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Embedding Radars in Robots for Safety and Obstacle Detection

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Abstract:

A safety system is designed to use small, low-cost radars embedded in joints and end effectors of a robot to monitor an environment for potential safety hazards. In this way, the radars directly detect obstacles with respect to the moving parts of the robot. A safety controller analyzes the obstacle data provided by the radars and determines an appropriate operating state of the robot based on predefined safety requirements.

Keywords: embedded radar, robotics, safety, obstacle detection

Background:

The utilization of robots is limited due to risk of accidental injury and death. Conventional safety systems employ multiple layers of redundant safety gates and emergency stops, which are expensive and not robust. External sensors, such as cameras and lasers, are capable of detecting objects and measuring proximity, but these sensors cannot be embedded in a robot due to size limitations and sensitivity to vibrations. Furthermore, cameras and lasers have additional drawbacks, such as sensitivity to environmental lighting conditions and cost.

Description:

To address this problem, a safety system is designed to use small, low-cost radars embedded in joints and end effectors of a robot to monitor the environment for potential safety hazards. In this way, the radars directly detect obstacles with respect to the moving parts of the robot. An external layer of material, transparent to radar frequencies, is used to house the radars without degrading performance. The radars measure position and velocity of the obstacles and communicate obstacle data to a safety controller. The safety controller analyzes the obstacle data and determines an appropriate operating state of the robot based on predefined safety requirements. The operating state defines the robot's motion to prevent safety hazards. Using embedded radars, the safety system quickly detects changing environments and immediately responds to potential safety hazards, reducing the risk of accidental injury and death. This safety system is accurate, robust, and responsive, allowing the robot to operate efficiently and safely.

Figure 1 depicts an example safety system, which is described in further detail below.

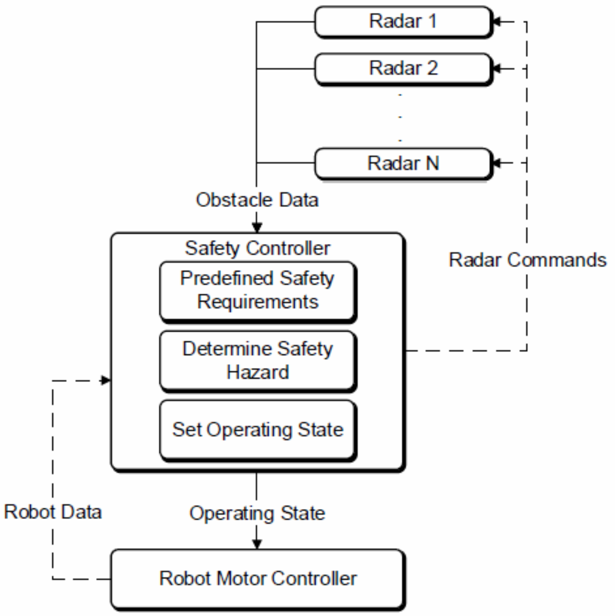

Figure 1

A variety of small, low-cost radars may be used. The radars may produce a variety of radiation fields, including wide fields, narrow fields, shaped fields (hemisphere, cube, fan, cone, cylinder), steered fields, un-steered fields, close range fields, and far range fields. Additionally, the radars may use continuous wave or pulsed Doppler and use a variety of frequencies, update rates, pulse widths, interpulse periods, transmit powers, and modulations. The radars are designed to physically withstand vibrations generated by the robot and may optionally compensate for the vibrations and motions of the robot.

The radars may also be configured in real-time by the safety controller. By sending commands to the radars, the safety controller enables/disables individual radars and commands the update rate, radiation field types, directions, and frequencies. Furthermore, the safety controller may coordinate operation of the multiple radars to focus on a particular potential safety hazard or mitigate interference.

The radars detect nearby obstacles by transmitting radio waves and receiving reflected radio waves. The radio waves are invisible and may be designed to penetrate materials, such as textiles. By measuring range, azimuth, elevation, and radial velocity of the obstacles, the radars compute a three dimensional position and velocity of the obstacles. The radars also predict future positions and velocities of the obstacles based on the measurements. Using the predicted positions and velocities of the obstacles, the radars automatically determine future radiation pattern characteristics to increase a probability of detecting the obstacles. The type of obstacles detected by the radar is customized according to a predefined set of parameters, such as a set of positions, velocities, and/or radar cross sections. Furthermore, the predefined set of parameters may be commanded in real-time by the safety controller.

