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Design of Control System for EOD Robot Based on Embedded Linux

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Abstract. The explosive ordnance disposal robot (EOD robot), refers to the robot which can conduct reconnaissance, disposal and handling of the explosives at the scene of the accident as a substitute under the circumstances which are not allowed or suitable for human’s appearance; it can also attack terrorists effectively. It is important to improve the power of antiterrorism and to safeguard the state development of politics and economy.
We introduce the implementation of control system based on the ARM9 microprocessor S3C2410 for our EOD robot in this paper. According to the robot’s hardware design, embedded Linux operating system is selected as the platform of the software development. The embedded control system can achieve many tasks of the robot, such as motion control, suspicious objects searching, explosive ordnance disposal, communication with the remote control system and executing complex control algorithms.

Keywords: EOD robot; control system; embedded Linux; teleoperation

1. Introduction

With the development of robotics technology, the application of robot has been extended more and more widely. The robot is required not only to complete some large-scale assemblage tasks in work, but also to achieve complex missions. The explosive ordnance disposal robot (EOD robot), refers to the robot which can conduct reconnaissance, disposal and handling of the explosives at the scene of the accident as a substitute under the circumstances which are not allowed or suitable for human’s appearance. The research on the EOD robot began in the 1960s. With the situation of the international anti-terrorism and the deepening of the fight against terrorism, especially after the "911" terrorist attacks, a number of large international companies, universities and research institutes have developed many kinds of EOD robots, for example Wheel barrow, SuperM, Hadrian, TSR200, Packbot, etc.

To protect the safety of the personnel, we develop an EOD robot for the searching and the explosive ordnance disposal of the dangerous articles in the danger zones. Our EOD robot is a ground mobile robot with six tracks as shown in Fig .1. Two main tracks are driver tracks. Two front arm tracks and two rear arm tracks are used to cross obstacles. Four tracked arms make robot be suitable for different terrain environments because robot can move in both tracked mode and legged mode. Having certain autonomy and the ability to go across the bumpy ground of a complex terrain, the robot achieves its strong obstacle-climbing ability through pre-and-post deformation of its arm movements. Five cameras are installed at different places of the robot so the remote operator could have a full view of the robot’s ambient environment and search suspicious objects easily. With the 7-joints long arm, the robot can complete the grasp of 8-10 kilogram objects. A force sensor is attached on the robot’s paw in case the suspicious object is broken by over grasped. Besides, an independent remote restart device is used for restart the robot if it becomes out of control.

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The control system of the EOD robot is based on the ARM9 microprocessor S3C2410 and embedded Linux operation system. The microprocessor features RISC architecture, high performance, low consumption, low cost and rich interfaces. The highest frequency of S3C2410 can be up to 203MHz, thus complex control algorithms can be executed easily. Rich peripheral interfaces make it convenient to communicate with external equipments. Compared with other embedded operating system such as Windows CE, VxWorks, QNX, and HOPEN, Embedded Linux has the advantages of open source code, high reliability, real time ability and scalable kernel.

Figure 1. Explosive ordnance disposal robot at the exhibition

2. The Overall Structure of the EOD Robot

The EOD robot is composed of mechanical institution, control system, motion system, grasping system, communication system, sensor system and power system. The system structure of the robot is shown in Fig .2.

Robot is a six tracks vehicle of which two main tracks are drive tracks. Two front arms and two rear arms tracks are used to cross obstacles. Two DC actuating motors (the power of each motor is 1000W) with reduction gears (the reduction ratio is 60:1), rotary encoders and servo amplifiers are used to drive the main tracks. Four arms are driven by four DC motors (the power of each motor is 400W and reduction ratio is 200:1) respectively so the robot can work in legged mode easily. A 7-joints manipulator is installed in front of the robot to grasp suspicious objects. Four joints of them are driven by pushrods; other three joints are driven by DC servo motors. The redundant DOF long arm can make sure that the end paw can reach any point with any gesture in its reachable range. In addition, there is a pan and tilt head driven by two stepper motors which enables object-searching function through the main camera.

