ARIKT: Adaptive Robot Based Visual Inspection

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In this document an architecture for robot based visual inspection of complex parts is introduced, which is developed within the framework of the ARIKT[1] project. The main components (host, machine vision system and industrial robot) and their collaboration will be explained. Based on this architecture an engine compartment inspection and a weld seam inspection for car manufacturing will be developed. The adaption of the system to new inspection tasks will partially be done automatically. Tasks which arise from generating an inspection plan are examined. Machine learning will be used to determine suitable camera positions and to influence the image processing procedures.

1 Introduction and Motivation

Vision systems are used in industry for manufacturing, assembly and quality control. Scenes, which contain only few objects or only objects from few a-priori known object types, can successfully be analysed on specified features by state-of-the-art systems. The use of vision systems in industry brings additional reliability, where humans tend to make mistakes, because of monotonous working processes. Results from a vision system can be documented automatically and are simple to integrate in a computer controlled manufacturing system. Running costs can be reduced. Disadvantages of the use of vision systems are costs and efforts for developing a problem solution and putting a system in operation. Existing solutions for certain tasks cannot be adapted simply to modified tasks. If cameras and lighting are firmly fastened to a special mounting, a new necessary sensor configuration can require a new mounting. Also programming of the vision systems requires still a specialist's knowledge, even if the systems have an explicit and documented interface. The use of vision systems is worthwhile thus only with the production of appropriate high numbers of items.

Inspection systems are desirable, which allow an easy adaption of the positions of camera and lighting and which are easy to reprogram for new vision tasks. Ideally a system would determine the needed image processing algorithms and parameters by itself from a problem description. Ideally, as well, a suitable configuration of camera and lighting would be determined automatically from a product model and would be physically arranged.

In section 2 the goals, project partners and planned demonstrators of the project are described. The main components of the system (host instance, a vision system and an industrial robot) and their collaboration are explained in section 3. Furthermore the buildup of a so-called inspection plan which holds commands, defining robot movements and image processing procedures for inspection is introduced. Automation, knowledge representation and learning with the generating of an inspection plan are discussed in section 4.

2 The ARIKT Project

2.1 Goals

Within the scope of the ARIKT project a system is developed, which supports the automatic computation and physical arrangement of sensor configurations. As well the automatic determination of image processing algorithms or parameters for specified visual inspection tasks is supported. An industrial robot moves camera and lighting to the desired positions. A further goal of the ARIKT project is the definition of a reference architecture for robot based visual inspection systems and the definition of a standard communication interface[1] (XML[2]-based) for industrial robots and vision systems.

2.2 Project Partners and Planned Demonstrators

The interfaces for robots and vision systems, which are to be defined, must be acceptable by different manufacturers. The system architecture should be transferable to different applications. To show this, two demonstrators will be set up: An engine compartment inspection and a weld seam inspection. The appropriate vision systems are brought in by RMV machine vision (ISRA AG) and by VITRONIC Dr.-Ing. Stein Bildverarbeitungssysteme GmbH. Each of the two vision systems can be combined with robots from KUKA GmbH as well as robots from REIS GmbH & Co Maschinenfabrik. The company AMATEC Robotics GmbH brings in their experience in the field of sensor integration into the project.

3 System Organisation

3.1 System Components and Their Collaboration During Inspection

The main actors in the ARIKT system are: a host instance, a vision system and an industrial robot. The vision system comprises a sensor head, consisting of a camera and lighting. For illustration we have a look at their tasks during the engine compartment inspection: The host instance sends movement instructions to the robot control, so that the sensor head of the vision system is moved to the desired position. Likewise the host instance sends information to the vision system, which describes the image processing task to be accomplished at the next position. As soon as the sensor head was carried by the robot to the desired position, robotic control announces this to the host instance. The host instance activates thereafter the image processing procedure on the vision system. The vision system can come to three results: The inspection item fulfils the test criteria, the inspection item fulfils the test criteria not, or: it cannot be determined whether the test criteria are fulfilled. In the first two cases the vision system announces simply the result of the examination to the host instance. If the vision system

[1] ARIKT = Adaptive Roboter-Inspektion komplexer Teile (German, Adaptive Robot Inspection of Complex Parts)

[2] XML = eXtensible Markup Language

does not come to a decision, it can be e.g. because of the fact that the lighting has slightly changed in relation to successfully accomplished examinations. Shade or light reflexes can disturb an image processing procedure sensitively. In this case the vision system has the possibility to inform the host to change the position of the sensor head in a certain direction and to accomplish the inspection again.

In the case of the engine compartment inspection the robot has to bring the camera into a certain position. The trajectory, on which it is moved there, is arbitrary apart from collision avoidance and time optimisation. Possibly point-to-point movements can be used here. In the case of the weld seam inspection the main components collaborate in a slightly different way. The camera must go through a certain trajectory during the inspection procedure in order to take up a welding seam. Here, a continuous-path movement is needed during which the vision system in short time intervals is informed by robotic control about the current camera position.

3.2 Inspection Plan

The information for the control of robot and vision system, which is dispatched during the inspection procedure by the host instance to these, is retained in a so-called inspection plan. The inspection plan is settled on the host instance. For each test item it contains the position resp. trajectory for the camera and the image processing procedure together with associated parameters and data. An image processing procedure means a program build up from calls of filter operations, feature extractors and matching operations. The generation of the inspection plan happens offline before the inspection and is to be partly automated. Before we come to the subject of automation in the next section, we regard first functional dependence in generation of an inspection plan.

