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Safe Collaboration of Humans and SCARA Robots

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Abstract—**This paper presents a method to determine distance between human operator and SCARA robot using computer vision in order to provide a safe workstation for human robot collaboration. Kinect sensor is used as the input device to the system. Kinect has four streams of data among which depth data is effectively used in this approach. The measured distance is used to calculate danger index. Online trajectory generation allows the robot to perform appropriate action. The results of applying this system to FUM SCARA is presented.**

Keywords—human robot collaboration; SCARA robot; Kinect; online trajectory; industrial safety

I. INTRODUCTION

Soon after the introduction of robotic manipulators, they became an integral part of the manufacturing technology and automation industry. Firstly they were applied to hazardous environments. Improvements in the design of mechanisms and implementation of advanced control systems led to more productivity and appearance of industrial robots in wider range of application such as pick and place, material handling, welding and painting. Despite other sections of production systems, less robots are used in assembly lines due to changeability and flexibility of assembly processes. Advances in robotics made improvement to assembly tasks by interaction between robots and humans.

Human robot interaction involves a vast area of research fields from long term interactions due to cohabitation with assistive and service robots, direct verbal and emotional communications, to robots that can grow by acquiring skills and increasing their knowledge [1]. When it comes to industrial robots, the focus is on a safe collaboration with human workers to perform an effective human guided-robot assisted assembly task [2].

The basis for safety in a collaborative task between robot and operator is defined by ISO 10218-1 which gives instructions for achieving risk reduction by monitoring separation distance and exerting limitation on robot speed, force and power [3].

The first step to attain safety in HRC systems is danger evaluation. Measure of danger forms the basic idea in design of systems dealing with human safety in vicinity of working robots. Depending on measure of danger different methods may be applied [4-6].

The second step in designing an HRC system is human detection which plays a key role in system efficiency. This can be achieved through a variety of techniques. Some authors used special human clothing in their proposed methods. In [7] a system is developed to track multiple human workers wearing reflective safety clothing in industrial environment. A pair of images, one with an IR flash and the other one without a flash, were used for detection process by identifying blob like reflective regions in the flashed image. Detected regions were verified comparing with the non-flash image. In another method, not only human worker has to wear a special clothing, but also each area of this seven segmented cloth is in a different color. This clothing allows to track 3d position of human operator [8].

A ceiling mounted stereo vision system consisting of low-cost commercial RGB surveillance cameras was used in [9]. Particle filter based strategy was implemented in order to track human motions. In contrast with method presented by [10], human detection does not depend on skin segmentation in [11]. In this approach, humans are detected as image foreground by background subtraction. Also, the industrial robots are detected and neglected from surrounding to prevent occlusion in background. It is possible by means of 4 RGB cameras and benefiting industrial robots distinct color. The polyhedron representation of human can be improved utilizing sphere based geometric modelling for faster human robot minimum distance measurement [12].

In some approaches Microsoft Kinect is used to obtain depth image of the robot cell due to 20-joint human model output beside its low cost. In [13] an N-Kinect based system has been developed to cover all robot workspace and reduce occlusion. Using the obtained data and generated trajectory of robot a 3d simulation of near future is made in almost real time (~30 HZ) to predict collision and take appropriate action. In [14] implementation of a multi-Kinect system called JAHIR is described.

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Not all human detection systems solely depend on computer vision techniques. A new method for human detection, motion tracking and predicting has been developed using safety mat which helps to obtain location and orientation of human body based on longitudinal distribution of body mass on the feet's soles [15]. However, this method requires additional camera system for 3d modeling of human body and gestures. Self-organizing maps, a class of artificial neural networks, is used to cluster the activated nodes into location and orientation of the soles.

In another approach physiological signals are used in the presence of a stereo vision system to provide safe human robot interaction [5]. Two dimensional representation of valence/arousal gives a measure of user approval by utilizing the acquired physiological signals. Head orientation estimation is made based on head location in order to measure user's focus of attention. 3d location of head, torso and hands are represented by a set of spheres benefiting the stereo vision system. Benefiting these collected data, safe online motion planning will be performed.