The radars report obstacle data to the safety controller. The safety controller analyzes the obstacle data according to the predefined safety requirements to determine a potential safety hazard. The safety controller may also use data describing the robot's motion in combination with the obstacle data to determine the potential safety hazards.

The predefined safety requirements define multiple operating states of the robot. For example, in a normal state, the robot operates at intended speeds and/or ranges of motion. In a safety state, the robot operates at reduced speeds and/or limited ranges of motion. In a stop state, the robot ceases all movement. Example operating states are determined for individual joints and end effectors or for the entire robot.

In addition, the safety requirements define when to use each operating state. For example, the normal state is used when obstacles are located in a normal sector, the safety state is used when at least one obstacle is located in a safety sector, and the stop state is used when at least one obstacle is located within the stop sector. Example sectors are predefined as three-dimensional volumes and shapes. In addition, the sectors may be predefined with respect to each joint and end effector of the robot and dynamically change based on a speed and direction of motion of the joint and end effector.

In addition, example safety requirements define a number of obstacles, required characteristics of obstacles, and type of obstacle data used in determining the operating state. Example safety requirements specify different rules for moving and stationary obstacles and specify using measured or predicted obstacle data to determine the location of the obstacle.

Based on the safety requirements, the safety controller analyzes the received obstacle data to determine potential safety hazards and automatically determines the operating state of the robot, joints, and/or end effectors. Based on the operating state, the safety controller sends the necessary commands to control the motion of the robot. Alternatively, the operating state is communicated to a robot motor controller. The safety controller is implemented in software and executed by a processor and may be separate from or included in the robot motor controller.

This safety system is closed loop. The radars continue to report obstacle data to the safety controller based on the update rate, the safety controller analyzes the received obstacle data and determines the operating state of the robot, and the robot adjusts it’s motion according to the current operating state. As such, the safety system is responsive, allowing the robot to operate efficiently and safely.

Example:

Figure 2 depicts an example robot with three joints and three embedded radars.

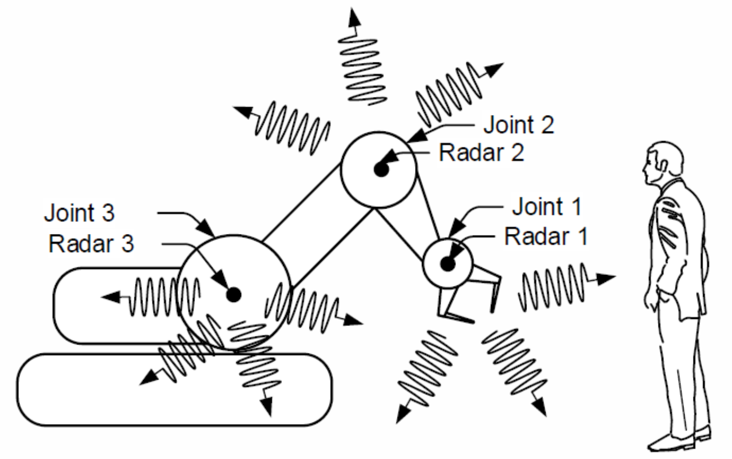

Figure 2

In Figure 2, the radars detect obstacles, such as a person, and report obstacle data to the safety controller. The safety controller determines an operating state of the robot according to predefined safety requirements and based on the received obstacle data. The robot is configured to move according to the operating state determined by the safety controller.

Figure 3 depicts a top-down perspective of the robot in Figure 2 with overlaid safety requirement sectors.

