Recognition of Moving Objects Using Sensor System for Robot Teamwork

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Abstract

Robots are used more and more in industries; it inevitable that that they are going to share the same environment in which humans work. The aim of this research is to sense and recognize the human or any other moving object that appears in it the working envelope of the robot and to calculate the precise location and direction of motion of the human or object. An approach has been proposed, to collect the precise information about the position and movement of the human or object, with the help of multiple sensors data fusion. This information about the location of human or object is then used by the Intelligent Robot Controlling System (IRCS), which controls the movement of robot, to recognize new obstacles in path of movement of robot and modify trajectory accordingly. This would make human and robot interaction safe in shared workplace and can be used for cooperate with each other on some manufacturing of assemble process to work in an efficient manner.

Keywords: robot, human-robot interaction, coordination, path adjustment, space motion, virtual reality

1. Introduction

People are working in shared human-robot spaces. According to the World Robotics Organization [1], approximately industrial 174,600 robots were in operation throughout North America in 2010, after significant increase of 33 percent, with annual rate of 9 percent increase for the following three years and beyond. There is exponentially increase of the number of robots in industry, households, children’s toys, and space and sea exploration is increasing. Worldwide industrial robots in operation are 1,027,000. In addition, one of the fastest growing groups of robots are service robots: domestic use - 5.6 millions and entertainment and leisure use - 3.1 millions for 2009.

At present the existing industrial practice is to keep humans and robots completely separate. Each robot is placed inside a metal cage to keeps people away and safe. Safety can also be provided by a so-called three-level safety system that includes a light curtain, pressure mats, and ultrasonic sensors. The existing systems provide safe workplace by eliminating any close contacts between humans and robots is based on technological assumptions from the last century. Most robots used in daily life already use the newest technologies (sensors, computers and software) to provide safe work-at-home and services sector. Therefore the application of robots in industry needs to be modernized to be able to perform in human presence and to collaborate with them.
Most of robots used today in industry do not have much intelligence in sensing and computing capabilities, but new robots shall be able to react and adjust to any changes in their environment in real-time; thus working together with humans is shared space should be safe and possible.

At present robots are not only replacing human in attaining difficult tasks, but also they can pose new risks to workers. For example, while a robot may appear to be idle a remote signal may cause sudden motion, which may lead it to change its path and respond to a change in conditions [2]. Existing robot with their control systems can harm the human or objects which are in the working space of the robot. So for the robots to be able to work effectively in a human environment they should have clear perception of the environment in which it operates. They should extract enough information about the environment, so that it can interact with human that are present in the surroundings of the robot. We have proposed an approach, with the help of sensors data fusion in collecting the information of the human present in an environment. The main aim is to detect, recognize the human present in the sensing range of the robot.

1.1 Application of Sensors in Robots

To make robots to work effectively and to perform assigned tasks in human environment, there is a need for comprehensive information about surroundings that can be supplied by multiple sensors. The environments in which sensors operate can produce broad range information such as temperature, humidity, light levels, and change in position. Therefore sensing any changes in the environment the robot controller shall be able to modify the motion path.

For the robot completing an assigned task is important, while at the same time it should ensure the human safety. Sensors are being developed to meet this need by making robot systems adaptive and intelligent. This can be attained by obtaining information about the robot’s workplace and the object present in the environment.

1.2 Using Virtual Reality for robot simulation and control

The rationale for choosing virtual reality (VR) is its unique features and flexibility. A 3-D virtual environment [3] includes a map of the environment such as the walls etc., the location and orientation of the robots, which are marked with panoramic images, and the virtual location of the other users present in the system. The user is not only able to explore the environment, but also to control the robots to ensure that a collision does not occur and to avoid obstacles. It gives us real life experience to interact with the life like model or environment in safety and convenient times. We can build any environment virtually and control the objects as we like. It provides us control over the simulation that is usually not possible in real-life situation [4].

Virtual Environment (VE) is the VR space where the simulation is done. Within VE, we can visualize, simulate, and analyze the human-robot interaction from each side respectively. On the other hand, if we perform the same interaction in real situation we can face limitations. For example, the robot cannot resume work after an improper operation that can also harm the human or robot itself. If the operation is not conforming to the accepted standards we have to test it again. As a result, the real simulation would be very expensive and sensors could not use be
tested in advance. However in VR we can easily change the location, orientation, and program path of the virtual robot and the placement of virtual work tools and manufactured products. The added advantage is that we can make desired modifications immediately and easily and test the simulation number of times.

