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Embedding Radars in Robots to Accurately Measure Motion

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Embedding Radars in Robots to Accurately Measure Motion

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Abstract:

A motion correction system is designed to use small, low-cost radars embedded in joints and end effectors of a robot to measure motion of the robot. In this way, the radars directly measure the robot's motion and relative position and velocity with respect to a target. A motion correction controller analyzes the motion data provided by the radars and determines an amount of motion correction required to accurately position the robot.

Keywords: embedded radar, robotics, accuracy, measuring motion, motion correction

Background:

In order to interact with objects in an environment, robots need to determine locations of their end effectors. Due to drift errors in robotic motors, measurements are needed to determine the actual position and velocity of the robot. Conventional motion measurement systems use mathematics based on measurements in the robot's joints. However, these measurements are only accurate to hundreds of microns. External sensors, like cameras, may be used, but these sensors cannot be embedded in a robot due to size limitations and sensitivity to vibrations. Furthermore, cameras have additional drawbacks, such as sensitivity to environmental lighting conditions.

Description:

To address this problem, a motion correction system is designed to use small, low-cost radars embedded in joints and end effectors of a robot to measure motion of the robot. In this way, the radars are able to directly measure the robot's motion and relative position and velocity with respect to a target. An external layer of material, transparent to radar frequencies, is used to house the radars without degrading performance. The radars report measured motion data to a motion correction controller. The motion correction controller compares the measured motion data to expected motion data and determines an amount of motion correction to apply (if any). Using embedded radars, the motion correction system accurately measures the motion of the robot and quickly provides motion corrections, allowing the robot to be accurately positioned within tens of microns. In addition, the motion correction system provides a robust closed-loop system, allowing the robot to operate efficiently.

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

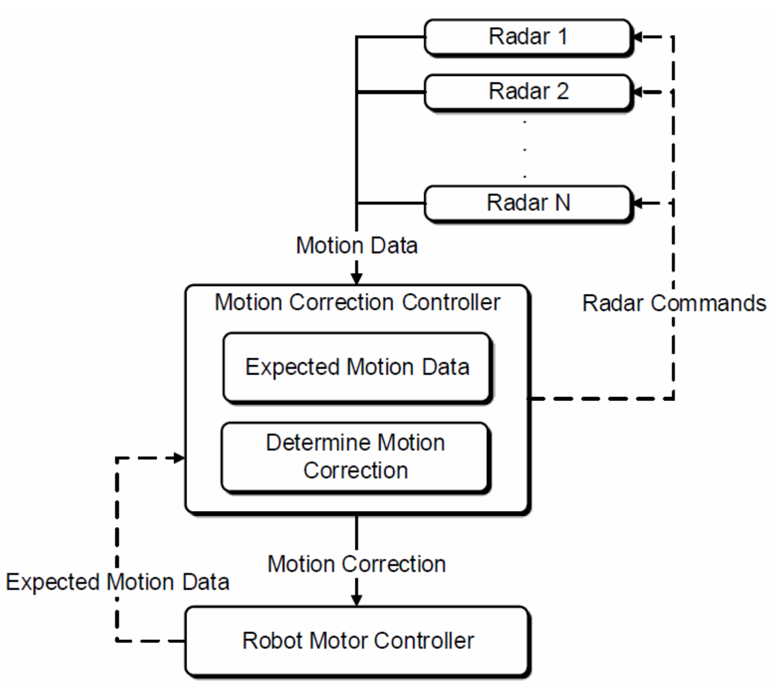

Figure 1

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 power, 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 motion correction controller. By sending commands to the radars, the motion correction controller enables/disables individual radars and commands the update rate, radiation field types, directions, and frequencies. The update rate of the radars may be commanded based on the robot's motion and proximity to the target. In this way, the controller increases the responsiveness of the motion correction system.

The radars measure motion data of the robot by transmitting radio waves and receiving reflected radio waves. Example motion data includes position and/or velocity of the individual joints, angle and rotation rate of the robot's appendages, and relative position and/or velocity of the robot with respect to the target. Furthermore, the type of motion data may be commanded in real-time by the motion correction controller.

The radars report the measured motion data to the motion correction controller. The motion correction controller compares the measured motion data to expected motion data. The expected motion data is determined by the motion correction controller based on commanded motions of the robot or provided to the motion correction controller by a robot motor controller. The controller compares the measured motion data to the expected motion data and calculates an error. Based on the error, the controller determines a motion correction and reports the motion correction to the robot motor controller. The robot motor controller adjusts the robot's motion based on the reported motion correction effective to re-align the robot's motion with the expected motion data. Example motion corrections include corrections to location, speed, and direction of motion. The motion correction controller is implemented in software and executed by a processor and may be separate from or included in the robot motor controller.

The motion corrections are applied in real-time as the robot is moving, allowing the robot to efficiently approach the desired position. As the robot continues to move, the radars continue reporting the measured motion data, the controller continues determining motion corrections and the robot motor controller continues applying the motion corrections. This motion correction system provides a closed loop solution, allowing the robot to be accurately positioned.