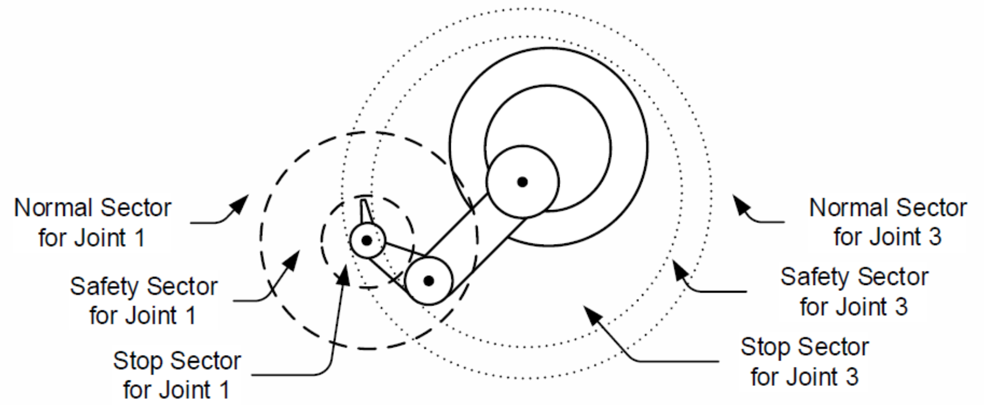

Figure 3

In Figure 3, the safety requirement sectors for joint 1 and joint 3 are with respect to the range of motion of the appendage attached to the joint. As shown in Figure 3, these sectors overlap based on the position of the joints. Additionally, as the robot's joints move, the sectors move in order to keep the joints positioned in the center of the sectors.

Figure 4 shows an example time lapse of the robot's motion.

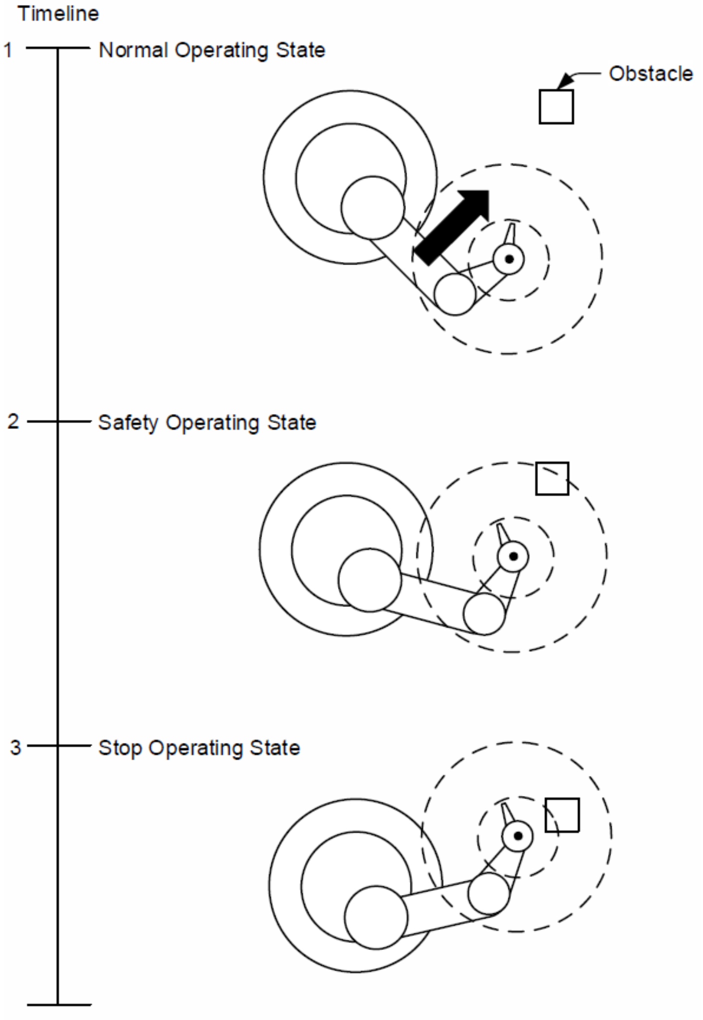

Figure 4

During the time lapse, the radars continually detect and report the obstacle data to the safety controller. For each report, the safety controller analyzes the obstacle data and determines, based on the predefined safety requirements, the operating state of the robot. At time 1, the obstacle is determined to be located in the normal sector and the safety controller sets the operating state of the robot to the normal state. Between time 1 and time 2, the robot moves according to the normal state. At time 2, the obstacle is determined to be located in the safety sector and the safety controller sets the operating state of the robot to the safety state. Between time 2 and time 3, the robot moves according to the safety state. At time 3, the obstacle is determined to be in the stop sector and the safety controller sets the operating state of the robot to the stop state. In the stop state, the robot ceases all movement and the radars continue to monitor the environment. The radars detect when the obstacle moves into the normal operating sector and the safety controller responsively sets the robot's operating state to the normal state.