, FPGA data processing module and ARM control. The ARM system is the main control system and realizes 3D reconstruction function. CAN bus communication is selected between these modules. Thirdly, this paper introduces the design of communication programming under ARM control system. At last, this paper presents the 3D reconstruction method with laser scanner and driving motor by Mesa3D based on RTLinux system.**

***Keywords* - Embedded System, 3D Reconstruction, Mobile Robot, Laser Ranging**

I. INTRODUCTION

Mobile robot self-localization and navigation has become a research hot of intelligent robot. 3D reconstruction is the base of mobile robot self-localization technology and provides the environment modeling for mobile robot navigation and obstacle avoidance research. As to the control system of mobile robot, which is mainly the PC control system in the past, more and more embedded system, including embedded hardware and embedded software, is applied to mobile robot control. The embedded system used in robot 3D reconstruction is a research trend.

In University of Hannover, Wulf presents 2D mapping of cluttered indoor environments by means of 3D perception. He gets the 3D point cloud of the surrounding environment, in which the third degree data is acquired by a driving motor. The controller system which Wulf used is a traditional microcomputer [1] [2]. Christian Brenneke presents using 3D laser range data for SLAM in outdoor environments and realizes 3D reconstruction by SLAM algorithm. His work platform is the same as wolf's [3]. In University of Oxford, David M. Cole presents the method of using laser range data for 3D SLAM in outdoor environments, and he gets the 3D reconstruction by 2D laser scanner and 1D driving motor. The controller system Cole used is also microcomputer [4]. In Chiba University, Zhenyu Yu presents development of 3D vision enabled small-scale autonomous helicopter. The control system he used is RTLinux and he realizes 3D reconstruction by MATAB in PC [5]. Robert Geist realizes 3D reconstruction by Mesa3D on linux system and makes performance compare with Windows NT. His result indicates the performance on linux system is better [6]. However, Robert Geist does his researches on linux of PC. The volume and performance of the system are needed to be improved.

In home research, Zi-xing CAI from ZhongNan University presents the 3D reconstruction method with 2D laser scanner. The third degree data is acquired by step motor which makes the laser scanner moving in the vertical direction in range of -45 degree and +45 degree [7]. In addition, he presents the modeling method based on voromoi boundary gridding and realizes the mobile robot self-localization and route planning [8]. Thus, his research is based on IPC and windows operation system. The Real-time performance is deficient and 3D dynamic lag is tremendous [7]. SHI Hua presents using RTLinux to improve the Real-time performance of mobile robot control. He divides the mobile robot controller into real-time domain and nonreal-time domain by the multi-threading mechanism. The control system he used is a Pentium-III IPC (Industrial Process Computer) [9]. In home research, 3D reconstruction technology of mobile robot is mostly based on traditional PC and mobile robot control system imported from the abroad. The real-time property of 3D reconstruction cannot be satisfied and it costs a lot. As to the 3D reconstruction software, most research use OpenGL which is a commercial graphical development library from SGI Corp. As commercial software, it is not open-source. Mesa3D is the open-source realization of OpenGL and it can be transplanted into different system with its wonderful transportability. Mesa3D almost supports all the API functions that OpenGL provides.Mesa3D has not been widely used on linux system. Thus, more and more people are interested in Mesa3D

According to the home and abroad research situation of mobile robot 3D reconstruction, self-localization and navigation, this paper presents the mobile robot 3D reconstruction based on DSP data ACquisition, FPGA data mending and ARM main control system and RTLinux system. This paper realizes 3D reconstruction by Mesa3D on RTLinux system and the result indicates Mesa3D works as well as OpenGL. However, Mesa3D has the unique advantages of open-source, expandability, transportability, low costs, etc.

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II. Configuration of Embedded Control System

The whole 3D system consists of LMS291 laser scanner, motor driving motor and the embedded control system. LMS291 is the laser scanner. DC motor in motor module is controlled by the DSP module and driven by a motor driver board. The whole system is controlled by ARM system LMS291 laser scanner and motor driving module is shown in the following figure.