The third step to an industrial HRC system is motion planning and control which allows to apply safety considerations. Real time trajectory generation approaches are implemented in systems to execute obstacle avoidance strategies [16]. Trajectory modification should be done in a smooth jerk limited manner [17-19].

The fourth step is application of physical human robot interaction criteria which takes action in case of collision or human guided tasks using force control [20, 21].

For human tracking, background subtraction would be a good solution similar to the work presented in [11]. Also, for this purpose, a human detection neural model using a Sigma-Pi network architecture which combines color memory, motion, shape and shape memory streams is developed [22]. A circle like (2D projection of spheres) representation for human and robot links allows fast calculation of minimum distance between human and robot which is the most common danger evaluation index.

In this paper FUM SCARA is shortly introduced and the computer vision method to benefit from Kinect sensor in calculation of human and robot distance is described. Introducing speed coefficient, different scenarios could be generated. Experimental results proofs the efficiency of the proposed method.

II. SYSTEM OVERVIEW

Among industrial robots, SCARA robots with 3 revolute and one prismatic DOF have become popular in packaging and assembly lines. Control systems of such robots are designed for common industrial applications and in general are not suitable for high level research purposes. As a result, FUM SCARA is a good test case with its open architecture control system [23]. Robot control in speed mode gives the operator permission to set maximum joint velocities. Fig. 1 shows FUM SCARA robot system.

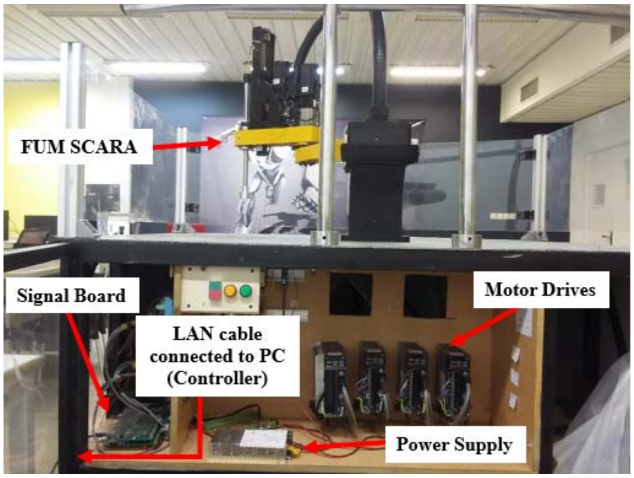

Fig. 1. Architecture of FUM SCARA robot

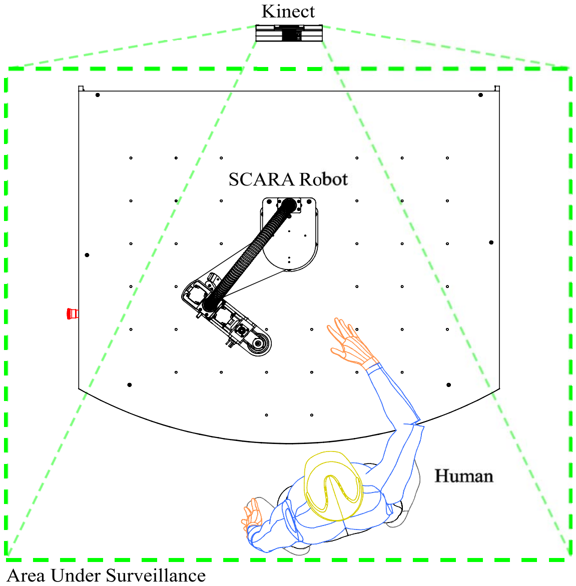

Fig. 2. Using Kinect sensor to observe human and robot shared workspace

In case of a SCARA robot for collaborative applications, since motion in Z direction is independent of motion in XY plane, a Kinect sensor parallel to XY plane could be used to monitor robot and its work cell as shown in fig. 2.