Robot can communicate with remote control system (RCS) through two ways. One channel uses radio transceiver through RS232 interface; the other one is the optical fiber communication system which can transmit serial data signals by RS485 interface and cameras' video image at the same time. Besides, video image signal can also be send by wireless image transmitter whose working frequency is 1.2GHz and communication distance is 1Km in open field.

Sensors system is composed of cameras, electronic compass, GPS, force sensor and voltage sensor. Some of these sensors output analog voltage signal sampled by peripheral A/D converter. Electronic compass is a direction sensor. It can give vehicle direction according to the earth magnetic field. Electronic compass XW-EC1710's precision is 0.5 degree. It outputs data of direction through RS232 and can work in strong ferromagnetism field. GPS is Global Position System. GARMIN GPS 25LP OEM is a kind of GPS product. It can give a longitude and latitude date of vehicle. Precision is 10m.When vehicle can't be seen by remote operator, he can know the position of vehicle approximately. Electric compass and GPS enable the robot work in auto or half-auto mode. In order to measure force of grasp to avoid damage objects, a force sensor is fixed on paw which can control grasp force to a set value. There are 5 cameras attached on robot. One is on robot body front to look picture before robot. One is on robot behind body to look picture after robot in order to move toward behind. One is on a pole of robot body to look picture of environment in order to search and grasp. One is on waist of robot to look explosive nearly.

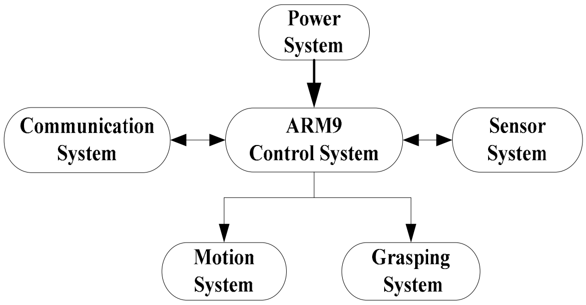


Figure 2. System structure of the EOD robot

The power supply system is Li storage battery. Voltage is24VDC, electric capacity is 200AH. There are 2 sets Li storage batter in order to have more capacity, bigger max current and can be installed easily. It can supply vehicle motionless work 8 hours or move 4 hours. Because voltage of Li storage batter waves from 19VDC~29VdDC, stable voltage blocks are used to stable the voltage at 24VDC. Three stable voltage blocks output is connected together. In order to protect communication system; an assist battery is used to supply power when main power supply is low. Two supply system scan assure normal work of communicate system. The higher voltage of two batteries can supply power to communication system.

3. Robot control system design

The control system which is regarded as the brain of the robot is the most important module of the robots. It gathers the robot's internal and external information, receives commands from the remote control system, and executes complex path planning algorithm and so on. The embedded control system structure of the EOD robot is shown in Fig. 3.

3.1 Hardware design of the control system

With the increasing requirement of high processing speed, real time, multi tasks, and ultra low energy consumption, high-end processors have been attached importance and applied widely. ARM processors based on RISC architecture have been chosen as the main controller of various products for its advantages of high speed, low consumption, low cost and small size and so on.

