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SAFE HUMAN-ROBOT COOPERATION BASED ON 3D SURVEILLANCE

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ABSTRACT

The increasing need of a closer cooperation between human and robots in industrial environments requires the appropriate handling of the danger situations that arise in the shared working spaces. The authors present a system which predicts and controls such situations, in order to ensure the safety of the workers while preserving the highest possible efficiency. The system is based on the fusion of the information from several sources, including stereo cameras used for monitoring the whole working space, and cameras used for controlling especially dangerous areas (such as the surroundings of the gripper). The information from the stereo cameras is processed in order to build a 3D model of the scene, which is then used to compute the distance and relative velocity between the robot and humans. These data are stored and used to predict future hazardous situations, which are treated by an appropriate reaction on the behaviour pattern of the robot. Additionally, the authors present a tool that serves to pre-select the most appropriate configuration of the system, according to the needs and characteristics of the use case to be applied. The amount and type of cameras, as well as their position and direction can be configured, and the degree of visibility of each of the regions in the working space is calculated, in terms of the number of cameras which can view those regions.

Index Terms – Human-Robot cooperation, robot safety system, danger control, sensor fusion, 3D surveillance

1. INTRODUCTION

Nowadays, human-robot cooperation is an inseparable part of industrial environments. Humans are typically able to respond, adapt and improvise according to the task and situation where they are involved, however, they are slow, have low power, and are not able to produce with a constant quality. The human weaknesses typically correspond to the strengths of robots, but in the same way the robots weaknesses correspond to the strengths of the humans. The synergy between them allows producing with a higher flexibility in a semi-automatic manner, sparing in the number of robots, and being more flexible in the arrangement of the robots in the working space, typically using less space than in a working space where no cooperation is allowed. However, some problems derive of such shared working spaces. The next section offers some insights on aspects, which need to be considered in industrial environments.

2. IDENTIFIED PROBLEMS

Working environments where human and machines cooperate, concern problematical aspects which deal with the safety of the workers. The environment needs to be compliant with standards and specifications addressing human-machine cooperation such as [2]. In addition, possible collisions need to be handled automatically in an appropriate way: collisions must be avoided, or they are allowed only in some specific conditions (e.g.: the worker could be allowed to touch certain parts of the robot, if the velocity of the machine is low).

The simplest solution to a collision problem is the separation between the working areas with lasers or optical fences, however, such systems provide reduced reliability and flexibility. Thus, in order to optimize the production, the human and machine cooperating together should be able to share their working space, as illustrated in Figure 1.

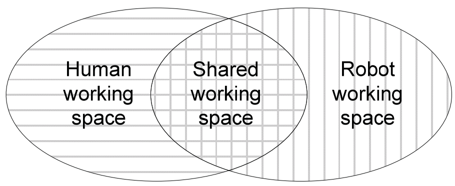

Figure 1: Shared working space

This approach requires a high flexibility of the monitoring system. Camera based systems have been used to monitor shared working spaces, and to calculate the distance between the human and robot, serving as a basis to stop the machine [3]. By now, different methods have been employed to calculate the physical extent of the elements and to infer the distance between them. Back-projection has been used to precisely reconstruct objects in a 3D space [4], and also for performing image-based collision tests as presented in [5]. More complex systems consider the situation of the environment (such as the behaviour of the human) to produce a reaction in order to avoid the hazard without a need to stop the machine, such as reducing the velocity, or steering the movement of the robot in an appropriate direction. [6,7,8,9]

A further identified problem deals with the application of a monitoring system in a specific use case. Thus, the selection of the most appropriate configuration of the monitoring system needs to meet the specific use case needs. The characteristics of the working space, the type of collaboration, the required degree of safety, and budget constrains influence the selection of the most appropriate configuration. Additionally, the application in the use cases concerns an analysis of the possible hazards in the environment where the system will be integrated. The definition of the hazardous situations and the proper reaction to avoid the undesired collisions is thus dependent on the application, and needs to be performed purposefully.