Although robot position is known from its kinematics, as a surveillance system it is advantageous to detect the robot location automatically. The Kinect sensor could be utilized to measure distance between robot and human operator in order to provide a safe collaboration by reducing robot speed.

III. SEGMENTATION ALGORITHM

Using depth stream of the Kinect makes it easy to detect the robot, considering the special characteristics of this problem. To use the depth image for robot detection some preprocessings are needed.

A. Noise Removal

Noises almost occur in image border as points with zero distance. Obviously, as the sensor is mounted on ceiling there should be nothing in its near distance. The value of these zero distant points will be changed to the furthest value in Kinect range.

B. Distance Limit

Due to their applications SCARA robots are usually mounted on tables to increase their height. These tables are not higher than human abdomen. Thanks to Kinect ability in providing depth image, a distance filter could be applied in order to ignore objects that has a height lower than robot station. In addition, applying the distance limit filter will allow to detect objects in the environment with height similar to robot. Constant position objects in environment higher than defined limit could be removed manually.

C. Morphological Operations

After successfully applying the distance limit, depth image could be converted into binary image. An opening will be applied following a closing in order to improve faulty regions. The structuring element used for closing depends on the shape and size of objects existing in workstation. Since these objects are smaller than robot and human operator, they can be removed by appropriately selecting number of pixels for closing operation.

D. Edge Detection

Before application of edge detector, each region should be identified with a label. By assigning edge pixels the value equal to the region label, labeled edges would be obtained. Labeling helps to find distance between regions in an easy manner.

IV. DANGER EVALUATION

The minimum distance between edge pixels of the two regions gives the key component of danger index. Also, the minimum safe distance for robot working in its maximum speed with human operator is defined by user. The ratio of measured distance to the constant predefined safe distance gives the distance coefficient. On the other hand, speed coefficient is a positive real number in the interval of zero to one determines maximum permitted robot velocity, e.g. speed coefficient of 0.7 means that the robot joint velocities are limited to 70% of the actuators capacity. For the distance coefficients greater than one, speed coefficient has the value equal to one. Different scenarios and speed coefficients could be defined based on distance coefficient value. The speed coefficient is directly used in control system to balance the robot speed with its distance from human operator.

V. ONLINE TRAJECTORY MODIFICATION

Presence of human operator in robot workspace does not affect robot trajectory as far as the minimum safe distance is maintained. Whenever the danger criterion is met, robot trajectory is discontinued immediately and the robot will stop after travelling a short distance. The travelled distance is calculated depending on instantaneous velocity and acceleration of robot links and their mechanical properties of the system such as weight, inertia, motor torque and its braking capability. At danger occurrence point, joints positions are obtained from encoders and velocity and acceleration are derived from robot kinematics. At robot stop point velocity and acceleration must be zero. The stop position is calculated based on danger occurrence position and direction of velocity. Between these two points a smooth trajectory such as fifth order polynomial, double S-curve or any other appropriate method, is generated in real time. The described procedures for safe human SCARA robot collaboration using Microsoft Kinect sensor are illustrated by a flowchart in Fig. 3.

VI. EXPERIMENTAL RESULTS

The proposed method is applied on FUM SCARA robot to provide a safe environment for collaborative applications. The initial settings such as defining distance limit, minimum distance and excluding stationary objects in the environment are applied. Operations applied by computer vision system are illustrated in Fig. 3. As a result distance coefficient is obtained for each frame. Fig. 4 shows the process applied on each frame. The setup used for experiments is illustrated in Fig. 5.