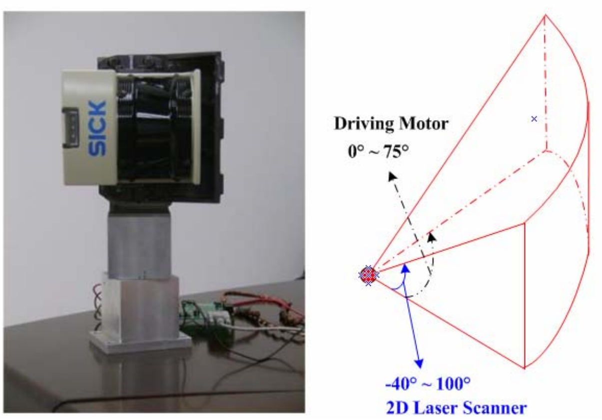

Fig.1 LMS291 laser scanner and motor driving motor

A Hardware Configuration of *Embedded Control* System

Multi-module embedded system consists of DSP data acquisition module, FPGA data processing module, ARM main control system and graphic reconstruction platform. These three modules realize the functions of data acquisition, pretreatment, arithmetic realization and graphic display respectively. The structural diagram of the whole system is as following:

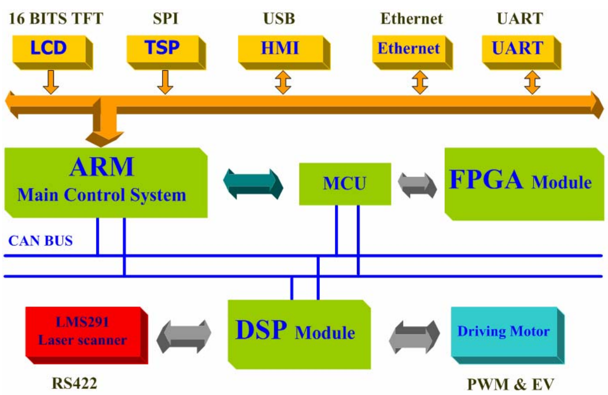

Fig.2 Structural diagram of embedded system

FPGA data pretreatment system is realized by FPGA and MCU. The system gets the range data form DSP module through CAN bus, and finishes the functions of coordinate transformation, filtration, data smoothing, mending, and formal definition, etc. The data is send to ARM form CAN bus and is processed and displayed. FPGA module realizes data pretreatment by VHDL programming language. The MCU is used for the communication between CAN bus and FPGA chip, which simplifies the design of FPGA module communication. The advantages of data pretreatment by FPGA are as follows: FPGA has high parallel processing rate, so tremendous data can be processed and real-time performance is satisfied. FPGA has great stability and work efficiency. The design of FPGA is agile, and is easy to realize peripheral circuit, data buffer, storage circuit and data processing module. It is convenient for the circuit improvement and arithmetic update.

Main control system is based on ARM and RTLinux system, and provides the HMI (Human Machine Interface) and GUI (Graphic User Interface). It works as the control core and accomplishes the system task scheduling, graphical reconstruction and display. In conclusion, main control system acquires the processed data from FPGA module, builds the 3D gridding model of robot forward environment by gridding arithmetic and displays 3D graphic on LCD displayer.

The communication mode between modules in the system is selected by two aspects. One is the communication rate and the other is convenience for the system development and debugging. With whole calculation, the data quantity is 80KB/s around. According to this characteristic, CAN bus is selected. CAN bus was developed for the electrical system of car application in 1983 by Bosch Corp. It is a kind of FieldBus and serial communication network which supports the efficiently distributed control and real-time control. With the bit-serial data transmission, the transmission rate of CAN bus is 1Mb/s. it satisfies the system communication rate, supports multi-point control and real-time control. With CAN bus, the design of modules can be synchronized and the system development efficient can be improved.

B Software Configuration of Embedded Control System

Software program is developed under linux OS (Operating System) in PC and runs under RTLinux OS in the ARM system. The program debug is based on these two systems. Software program mainly includes two parts:

1) The 3D data acquisition program which gets the data from FPGA module by CAN bus.

CAN communication program is based on CAN driver. CAN driver provides the API (Application Programming Interface) of interface reading, interface writing, and interface setting. The program realizes communication functions by driver functions.