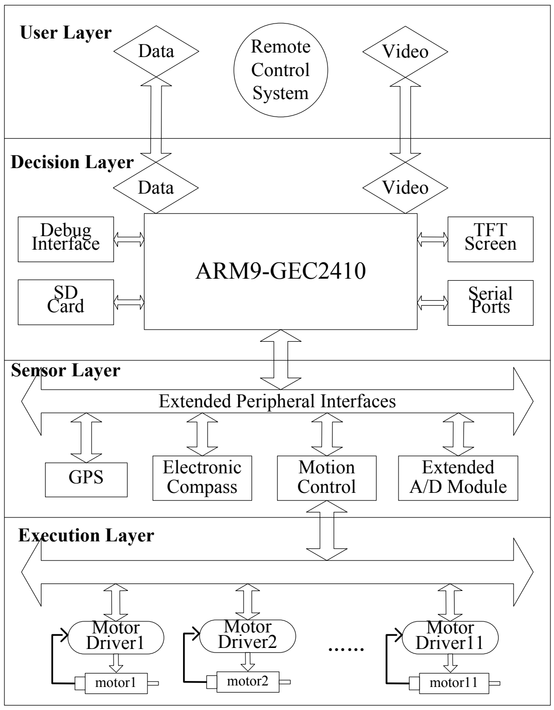


Figure 3. Control system structure of the EOD robot

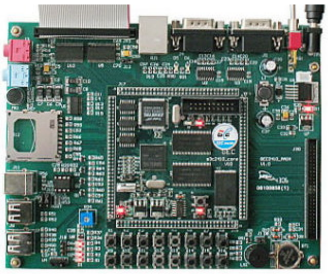


Figure 4. ARM9 development board of the embedded control system

We choose GEC2410 embedded ARM development board as the control core of the robot. Fig. 4 is the ARM9 development board. The board has rich peripheral interfaces. The ARM microprocessor has three UART serial ports whose highest baud rate can be up to 115200. COM1 and COM2 are used to communicate with RCS. COM1 is connected to radio transceiver. COM2 is connected to the optical fiber for line communication. Before connected, a RS232/RS485 converter is needed. Because wheels' motors, arms' driver motors and several other motors are driven by motion controllers which work in pulse/direction mode, four timers of the board which can output PWM signals are used to control the nine motion controllers by channel switched.

There are other devices that also need serial port to communicate with the core board, so a serial ports expansion IC GM8142 is selected to expand four standard duplex serial ports. GM8142 communicates with S3C2410 by SPI bus and works in interruption mode. When serial data from any of four ports is received, a low active interrupt signal is triggered and then data stored in the FIFO buffer of GM8142 is read by the microprocessor subsequently. Two MAXON DC motors' motion controllers (EPOS70/10) are connected with each other through CAN open bus while one of them is connected to the extended COM1 of GM8142 and regarded as the gate node. Electronic compass XW-EC1710's information from which we can obtain robot's orientation, roll degree and pitch degree is read from the extended COM2. The extended COM3 is used to receive GPS data. XW-EC1710 and GARMIN GPS 25LP OEM are shown in Fig. 5.

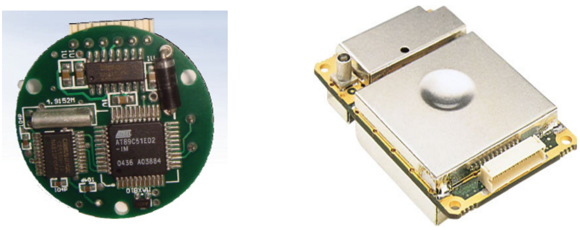
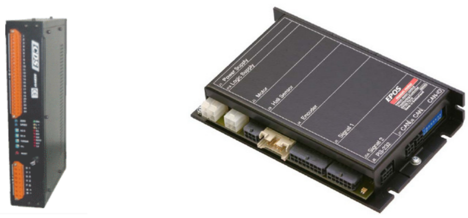


Figure 5. (a) XW-EC1710 (b) GARMIN GPS

Two wrist joints of manipulator use MAXON DC motors. Therefore two EPOS70/10 motion controllers are connected by CAN open bus to driver the two motors. Every EPOS70/10 motion controller is allocated a unique address through 8 DIP switches. All the motion control commands from the control board arrive at the gate node first. If the command frame is sent for itself, the gate node will process it immediately and then sends back the responding data frame, else the command frame will be sent to the corresponding node. After the command is processed, the responding data frame is sent to the gate node and then transmitted to the control board by the gate node. The data transmission between motor drivers are depended on the CAN open bus and the highest speed of communication can be up to 1Mbps. Fig. 6 shows the motion controllers of motors used for robot.



(a) (b)

Figure 6. The motion controllers: (a)CDS-CUF (b)EPOS70/10

Two stepper motors used to drive pan and tilt head work with two-phase stepper motor drivers. We choose the SYNTRON SH-20402N drivers which feature constant phase current control, high reliability and low cost. It is also controlled by PWM signals. A pulse signal and a sign signal are basically needed to make the motors run. The driver, motor and wire-connecting sketch map is shown in Fig. 7 and Fig. 8.