In general, experimenting with a working robot and human is too dangerous. In addition testing the simulation practically with real sensors is very expensive. On the other hand, industrial standards do not allow for human-robot interaction because it can be risky for the human. Safeguarding devices and practices are used to minimize any hazards associated with robot experimentation but cannot be completely eliminated. In this research we have used VR for the detection and recognition of the human or object and its position from the robot with the help of sensors. We believe that VR simulation is the best choice for testing human-robot interaction using sensors and in the future could be used for some functions in real environment. Once the simulation is tested within VR simulation with affirmative results the actual implementation system using real robot and sensors can be built.

2. Methodology

This study proposes an approach to detect and recognize any human or object present in the vicinity of the robot. It gives a concept of how to explore the unknown environment in the surroundings of the robot. For this approach, we have used VR as a tool, using group of sensors to do the simulation. It allows any robot to work in the human environment without any risk involved to human or robot. The required data is collected in Virtual environment using selected group of sensors. These sensors are mounted on robot to collect the required data set. Each data set is a collection of different types of information such as position, orientation, shape, size etc.

In this research, sensors are mounted on the top of the robot. The set of sensors used are proximity sensors, video camera, and laser sensor (or ladder sensor). The data collected is updated continuously by providing the latest information about the surroundings of the robot.

The robot currently used in this research is Motorman UPJ. It has six axes: sweep, lower arm, upper arm, rotate, bend, and twist. Each joint has its respective axis namely S-axis, L-axis, U-axis, R-axis, B-axis, T-axis. The robots’ parts were measured, then modeled in Pro/Engineer and Catia, and finally imported to Virtual Reality software Eon Reality. The individual robot parts are assembled with respect to their axis in Eon Reality and appropriate degree of freedom as placed on each axis. Behavior model, control algorithm, including input/output from sensors signals, and intelligent logics for interaction with human were developed and run within the VR software.

2.1 Virtual Reality simulation, algorithm, and function control system

Virtual Reality simulation and control system developed is shown in Figure 1. Sensors are activated whenever the human or moving object is detected within the range of the proximity sensor of the robot. It main objective is to locate and measure the distance to the human or object.
When the proximity sensor detected new object it sends the measured data to the Intelligent Optimized Control System (IOCS) that activates a video camera.

The video camera records the human or objects approaching and captures motion frames. The data captured is processed by MATLAB algorithm that calculates the two dimensional (2D) silhouette (outline and shape) of the captured human or object. The silhouette points of the human or objects are converted to three dimensional (3-D) space points and send the IOCS. As a result a laser sensor is activated that scans only the area defined by the silhouette algorithm of the human or object, present in the sensing area, and determines the exact position and the three dimensional coordinates (x, y, z). This collected data points from the laser sensor is send to the IOCS.

Alternatively to the laser sensor, a lader sensor can be activated (it is designed as a group of laser beams). It scans the area of the human or objects that is in sensing range of the robot and gives the volume of the data points of the human or object. The main advantage of the ladder sensor over laser sensor is it scans larger area with high speed and accuracy. It also gives more data points of the human or object than can be directly converted to volumetric information.

The IOCS analyzes the collected data from proximity sensor, camera and laser sensor (or ladder sensor) and determines exact position and orientation of the human or object and its 3-D
measurements. It also can define if the approaching human or object is near to the robot working envelope then it can modify the robot arm motion and avoids any further collision from the human or object. Intersection of calculated 3-D space motion envelopes of robot and approaching human/object is used to calculate new the modified path that is sent to robot controller. Further precise calculation of those 3-D envelopes would allow safe collaboration between humans and robots, when a human can give/take a part to/from robot.

### 2.2 Distance measurement with proximity sensor

The proximity sensors are mounted on the robot with a sensing area that is in the form of semi-sphere. We will explain the concept of the sensors operations with an example, shown in Figure 2. The sensing range can be divided into three (or more) areas namely proximity area 1, proximity area 2, and proximity area 3. The main objective of the proximity sensor is to locate an approaching human/object and detect the distance to it. To cover completely the surrounding area several proximity sensors are used. The sensing range detects any obstacles within the predefined range from the center of the robot.

![Proximity Sensor measurement of the human approaching the robot](image)

Figure 2 shows the function of the proximity sensor, where the human approaching the robot. It gives the distance of the object from the robot, whenever any obstacle is detected in the proximity range. Proximity sensor gives the signal of presence of a human or object is in the sensing range and the distance to it. This signal is sent to the IOCS, indicating that the human is in the sensing range; the distance is measured and is collected in the data collection file.

Whenever a human or object enters the vicinity of the proximity sensor, it gives the updated distance of the object with respect to the time. The updated distances detected are saved in data collection file through IOCS to be used for calculation and control of other sensors.