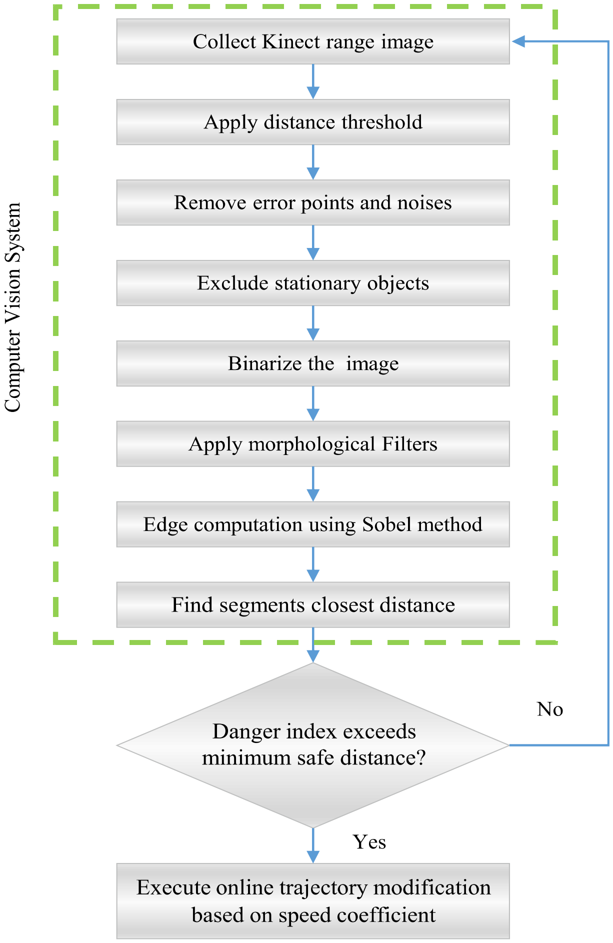

Fig. 3. Human SCARA robot collaboration algorithm

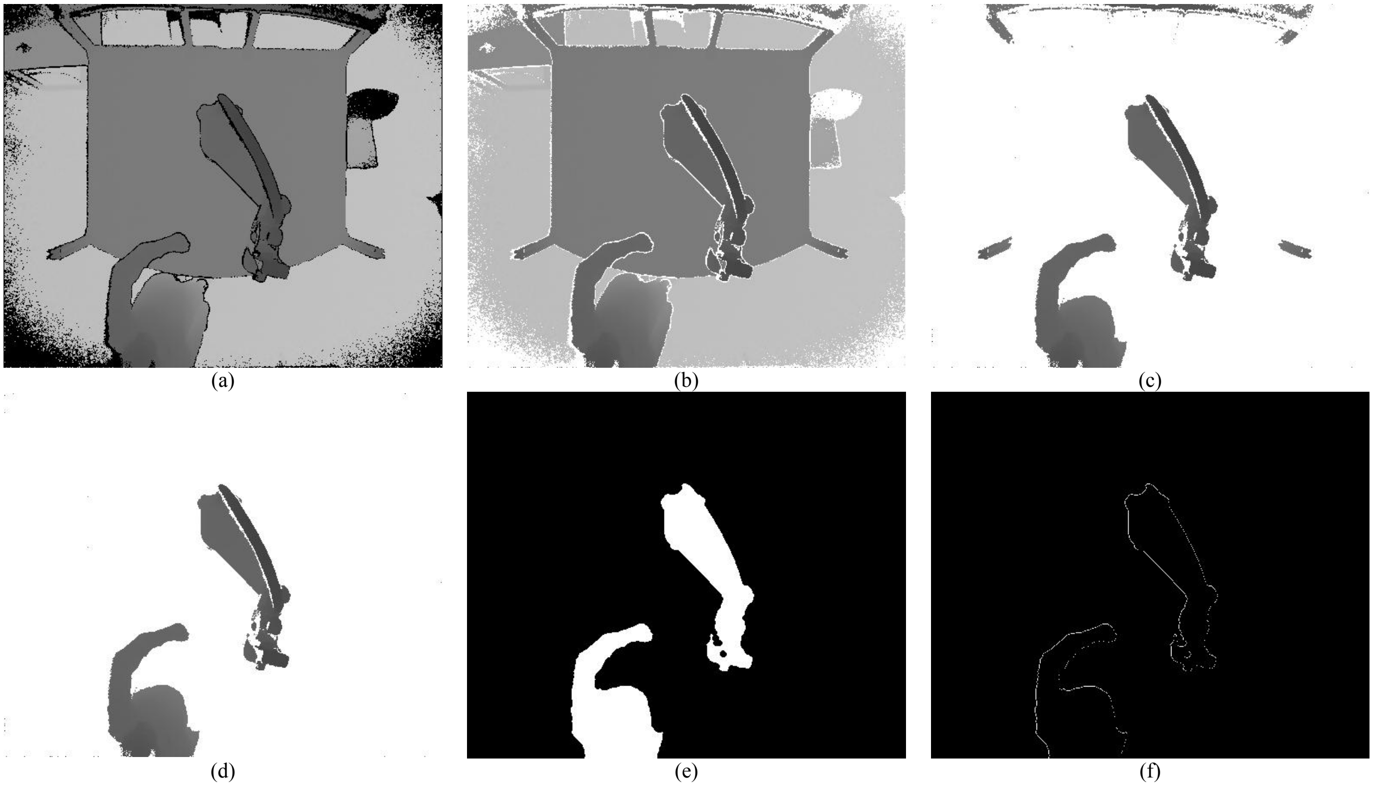
(a) (b) (c)
(d) (e) (f)