Example:

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

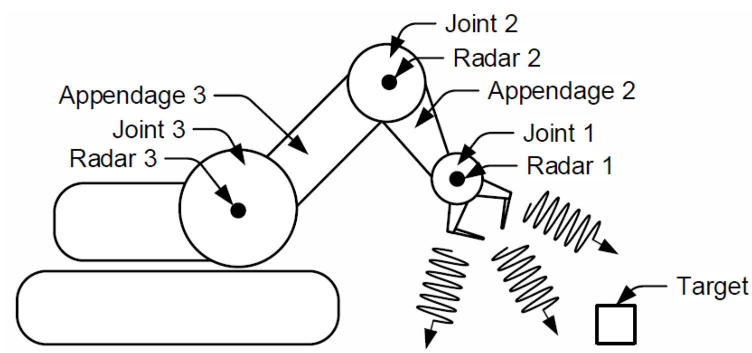

Figure 2

In Figure 2, the radars measure motion data of the robot and report the measured motion data to the motion correction controller. The motion correction controller uses the measured motion data to determine motion corrections. The motion correction controller reports the motion corrections to the robot motor controller. The robot motor controller applies the corrections to accurately position the robot. In Figure 2, radar 1 periodically measures a relative position and velocity of joint 1 with respect to the target. The motion correction controller evaluates the measured motion data and determines the motion corrections. If the measured motion data from radar 1 shows that joint 1 is too far to the left, the motion correction controller determines a motion correction that will move joint 1 to the right. As another example, radar 2 measures the angle between appendage 2 and appendage 3 and the motion correction controller compares this angle with respect to a commanded angle. If the measured angle is too small, the motion correction controller determines a motion correction that will increase the angle.

Figure 3 depicts the robot moving to pick up the target.

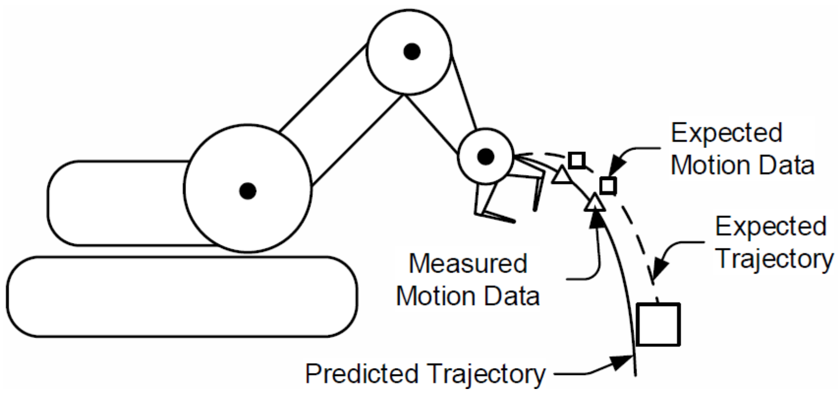

Figure 3

In Figure 3, the motion correction controller computes an expected trajectory of the robot. However, as the robot moves, unexpected errors and drifts in the motors cause the robot's end effector to deviate from the expected trajectory. The embedded radars report measured motion data to the motion correction controller, which shows the actual trajectory of the robot. The controller determines errors between the measured motion data and the expected motion data. The controller computes a predicted trajectory of the robot based on the measured motion data and a expected trajectory of the robot based on the expected motion data. By comparing the predicted trajectory with the expected trajectory, the controller determines the necessary motion corrections to cause the robot's end effector to be correctly positioned at the target. The motion correction controller reports the motion corrections to the robot motor controller. The robot motor controller applies the motion corrections and the robot is accurately positioned to pick up the target.

Figure 4 depicts an example robotic hand.

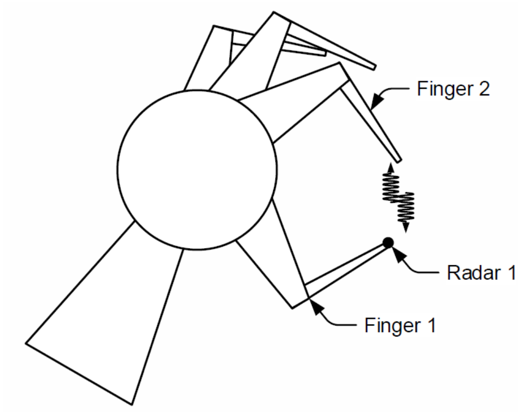

Figure 4

In Figure 4, the robotic hand includes an embedded radar in finger 1's tip. The robot is commanded to touch the tip of finger 1 with the tip of finger 2. The embedded radar is configured to measure the motion of finger 1's tip with respect to finger 2's tip. The radar reports the measured motion data to the motion correction controller. The motion correction controller uses the motion data to determine required motion corrections. The motion correction controller reports the motion corrections to the robot motor controller and the robot motor controller applies the correction to the robot's motion. As finger 1 moves closer to finger 2, radar 1 continues to report the motion data, the controller continues to determine the motion corrections, and the robot motor controller continues to apply the motion corrections. Through continuous adjustments as needed, the motion correction system modifies the movements of the robotic hand that eventually cause finger 1 and finger 2 to touch.