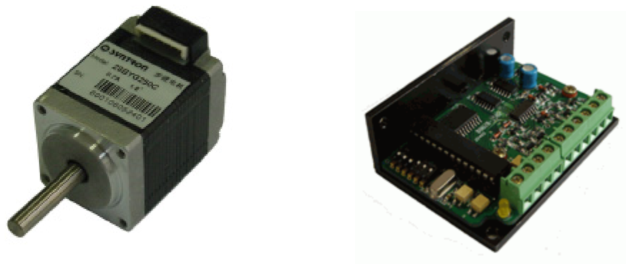


Figure 7. (a) stepper motor (b) SH-20402N

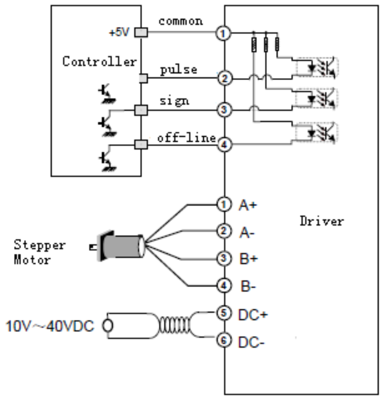


Figure 8. The typical wiring of stepper motors

There are force sensor and battery voltage that need to be sampled by microprocessor. 11 analog input channels A/D converter TLC1543 is used to gather these sensors' information. TLC1543 is CMOS 10-bit switched-capacitor successive-approximation analog to digital converter. It has three digital inputs and a 3-state digital output (chip select, input-output clock, address input and data output). So the SPI1 interface of S3C2410 is used to read the converted results of the analog inputs.

When the operation arm is used, several I/O ports are needed to control the joints' DC motors by bridge circuits. Because the I/O ports provided by the extend interface of the development board are not enough, three I/O expanders (PCF8574) are used to expand another three ports through IIC bus. PCF8574 is a silicon CMOS circuit that can provide general purpose remote 8-bit I/O port for microcontroller via the two line bidirectional bus (IIC bus). It can be addressed by three hardware address pins so that as many as eight devices can be extended through the two line bus if needed.

Furthermore, the LCD and touch screen can be used to display the status information of the robot and diagnose faults when robot is working abnormally. Status information such as running speed, angles of arms, gestures, force intensity, battery voltage and communication status is updated in time and inquired at any time.

3.2 Software design of the control system

Based on the developing board, several operation systems are feasible. For example, open source Linux, Microsoft's WinCE and uCOS are most often used as the software platform. Linux is a time-sharing multi-tasking open source operating system which has the advantages of stable, reliable, safe, easily tailoring and strong network function. Based on the consideration of these features of Linux OS and technical requirements of the control system, embedded Linux OS is selected as the software platform on which we can develop applications of the control system.

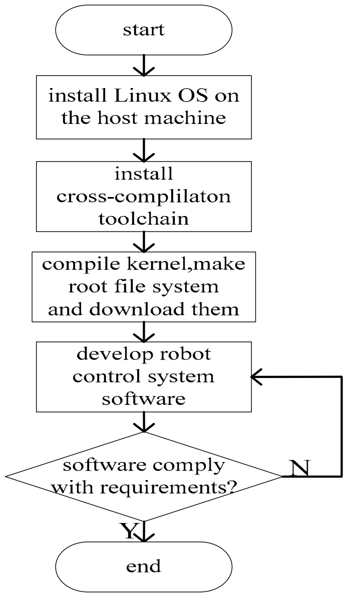


Figure 9. Steps of software development

1) Steps of the Software Development: First install Linux OS such as Redhat or Fedora core on PC. If not, virtual machine software VMware-WorkStaion can also be installed on the host PC and then install Linux OS mentioned before. Second, we need install cross-compilation toolchain which is made up of binutils, gcc, glibc and kernel-header; compile the kernel of ported Linux OS and make cramfs root file system. Third, we download the vivi bootloader, kernel and file system to the ARM board' nand flash. Thus, the software development environment has been fully established. Finally, we can develop program for control system of the robot, compile it on the cross-compilation platform and download it to the board for running. The flow chart of robot's embedded control system software development is illustrated in Fig. 9.