Fig. 5. Procedures of the implemented computer vision techniques to obtain danger index from Kinect sensor: (a) Raw depth image, (b) Removal of noisy pixels, (c) Applying predefined distance filter, (d) User defined exclusion of stationary objects, (e) Applying morphological filters on the binarized image and labeling regions, (f) Edge detection and calculating regions distance

In this study, speed coefficients are defined conservatively in only two levels. For distance coefficients below one, the speed coefficient will be set to zero, which activates robot's emergency stop mode. Otherwise the robot will work at 100% speed capacity. Whenever a scene with high chance of collision between human and robot is spotted by the system, online trajectory modification takes action to stop the robot immediately. Fig. 6 compares the modified double S-curve trajectory in danger occurrence position with the predefined desired trajectory. The emergency stop mode is activated at 3.748 second.

VII. CONCLUSION

In this paper application of Kinect sensor in safe human SCARA robot collaboration was described. SCARA robot was used as a representative of planar robots and robots with decoupled motion in certain planes. Using the depth data, human and robot segmentation was done with least possible operations. As a result, distance between robot and operator was calculated in real time. Introducing speed coefficient as a new concept, different scenarios could be defined with assistance of distance coefficient. This coefficient allows the system to lower the robot velocity as human operator reduces his distance to the robot. Online trajectory generation made the immediate modification of robot velocity possible. Double S-curve trajectory generation method was used for smooth real time trajectory update. The system was successfully implemented in FUM SCARA robot to provide a safe human robot collaboration.

