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# Industrial Safety

[Write some stuff here about OSHA and NIST] [CITE Marvel]

## Emergency Stop System

Mobile robots, particularly experimental platforms, require safety systems to disable them. These systems, often called emergency stop or e-stop systems, cut power to the robot actuators on command or if certain safety conditions are met.

### E-Stop Systems Used in This Lab

The Case Mobile Robotics Group has used a few emergency stop systems in its robots. All of the HARLIE-class robots developed for the Intelligent Ground Vehicle Competition used a commercially-available wireless relay system from Remote Control Technologies. This system, shown in FIGURE, consisted of the remote control relay in series with an onboard disable switch and a second relay switched by an active-high enable signal from the cRIO, which is software-controllable. These three switches (one manual and two relay) control the current through the coil of a solenoid, which in turn switches the power to the motor controller on and off. This system has one critical flaw, which is that there is no “heartbeat” from the wireless remote to the remote control relay. This means that if the battery in the wireless remote dies or the radio communication is lost between the wireless remote and the robot, there is no way to remotely stop the robot, nor is there any indicator to the operator that the robot cannot be wirelessly stopped.

OTTO the smart wheelchair used a custom remote mode switching system designed to interface with the Arduino-based control system used to control the wheelchair drivetrain. Using a pair of XBee 2 Pro wireless network modules, a GPIO signal is transmitted from a remote control unit to the input of an Arduino on the wheelchair, disabling the autonomous functions of the wheelchair when a button is pushed on the remote. Because the Xbee wireless modules' GPIO mirroring has a programmable timeout and default output state, this system automatically disables autonomous functions if communication is lost between the remote and the robot. However, this system does rely on an Arduino microcontroller and was not designed as an emergency stop system, but as a switch between autonomous operation and normal (joystick) operation of a wheelchair.

### E-Stop Requirements for This Robot

This robot has several requirements that motivated the development of a new emergency stop system combining the merits of the HARLIE-class stop system and the OTTO remote switching system. First, the emergency stop system needs to be able to switch the high current, 24 volt rail providing power to the motor controllers. Second, the system needs to be able to activate the 24 volt emergency stop input on the IRC5 robot controller, which must be electrically isolated from the rest of the robot's DC electronics. Third, the system must monitor four sources, stopping the actuators if any of them are disabled:

1. 5 volt active-high enable signal from the cRIO, which is controlled by the ROS software
2. 24 volt active-high emergency stop signal from the IRC5, which is controlled by the emergency stop switches on the IRC5 and FlexPendant and by RAPID software.
3. Twist-lock stop switch mounted on the robot (The robot is disabled if the switch is opened or disconnected.)
4. Wireless remote control with a heartbeat signal of at least 1Hz

Fourth, the system should be implemented entirely in hardware for safety reasons. Software faults in a safety system are unacceptable and adequate testing of a software system would be too time-consuming for this project. Fifth, the remote control unit should have some feedback as to the state of the four emergency stop sources described above.

### Version 1 Prototype

Given the requirements, an emergency stop system was designed and fabricated using printed circuit boards. The schematic of the system is shown in FIGURE. The system consists of two circuits, a remote control and an emergency stop circuit on the robot.

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The remote circuit uses an XBee radio module's GPIO mirroring function is used to transmit the state of the emergency stop button to the emergency stop circuit on the robot in the same manner it was used on OTTO. This system also uses the GPIO mirroring function to send the states of the other emergency stop sources to the remote, where they are displayed on LEDs. Because a twist-lock style emergency stop button was not available, an S-R latch was used to latch the state of a normally-open momentary pushbutton, requiring that the remote be powered off and back on again to reset the wireless emergency stop.

The emergency stop circuit on the robot has inputs for the onboard emergency stop button, the cRIO's enable signal, and the emergency stop output of the IRC5. The input from the IRC5 goes into an optoisolator IC because the IO on the IRC5 is floating relative to the rest of the robot's DC systems. A 7400 series AND IC is used to generate logic signals to enable the drive base and the IRC5's emergency stop input. The drive base logic signal controls a Darlington transistor, which in turn switches the coil of a solenoid that controls the drive base in the same manner as on HARLIE-class robots. The IRC5 output logic signal switches the 24v General Stop input of the IRC5 using an optoisolator IC.

These circuits were prototyped and installed on the robot. The input from the IRC5's emergency stop was defeated by installing jumper J1 because the output had not been configured in RAPID software. Additionally, testing showed that the 4N35 optoisolator used to switch the IRC5's emergency stop could not switch enough current to enable the emergency stop circuit, causing the IRC5 to go into General Stop mode seemingly at random. This function was defeated by disconnecting the IRC5   
Stop output and shorting the General Stop input of the IRC5. These two changes completely decouple this emergency stop circuit from the IRC5, meaning it no longer meets requirements 2 and 3b described above. Furthermore, the wireless link between the XBee modules proved unreliable, causing the system to momentarily switch into emergency stop mode seemingly at random. Extensive bench testing of the system suggests that this problem is caused by an insufficiently reliable power supply to one or both of the XBee modules. In order to make the system usable, the wireless emergency stop was replaced with a twist-lock style emergency stop button on a ten foot wired tether. This modification means that the system no longer meets requirements 3d and 5 described above. The system does reliably control the power to the drive base, providing a level of safety for the robot, but revisions are required to make the system function as specified.

### Version 2 Design

A revised version of this emergency stop circuit was designed and portions of it prototyped, but it has not been tested. This version should fix the problems discovered in the first version of the emergency stop.

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To integrate the system with the IRC5, the optoisolator on the output of the emergency stop circuit was replaced with a relay module, which will more reliably switch the General Stop input of the IRC5. To complete integration with the IRC5, the RAPID software must be modified to output the current General Stop state to a GPIO, which must be connected to the IRC5 input of the emergency stop circuit.

To solve the wireless communication issues, the power supply in the remote was replaced with a 3.3 volt boost supply, which should be much more reliable, and bypass capacitors were added to the power rails of the XBee modules on both the remote and the emergency stop circuit. Testing has shown that the XBee modules are reliable when a sufficiently clean and reliable DC supply is available to power them.

In addition to solving the problems described above, some small changes were made to improve the circuit. To reduce the power consumption of the emergency stop circuit and reduce the heat produced by the onboard power regulator, the Darlington transistor used to switch the coil of the drivebase enable solenoid was replaced with a MOSFET circuit that performs the same function. To make the system easier to use and more reliable, the momentary switch and latch used on the previous version was replaced with a twist-lock style emergency stop switch.

Although this system has not been constructed, its constituent parts have been tested individually. The MOSFET switching circuit has been confirmed to work with a resistive load equivalent to the coil resistance of the solenoid used to switch the drive base power rail. The power supply circuit in the remote has been tested and provides a reliable 3.3 volt power supply from a pair of AA batteries. The use of a relay instead of a transistor to control the General Stop input is in line with recommendations from ABB's documentation, and the relay used meets the requirements. If the necessary components can be acquired for this emergency stop circuit, it should be able to meet all of the requirements described above.

## Reflexive halt