2) The Implementation of Robot Control System Software: When power is up, several peripheral devices' driver modules, such as GM8142, TLC1543 and PCF8574 are installed and then these hardware devices can be read and writen like normal files in the user's program. In the process of the main function, the whole task of robot is divided into several child processes (CPes). These child processes communicate with each other through message queue mechanism. Once these child processes are created, the main process creates a timer and waits for a long time to kill them and deletes the message queue from the Linux kernel. Fig. 10 shows the flow chart of the device drivers of GM8142, TLC1543 and PCF8574.

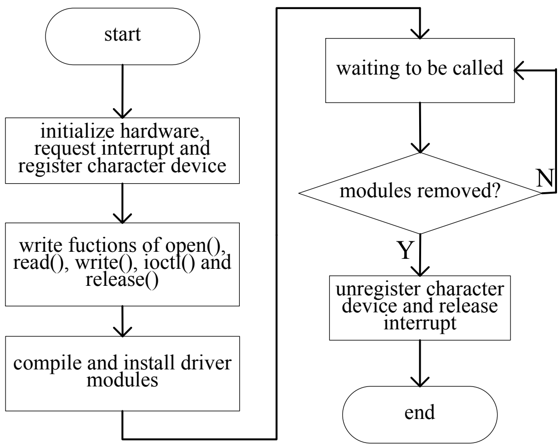


Figure 10. Flow chart of the device drivers

Now have a look at the detail task of these processes. In the main process, a message queue that is used to exchange information between child processes will be created first. If a message queue is already existed, it will be deleted from system kernel to clear junk data and then a new message queue will be created. And then receive CP, send CP, dispatch CP, GM8142 CP, TLC1543 CP, PCF8574 CP and LCD_TS CP will be forked sequentially.

Receive CP mainly listens to two serial ports all the time. Whenever there is a command frame from the RCS, it will be resolved and a corresponding message will be sent to the dispatch CP. Send CP does the work of retransmitting messages that come from other CPes to RCS through the same channel as the receive CP uses. Dispatch CP receives message from the receive CP and dispatches tasks to corresponding CPes. GM8142 CP initializes the four expanded serial ports at the beginning. On one hand, it receives messages from dispatch CP to control MAXON motion controllers through expanded COM1; on the other hand it reads electronic compass's information through expanded COM2. Once information is received, it will be sent to the send CP and LCD_TS CP immediately.

TLC1543 CP and PCF8574 CP are similar to each other. They both operate device files through API provided by device drivers to contact with hardware devices as well as communicate with other CPes through the message queue that created by the main process. TLC1543 CP mainly acquires data of force sensors and battery voltage through SPI1 interface. PCF8574 CP controls the optional manipulator' joints' motor by the expanded remote GPIO ports. LCD_TS CP mainly displays robot's status information and is used to debug program through touch screen. It displays robot's status information in different windows. Besides, the robot can be diagnosed in the visible environment if there is any problem.

4. Experiments

We have done many experiments to test the performance of the EOD robot, such as its movement ability, objects grasping ability, water-proof, sand-proof, shock-proof and system working reliability in various cases. Fig. 11 and Fig. 12 show experiments of the EOD robot.

Figure 11. Robot is climbing the riverbank

Figure 12. Robot is working in city environment

The experimental results show that the robot can basically do the job of EOD robot. The embedded control system based on ARM processor and Linux OS is stable, robust and reliable.

5. Conclusion

The EOD robot is designed to help people dispose suspicious explosive ordnance under the circumstances which are not allowed or suitable for human's appearance. To address the special requirement, six tracks vehicle structure is adopted to enhance movement ability of the robot in the complex environment. Water-proof, dust-proof and shock-proof design are also important features of the robot.

The control system based on the ARM9 microprocessor S3C2410 and embedded Linux designed for the robot has the features of stable, robust and reliable. Hardware design of the control system has the advantages of scalability, flexibility and low consumption. Several peripheral devices are extended to enhance system performance through interfaces of the development board. As the platform of software development, embedded Linux OS has the advantages of scalable kernel, multi-user, multi-tasking and strong network function.

Various experiments prove that the EOD robot with the control system based on embedded Linux can basically meet the requirements of executing tasks of dispose suspicious dangerous objects.

6. Acknowledgment

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