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Multisensor System for Safer Human-Robot Interaction

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***Abstract* – The development of a system for automatically locating and tracking a human in the vicinity of a robot is described. The system consists of multiple passive infrared (PIR) sensors, two color cameras, a pair of microwave sensors and a pair of PCs for data collection, signal processing and data fusion. The cameras are treated as individual sensors rather than a stereo pair to minimize the affect of occlusion by the robot. The area around the robot is subdivided into an occupancy grid with 0.5m by 0.5m cells. A data fusion algorithm, based on Dempster-Shafer evidence theory, is used to estimate the probability of human occupancy for each cell. This information is used to estimate the human's location. A novel concept termed a "protective cell" is introduced to further increase the human's safety in the presence of sensor uncertainty. Experimental results are included demonstrating the system's effectiveness.**

***Index Terms* – data fusion, human-robot interaction, human tracking, multisensor system, robot safety.**

I. Introduction

In industry today, robot manipulators are separated from workers by physical barriers or sensor curtains to protect worker safety [1]. If these robots were able to locate and avoid humans the safe environment could be maintained and expensive factory floor space could be saved. To enable future robots in manufacturing, service and personal applications to work more co-operatively with humans, the abilities to distinguish humans from inanimate objects and to locate and track the positions of humans nearby will be necessary.

Most research on human tracking and locating has been limited to computer vision-based systems, e.g. [2,3]. However, occlusions and sensitivity to lighting conditions make vision systems too unreliable for the human-friendly robot application. Multisensor systems are able to perform human tracking more quickly and reliably. Due to the capability of passive infrared (PIR) sensors to distinguish human(s) from a cluttered environment, and their insensitivity to lighting conditions, several researchers have chosen to use PIR sensors in their tracking systems. In [4], a sensor network is built using PIR motion sensors and an infrared camera. However, the cost of the system is relatively high and the human locating is not accurate. In [5][6], a sensor system consisting of a stereo vision system, two microphones and several PIR sensors is implemented for face tracking. While the use of multiple sensors produced substantial benefits, in their experiments the tracking still failed roughly 30% of the time. A higher reliability is required when human safety is at risk.

In this paper, a human locating and tracking system that integrates PIR sensors, microwave sensors and color cameras is presented. The system is suitable for a robot whose work volume is limited (i.e. one with a fixed base or with a mobile base with a small movement range). The floor area near the robot is subdivided into square shaped cells. The sensing objective is to determine the cell occupied by a human. This world model is known as an occupancy grid and was used with the neuro-fuzzy robot safety system simulated in [7]. The reported location is quantized by the cell size but is sufficient for robot collision avoidance and preserving the human's safety. A data fusion algorithm is employed to fuse the uncertain sensor information and to estimate the likelihood of each cell being occupied. To increase the human's safety, the concept of a "protective cell" is introduced. Experimental locating and tracking results are presented, and conclusions drawn.

II. System Structure

2.1 Sensor Selection and Arrangement

There are many kinds of low-cost sensors that could be employed in a multisensor human tracking system. Some sensors give range data that can be used to detect object presence, such as ultrasonic sensors and vision systems. Other sensors, such as PIR sensors and microwave sensors, provide an on/off signal when movement is detected inside their coverage zones. Our vision system will be discussed in Section 2.2.

Ultrasonic sensors can measure the distance of the object from the sensor, however they cannot distinguish humans from other objects and are significantly affected by geometric parameters of objects including surface, size, angle, etc. Based on preliminary experiments with a Devantech model SRF04 ultrasonic sensor, they work best for flat surfaced objects and are not reliable enough for the human-friendly robot application.

Microwave sensors are reliable for detecting motion but cannot distinguish between humans and non-humans. In this system, two microwave sensors (MS SEDCO model D38) are adopted to monitor the two areas where people can enter/exit the occupancy grid. These sensors are used as a redundant measure of the occupancy/vacancy of the grid to enhance the human's safety. They are not part of the data fusion used to locate the human within the grid.

PIR sensors measure infrared radiation and can detect moving warm-bodied targets but not stationary