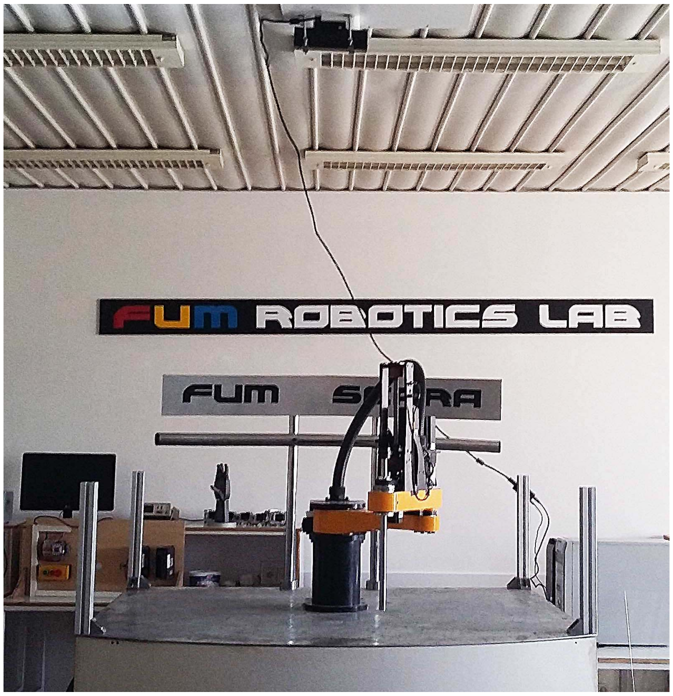

Fig. 4. FUM SCARA Robot and Microsoft Kinect used for HRC system

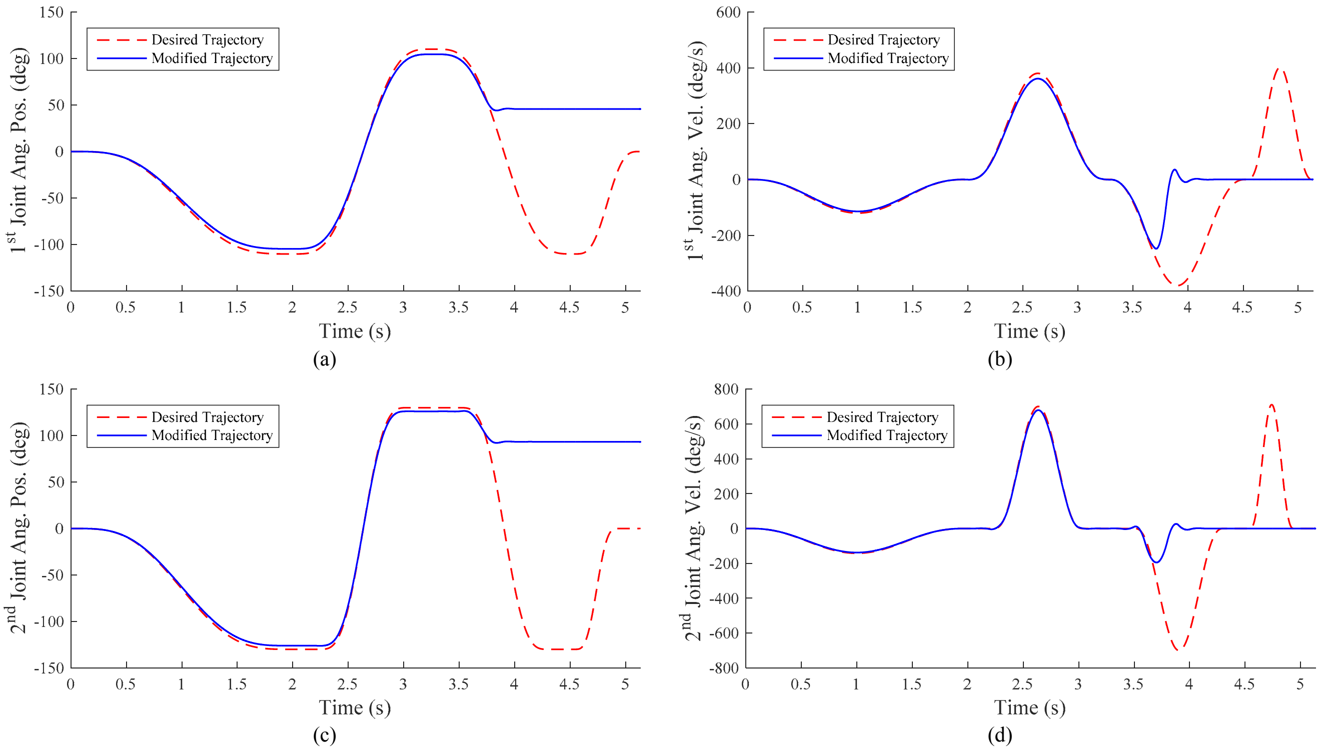

Fig. 6. Online trajectory modification in emergency stop mode: (a) and (b) demonstrates first joint angular position and velocity, (c) and (d) demonstrates second joint angular position and velocity, respectively.

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