### 2.3 Video camera silhouette algorithm
The video camera used in this research work is a CCD camera. These types of cameras are inexpensive and widely available. The camera is mounted at the base of the robot. Whenever any human or object enters in the proximity area of the robot, measured by the proximity sensors, a signal is sent to activate the video camera and records the information of any objects in the vicinity of the robot. We used a background segmentation algorithm [5], with MATLAB to obtain the silhouette. The main advantage of this algorithm is that it captures only the moving objects. It does not capture any static objects like walls, doors etc. This algorithm captures the approaching human or objects frame by frame and processes the movie in number of frames. The result is a capture of human or object image and that is represented in 2D data points. The algorithm essentially calculates the silhouette of the human or objects and detects the corner points of the image and gives it in pixel values. This algorithm builds the silhouettes by taking the pixel color from every fourth frame and clears the data above and below a pair of thresholds. From the remaining frames it estimates the mean and variance of each pixels color assuming to be a normal distribution.

![Diagram of camera](image)

Figure 3. Video camera captures the motion of human approaching the robot

In this research, we have used a video of human approaching the robot. An example of how the algorithm processes the video of approaching human is shown in Figure 3. Here we have taken three different positions where the human is at three different distances. These three different distances coinciding with a distance measured by the proximity sensor areas explained above. By synchronizing the time, we know the distance (from proximity sensor) of the human from the robot and obtain the silhouette data with respect to that frame. The information then is processed by IOCS and used to control the laser sensor movement.

### 2.4 Measurements with laser sensor

Laser sensor is a device which emits the light beam. The laser beam to be used in real environment is of type not harmful to the human. An example of the simulated laser that scans the surface of the object and collects the data points is shown in Figure 4. The laser scanning points controlled IOCS are calculate directly from video camera silhouette algorithm.
When the laser sensor is activated, it scans only the human or object silhouette (calculated from video foreground algorithm) that is in the vicinity of the proximity range. It measures precisely the distance to the human or object, from it x, y, z coordinates data points are calculated. The laser sensor collected data points set with respect to the time. Further 3-D surface models of the human or object is calculated as show later in this paper.

2.5 Measurements with Primesence sensors

Instead of exiting sensors that are very expensive and computer intensive we are investigating new technologies that became available recently. This technologies can be applied for measurements of the movement of robot and human in real time.

One of the promising technology we are testing now is using Kinetic for Windows that employ Primesense sensors [6, 7].

Real time motion depth data measurement is accomplished by as system with IR emitter and camera. The IR emitter radiates infrared light beams then the depth sensor reads the IR beams reflected back to the sensor. The reflected beams are measuring the distance between an object and the sensor and convert it a depth image (3D) In addition this system has RGB camera with high resolution 1280x960 resolution that maps the real image on the 3D measured data sensors [8]

The fast measurements and processing algorithms working with several moving humans/objects make it possible to be applied to propped human/robot interaction system. Since the processing of the 3D and picture image is in real time this make it possible to be implemented in control system. This technology was successfully tested to measure and calculate the movement of human that control robot in real time [9]. We are investigating the capabilities to be applied for high precision detail measurements to replace the array of sensors proposed, proximity, laser, radar, with one single combined sensor system.
3. Results and discussions

Sensors in this application are mounted on the arms of the robot or inside its working space. The robot control and sensor data will be collected for human/objects approaching the robot. The data from each type of sensors is used as input to the next sensor while at the same time accuracy increases while at the same time the built-in redundancy in measurement with each sensor allows safe operation.

The proposed OIRCS software/hardware system is built based on the following concept. A robot in the environment has the data for positions, sensory direction data, collision detection, or the point of collision information within the environment. Input data for the system of initial and target points for the robot are used by the OIRCS for its feedback system to control the robot and avoid collision (by calculating the intersection motion space envelopes) with the external source. A new position is self-determined by the intelligent system to make sure of any new encounters with an external object. When the system detects the approach or collision (close proximity) of humans or objects, it modifies the motion of the robot for a collision-free path until the robot reaches its goal point. From human movements, measured by sensor, 3-D space motion envelopes can be constructed, and from their intersections with the robot motion envelope a safe solution can be easily found.

3.1 Distance measurement with proximity sensors

The first group of sensors, several short range proximity sensors, is attached to the robot arms to provide safety measures with high fidelity and accuracy. Those sensors similar to the existing industrial applications allow safety work. Sensors measure the range to the human body/hand or object at any stage of the motion. If no external objects are sensed within a predefined minimum (safe) distance, the robot works normally. If a human body/hand or object is sensed, then the intelligent control system modifies the trajectory, leading to a collision-free path for the robot.