2) 3D reconstruction program.

3D reconstruction is based on Mesa3D graphical library by GLUT (The OpenGL Utility Toolkit) on linux system and the 3D graph is displayed. The functions referring with display is realized by LCD driver.

The software architecture can be described in the following figure.

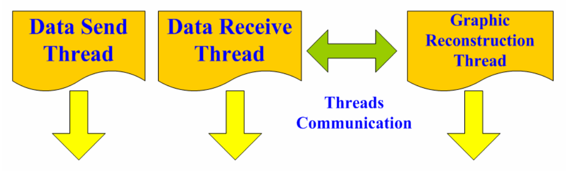

Fig. 3 Software architecture of the system

III. FUNCTION AND DESIGN OF THE EMBEDDED CONTROL SYSTEM

A Hardware Design of ARM Control System

The hardware interfaces designed are JTAG, UART, LCD, TSP, and Ethernet. The structural diagram of hardware is shown in Figure 4.

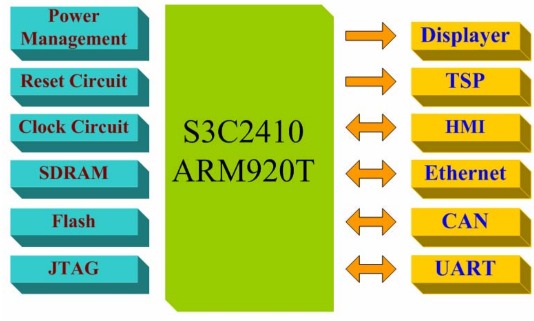

Fig. 4 Hardware architecture of the system

The controller is Samsung S3C2410. The S3C2410A a 16/32-bit RISC processor and was developed using an ARM920T core. The ARM920T implements MMU, AMBA BUS, and Harvard cache architecture. This CPU is designed to provide hand-held devices and general applications with cost-effective, low-power, and high-performance micro-controller solution. With these properties, S3C2410 is suit for mobile robot application.

S3C2410A provides a complete set of common system peripherals and eliminates the need to configure additional components. The designs of hardware interface are as follows:

1) There are three channels UART in S3C2410A and the communication mode of laser scanner can be selected RS232 and RS422. For high communication rate, RS422 interface is designed and the rate can be 10Mbit/s. additionally, the communication module between motor modules is RS485, which is realized by MAX491.

2) LCD controller is integrated in S3C2410A. The LCD controller in the S3C2410A consists of the logic for transferring LCD image data from a video buffer located in system memory to an external LCD driver. Using a time-based dithering algorithm and Frame Rate Control (FRC) method and it can be interfaced with SNT LCD and FTF LCD. In this system, 16-bit per pixel TFT LCD is selected and the LCD controller works in the mode of 16 BPP.

3) The A/D acquisition controller of TSP is integrated in S3C2410A. There is a 10 bits A/D converter for TSP control in S3C2410A and its conversion accuracy is sufficient.

4) Ethernet interface is realized by AX88796 Ethernet Controller. AX88796 is integrated with embedded 10/100Mbps MAC, PHY and Transceiver and supports different kinds of controller and processor. The address bus SA [9:0] and data bus SD [15:0] are respectively connected to its corresponding bus on CPU, which control the AX88796 work states through NE2000 register by I/O and swaps data by remote DMA FIFOs and internal buffer SRAM of AX88796.

The hardware of embedded control system is shown as follows:

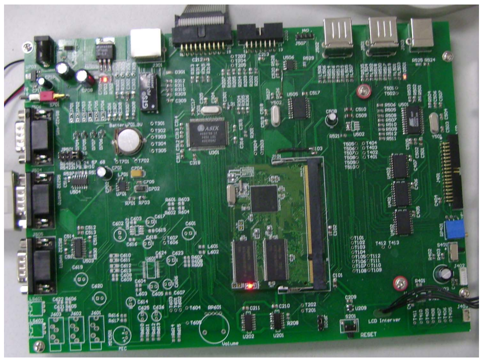

Fig. 5 Hardware of embedded control system

B Hardware Design of Embedded System

(1) Building Software Development Environment

Cross compile is adopted during the software development of embedded system. The development environment includes the host and the target. The host is the PC with linux OS, realizes the edit and cross compile of the program and builds the executable binary program which can run on the ARM system, then, the executable binary program is downloaded into the flash of the target through Ethernet, USB or other ways. The online debug of the target program is carried out by GDB, GDB server and NFS.