All of the identified problems require sufficient technological approach towards their resolution, as presented in the following section.

3. TECHNOLOGICAL APPROACH

The approach followed by the authors to ensure the safe cooperation between human and robots deals with the use of a camera based monitoring system.

The design of the system involves aspects such as hardware development, miniaturization of the cameras and image processing. This paper focuses on two further important aspects: (1) a runtime subsystem for the analysis of the data, including the prediction of the hazardous situations, and execution of corrective actions to avoid the danger, and (2) a pre-configuration subsystem for the customization of the system towards the specific needs and characteristics of the use cases.

The monitoring system as illustrated in Figure 2 reflects that the images gathered by a set of stereo cameras are processed in order to create a 3D representation of the scene. Human and robots are represented by simple models, such as ellipsoids, or more complex models, depending on the needs and characteristics of the application. In the runtime subsystem, elementary features are extracted, stored and combined with historical data to calculate the velocity and trajectory of the elements of the scene, and thus predict the future state of the scene. The scene is represented by a set of features, which are used for the definition and classification of the danger situations. After the evaluation of the potential danger, if necessary, a reaction is executed according to a set of rules, specified by each use case. Additionally, further sensors can be used for the definition and classification of the danger situations, such as sensors in the gripper area, which provide information about the state of the gripper (open or closed), and very precise information about the presence of a human in this dangerous area.

In order to optimize the applicability and efficiency of the monitoring system, a software tool has been developed which allows for the pre-configuration of the monitoring system according to the needs and characteristics of the environment where it will be used, in terms of the type, number, position and orientation of cameras, as well as the use of additional sensors. Additionally this tool provides a visual interface for the easy and intuitive creation of the rules which define the danger situations and the actions to be performed in such case.

3.1. Pre-configuration subsystem

The main purpose of the pre-configuration subsystem is to provide the possibility for customizing the monitoring system according to the particular use case needs. Two objectives can be distinguished: a) the support to perform the pre-selection of the most appropriate configuration of the monitoring system, according to the size and arrangement of the working space, the characteristics of the robots, as well as to budget constrains, and moreover, implications to the degree of safety, and b) the creation of the rules, which includes both the definitions of dangerous situations, and the corresponding actions to be performed to avoid the hazard.

A visualization tool has been developed in order to accomplish the introduced objectives. The first objective refers to the calculation of the degree of visibility of the working space corresponding to the selected configuration. The degree of visibility of a point can be defined as the number of cameras which include the point in their viewing angle. A higher degree of visibility corresponds to a higher level of accuracy in the creation of the 3D representation of the scene, which is the basis for the classification of the hazardous situation. Additionally, the occlusions which may occur in the working space affect the creation of the 3D representation. A higher degree of visibility would reduce their impact, since information of several cameras is available. In order to allow the pre-configuration of the monitoring system, various cameras can be selected from a database that holds their characteristics and specifications. The tool also allows the configuration of the sizes of the working space, positions of the cameras, as well as their directions. The tool performs an analysis of the degree of visibility of the points of the working space, with a resolution (distance between points) which can be specified by the user. The output of the calculation is the percentage of points which are