The second group of long range proximity sensors is used to measure distance to the human/object to be used by the next group of sensors. It is calibrated to detect motion toward the robot. When a human or object is on the path approaching the working robot, the video camera starts automatically at predefined distance measured by the long range sensor.

![Figure 5. Obtaining the Silhouette from video camera of human approaching the robot](image)

The camera captures the human in the first frame, where the human is at specified distance (e.g. 5m), and it gives the silhouette of the human and the pixel values of the human silhouette. The
pixel values will be in the form of $P(y, x)$. Figure 5 shows the silhouette of the human at several different frames at different distances with respect to the time.

![Figure 5](image)

**Figure 5.** Silhouette of the human at several different frames at different distances with respect to the time.

### 3.2 Human silhouette reconstructed from video capture

All the information of the human silhouette along with the pixel values $P(y,x)$ and the distance with respect to the time is continuously updated sent to the IOCS. By analyzing the different frames of the human silhouette and the distances the IOCS have the updated information of the human or object approaching the robot. It was tested and verified that the algorithm is independent on color changes of moving human objects or static background and obtains the silhouette only of the moving human or objects.

IOCS system analyzes and controls the robot-sensor interaction; it takes the information of set of human silhouettes and their respective distances from the camera and changes the 2D image plane coordinates $(y, x)$ into world coordinates of the object plane. Subsequently, conversion of the image coordinates to object coordinates $x, y, z$ points in real world are done. Then the laser sensor is activated and scans the human or object which is approaching the robot.

### 3.3. 3-D data points obtained from laser/lader/ Primesence sensors

Depending on the size of the object derived from the silhouette (Figure 6 (a)) and distance, laser sensor scans and collects the data points. IOCS systems control the laser sensor scans to move on defined pattern, with distinct single step in one direction, motion speed and number of turns steps in other direction required to measure the approaching human or object. The laser beam scans and send measured distance and data points back to OICS. From collected data points, Figure 6 (b), the surface, Figure 6 (c), of the human or object is calculated. By plotting the data points, a
point cloud is formed in the surface shape of the measured human. Point cloud is the collection of the three dimensional (3-D) coordinates of the data points. With this point cloud a 3-D model of the measured surface is constructed. Figure 6 shows the intermediate stages of obtaining of completed 3-D models of the human. With this comprehensive information of the sensors, and 3-D models robot can react to the human or object motion and can modify its path to avoid collision and behavior accordingly.

4. Conclusion

This study proposes an approach for a robot to detect and recognize the human or object in the unknown environment with the help of fusion of different sensors data. With the comprehensive information obtained from the sensors, robot can react to the human or object motion and can modify its path to avoid collision and behavior accordingly. The propose method is designed to work with industrial or other robots that work in unknown and dynamic changing environment. The modifications can be made using already available off-the-shelf, cost effective, components and Artificial Intelligent systems coupled with advanced Virtual Reality, which can be adapted to safely increase the workspace human/robot automation environment.

The system provides the robot/automated system a way to predefine a possible unsafe human/machine interaction by predicting in real time such things as human/object motion direction and position, the probability of dangerous conditions, and the execution of a safe alternative path. Early detection gives the OIRCS system timely modification of a collision-free path adjustment. This will allow development of a system that is safe, dependable, and easy to use. Robots could perform autonomous tasks and be cable of collaboration with humans. At present applications of actual sensors and their integration with robot control has been studied. New sensors, such as Kinect from Microsoft X-box can be used for real time calculation of motion envelopes of both, the robot and the human [6, 9]. Future work will continue on implementation of the actual sensors with existing robots and building of OIRCS capable to work in real time.

5. References


Biography:

Dr. Pavel G. Ikonomov is Associate Professor of Industrial and Manufacturing Engineering at Western Michigan University, Kalamazoo, Michigan, USA. He has been working on Virtual Reality simulation for more than 17 years. His main focus has been 3-D modeling design and VR simulation in manufacturing and assembly, nano-technology, medical application, robotics, and large scale dynamic simulation in various research organizations in Japan such as Hokkaido University (Vis. Researcher), Tokyo Metropolitan Institute of Technology (Vis. Assoc. Prof), 3D Incorporated and Virtual Reality Center Yokohama (CTO), UCLA (2001-3) and NIST (2002-3)-Vis. Prof. At NIST he was responsible for industrial Virtual Reality Assembly (VADE) and worked with VR simulation for the optical nano-tweezers. Dr. Ikonomov has more than 100 journals and refereed conference proceedings publications, three books and a book chapter.