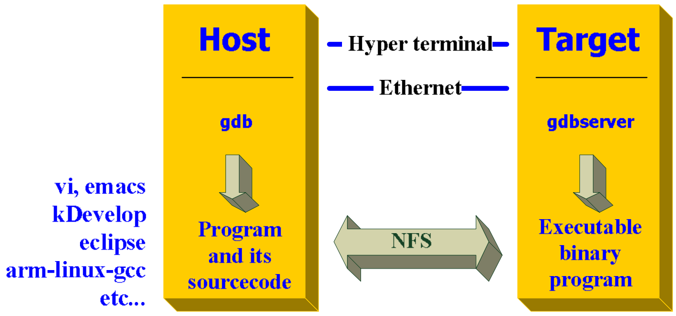

Fig. 6 Development environment of embedded linux

(2) Acquisition of 3D data

3D data is acquired by DSP module and is pretreated by FPGA module (includes data filtration, data mending, coordinate transformation, etc.). ARM main control system gets the 3D data processed by FPGA module. The communication mode between these modules is CAN bus.

There is no CAN controller in S3C2410A. The data is transmitted and received through MCP2510 CAN controller. MCP2510 wholly supports the CAN bus V2.0A/B technical standard. It includes three transmit buffers and two receive buffers that reduce the amount of microcontroller management required. The CPU communication is implemented via an industry standard Serial Peripheral Interface (SPI) with data rates up to 5 Mb/s.

The CAN controller consists of three parts:

1) The CAN protocol engine.

It is used to transmit and send the message on the data bus.

2) The control logic and SRAM registers that are used to configure the device and its operation.

3) The SPI protocol block.

CPU is connected with CAN controller via SPI and reads or writes the register by SPI command. The protocol includes three functions:

1) CAN SPI Interface Function
2) CAN Message Transmit Function
3) CAN Message Send Function

The programming of SPI in S3C2410A is to operate the SPI register. SPI functions are programmed to realize the data communication.

1) SPI initialization Function
2) Transmit Data Function
3) Send Data Function

These interface functions is realized through the call of device drive programs. The main control system gets 3D data from CAN bus in the rate of 80KB/s and provides the 3D data for the 3D construction.

(3) 3D reconstruction on RTLinux OS

1) The realization of RTLinux (hardware real-time)

RTLinux is an open source multi-task OS with hardware real-time character. It is the result of improving the linux system in the bottom of the kernel by adding a preemptive real-time kernel between linux kernel and hardware and using the standard linux kernel as a process of real-time kernel to be called as same as a user process. The PRI (priority level) of standard linux kernel is the lowest and can be interrupted by real-time process. The normal process is also can be run on linux kernel. With this method, the real-time system can work as standard linux to provide kinds of services, as well as providing real-time OS environment.

The hardware real-time property of RTLinux is realized by interrupt mechanism. In RTLinux system, a software simulation layer is added to intercept all hardware interrupts between linux kernels and interrupt control hardware. These interrupts is divided into two parts, linux interrupts and real-time interrupts. When RTLinux receives real-time interrupt, it will send the interrupt to the hardware. When RTLinux receives nonreal-time interrupt, it will judge that if linux kernel will mask the interrupts or not. If the interrupt is masked, the request of this interrupt will be passed. By contraries, the request of this interrupt will be disposed by linux kernel. From this principle, we can conclude that the mask interrupt of linux program cannot stop the happen of real-time interrupt and the delay time of interrupt realization is fully decided by the processing rate of real-time kernel.

2) 3D reconstruction on RTLinux OS

Mesa3D Library and GLUT are adopted for 3D reconstruction on RTLinux OS. With these two tools, high-performance graphic programs can be developed on linux system.