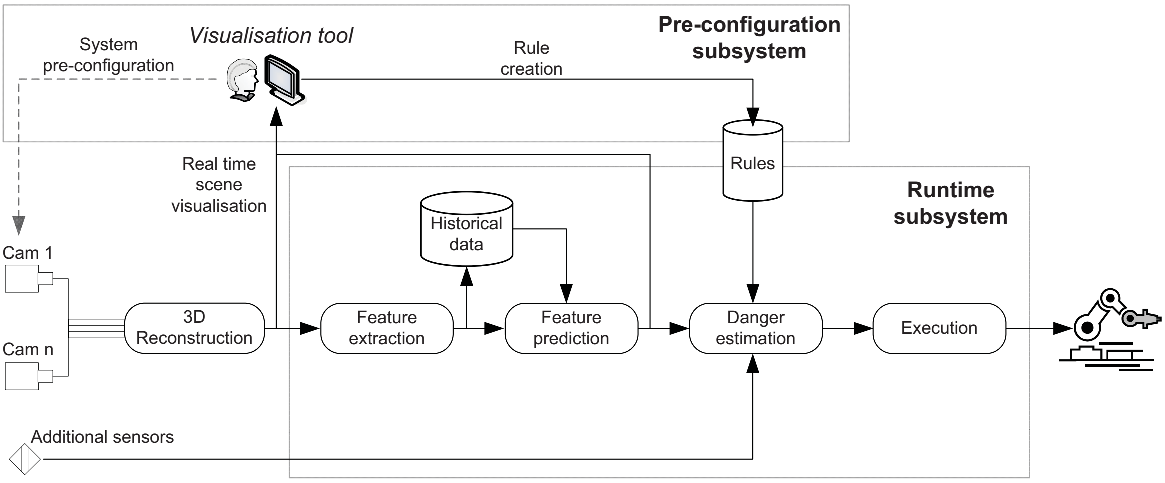

Figure 2: Joint view of the monitoring system, using a set of cameras and additional sensors

in the field of view of a determined amount of cameras. Additionally, the user is able to calculate and visualize the points with certain characteristics, such as those with a degree of visibility higher than three, as shown in Figure 3. Finally, a visual representation of the space is used to easily identify the effect of changes in the input parameters, or in the type or amount of cameras used.

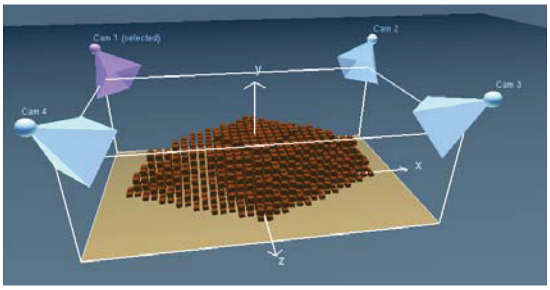

Figure 3: Visual representation of the points with a certain degree of visibility

The second objective of the configuration tool deals with the creation of the rules for the danger estimation and hazard avoidance. Each rule is formed by at least one condition, and an action to be performed in case all associated conditions are met. Each action has an associated degree of priority, so that only the action with the highest rank is executed in case the conditions of several rules are met. The definition of the conditions is based on the location of the human and the robot, their velocities, and derived features, as described in the following subsection. A further possibility is to use the state of the elements of the scene as a basis for the definition of the conditions. For instance, it is possible to include the state of the gripper of the robot as an element to be considered in the creation of the rules. Furthermore, additional sensors provide further possibilities for the creation of the rules, such as the consideration of the state of the gripper, or the distribution of the elements of the scene around the gripper. For instance, a camera in the gripper could be used as an additional sensor, providing information about the presence of a human in this particular area. The definition of the rules can be visually performed with the tool introduced, as shown in Figure 4.

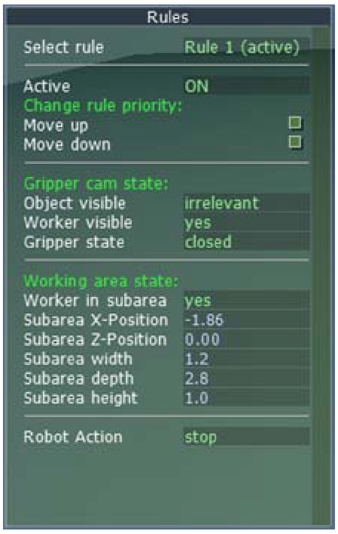

Figure 4: Definition of rules, based on the conditions and actions to be executed

Moreover, the tool allows the real time visualization of the 3D model of the elements of the scene, as well as their velocity and trajectory, along with the conditions of the rules. This is useful for the user dealing with the configuration of the system, in order to verify the correct definition of the rules. Figure 5 illustrates the simplified models of a robot and two humans, along with their velocities, and trajectories, and the definition of the areas which are used as a basis for the condition of a rule

The following subsection presents the runtime subsystem, including the application of the rules and a detailed explanation of the features used to characterize the hazardous situations.