Mesa3D is the most popular and extensive realization of OpenGL on linux system. Mesa3D is open-source software and almost provides the same API as OpenGL [10]. For the transportability, OpenGL just provides 3D graphic library Application Programming Interface, without functions for drawing windows, receiving message, processing message, etc [11]. Thus the third-part development tool is needed to develop the OpenGL programs. The most normal tool for graphic development used in linux is GLUT, which can build the OpenGL windows, process the operation, build pop-up menu, etc. Like OpenGL, GLUT can be transported in kinds of OS. As the power-full functions and excellent performance, GLUT has become one of the standard kits of Mesa3D.

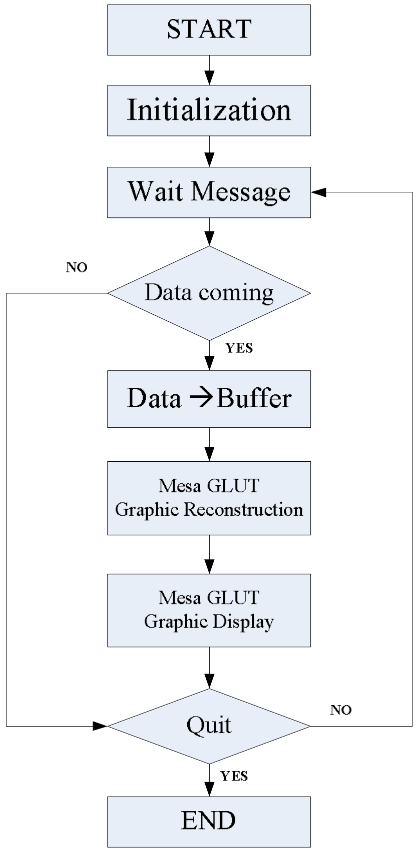

Fig. 7 Flow chart of 3D reconstruction

IV. EXPERIMENT

With Mesa3D and GLUT in embedded RTLinux system, we get the point cloud figure of the surrounding 3D environment. The figure rate is about 3s per frame by driving motor. The experiment result indicates the performance is very good.

Fig. 8 The real 3D environment

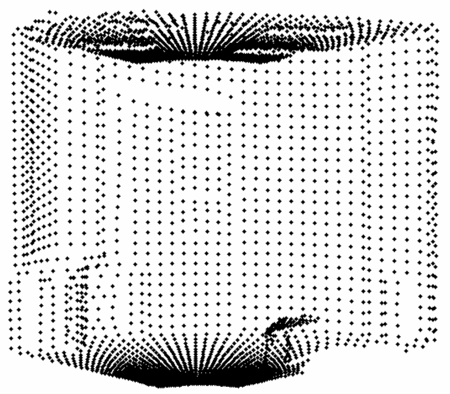

Fig. 9 Point could of 3D environment (front view)

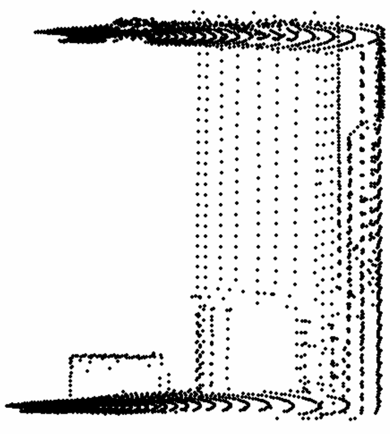

Fig. 10 Point could of 3D environment (side view)

V. CONCLUSION

Through the design of embedded system for mobile robot technology based on laser range, this paper transplants RTLinux which has hardware real-time character into ARM architecture and uses this system in the mobile robot research filed of laser range 3D reconstruction. This paper establishes the technology theory for mobile robot self-localization and navigation in the future work. The system in this paper combines the strong points of multi-task embedded system, great processing ability, hardware real-time character, low cost, good expansibility, etc, and can response to the control interrupt program well. With this system, the control effect of mobile robot is greatly improved compared with the traditional PC. Along with the deep research of this technology, the system combined with ARM and RTLinux will be a good scheme for mobile robot self-localization and navigation technology.

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