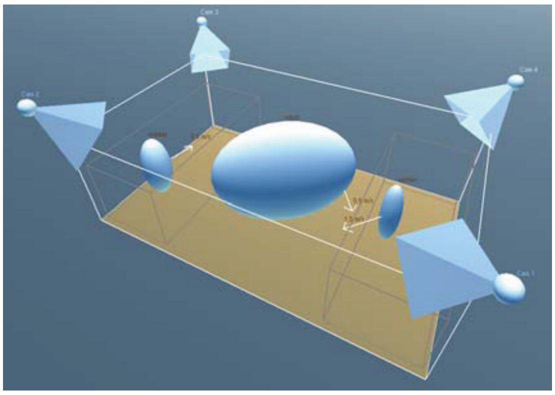

Figure 5: Real time scene visualisation

3.2. Runtime subsystem

The runtime subsystem involves the detection and prediction of hazardous situations, and the execution of a proper reaction, in order to avoid the danger.

The input of the runtime subsystem is a 3D representation of the scene. The humans and robots are represented by a model, created by analyzing the images coming from the set of cameras. This representation is initially simple (using basic elements such as ellipsoids), and can be refined. Further input from additional sensors can be considered for the danger estimation, depending on the needs of the use cases.

The 3D models of humans and robots are used as a basis to extract the basic features of the single elements in the working space. These features depend on the complexity of the model used in the 3D representation. In the case of ellipsoids, they are the centre, the radii and the orientation of the axes.

The features are stored, and used in a module, which deals with the prediction of the following state of the scene. Derived features, such as the velocities, trajectories, and relative velocities of each of the elements are computed by considering the basic parameters from the elements in the scene in the current state, and those of the previous states. The derived features are then used to predict the future state of the elements in the scene, and to calculate: the distance between them, the time remaining before a collision occurs, and the elements (or part of the elements) which would collide.

A further module deals with the danger estimation, and is used to react to the situation, in case it is regarded as a dangerous one, according to the specifications and characteristics of the use case where the monitoring system is implemented. The situation of the working space is classified according to its associated degree of danger as defined in the set of rules. The previously introduced features, such as the location of the elements of the scene, the distance between them, their velocities, relative velocities, the time before a collision takes place, and the predicted collision points are used as a basis to create the conditions. If the values of the features representing the current state of the scene meet the conditions of any of the rules, the situation is then classified as dangerous, and the corrective action associated to the rule is to avoid the danger. In case that the conditions of several rules are met, the action with the highest priority is selected. If the features do not fulfill the conditions of any rule, the situation does not represent any hazard, and no action is selected. As previously introduced, additional sensors can be integrated in the system, and the information they provide can thus be considered for the danger classification.

The last module deals with the execution of the selected action. In the simplest case, the action is sent via an interface to the controller of the robot. In case of more complex actions, various interfaces could be used to address different machines.

4. CONCLUSIONS AND FUTURE WORK

This paper presented the safety problems derived of a human robot interaction, and the approach followed by the authors to avoid and solve them.

The introduced system solves the problematic aspects that industry faces when dealing with collaborative environments, by providing the possibility to customize the hazardous situations, and the monitoring system according to the characteristics of the application. This pre-configuration subsystem is based on a tool which provides a user-friendly and effective visual interface to the user dealing with the configuration of the system – there is no need of deep knowledge in cameras, since the purpose of the included visualization tool is to show the implications of the selection of each configuration in terms of the degree of visibility of the working space. This has implications on the level of safety of the system. Further work is related to the consideration of the models of a robot and man to address the occlusions in the calculation of the degree of visibility of the working space.

5. ACKNOWLEDGEMENT

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