In Figure 1 we see input, intermediate and output data, as well as functional dependence in the generation of an inspection plan. The lines in the right column represent data models; the big grey arrows on the left side symbolize mappings or transformations between these. The head of the arrow points to the output data, the range set of a function; the small black arrows denote the input data, the domain set. The first task is to extract geometry, surface properties (texture) and functional structure of the inspection item (function 1 - F1: *preparation of part characteristics*). Starting point for this can be a CAD model from the construction department or a real object. The total inspection part could be for example an engine compartment. As geometry model serves a Constructive Solid Geometry (CSG) model. Surface properties [4] (colour pattern, reflexivity, transparency, deformation of the normal vectors) can be coupled directly to CSG objects. Functional structure means the purpose individual subparts fulfil. For example one can identify hoses, which transport liquids or gases in the engine compartment; or clips and sleeves, which fasten hoses.

From geometry, surface texture and functional structure of an inspection part derive subparts, which are represented like the total inspection part by geometry and surface texture (F2: *extraction of subpart characteristics*). From identified subparts due to the functional understanding of the total inspection item and due to knowledge of production process of the inspection item those are selected, which are to be examined visually. From function as well as geometry and surface texture properties test criteria are set up, which are to be controlled by the vision system (F3: *generating of test criteria*). For example the production subprocess assembly of hoses and their fastening

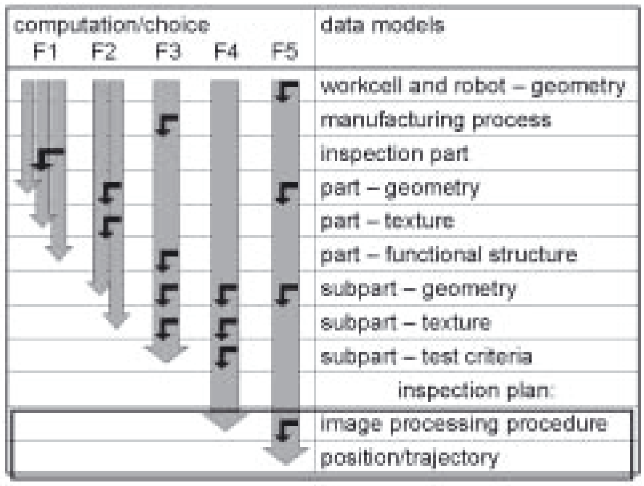

Figure 1: Functional dependence in generation of an inspection plan.

by clips could be regarded as critical, so that hoses and clips were selected as inspection items. Test criteria could be position and circle-shape of the clips. The image processing procedure for the inspection is a result made of geometry and texture of an inspection subpart as well as from its test criteria (F4: *determination of the image processing procedure*). Position resp. trajectory of the sensor head during the inspection results from the position of the subpart and the requirements of the vision system (F5: *computation of sensor head trajectories*). For the engine compartment inspection for instance a distance of 35 cm to the object is taken, at the weld seam inspection the camera is approx. 6 cm from the object. Geometry of the work cell and the total inspection item must be regarded for collision avoidance.

4 Automation, Knowledge Representation and Learning with the Generating of an Inspection Plan

Some of the tasks for generating an inspection plan, represented above, are to be partially automated. The split-up of the tasks allows performing the different functions either by software modules or by hand. In particular the partial automation of the following three functions is to be worked on: Generating of test criteria (F3), influencing the image processing procedure (F4) and computation of position/trajectory of the sensor head (F5). The latter function will be implemented first in the temporary progress of the project.

4.1 Test Criteria

For the automation of the production of test criteria (F3) a classical expert system [2] is to be developed. A suitable representation of the domain knowledge and suitable reasoning mechanisms have to be found. Knowledge shall rather be acquired from human experts than from machine learning. The knowledge domain can be product-oriented or manufacturing process-oriented. In the first case for example knowledge of the product 'engine compartment' would be formalized: "The fitting of hose clips is to be inspected","A hose clip fits correctly, if the parameters position and positive-fit do not deviate too much." The knowledge domain of the weld seam inspection can be regarded as manufacturing process-oriented: "If the

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welding method MIG welding is used, with the following material properties x and the following requirements y these parameters z have to be reached." It is not regarded directly, into which product the parts are built in. This takes place almost indirectly by the requirements y.

4.2 Image Processing Procedure

With the modification of the image processing procedure (F4) two subtasks are to be examined: (1) For a fixed image processing procedure parameters are to be adjusted optimally. (2) The programming of the image processing procedure, i.e. the choice of filters, operations etc. is to be supported. In both cases supervised learning is possible, since the result messages of the vision system can be used as feedback. I.e. an inspection item from which is a-priori known, whether it does or does not satisfy the test criteria, is inspected. There are works, which examine these topics in a general way [1] and which led to systems, able to successfully optimize parameters of an predetermined image processing procedure in specific application domains [3].

4.3 Position/Trajectory of the Sensor Head

In the case of a vision target at one position, like subparts in the engine compartment inspection, a sphere is determined as a result of the demanded distance (approx. 35 cm) between camera and target object. Possible camera positions are limited to this sphere. The sensor heads used in our demonstrators do not allow a separate positioning of camera and lighting. By neighboring objects as well as robot characteristics the possible positions are restricted additionally. Collision avoidance and path planning are standard problems in robotics [5]. The remaining camera positions will be differently suitable for a reliable result of the vision system procedure. Substantial object characteristics will be well recognizable only from certain directions. Shade and light reflexes affect the result of a vision system procedure from different points of view with different impact. In the case of the weld seam inspection there do not exist so many degrees of freedom for possible sensor configurations.

Two approaches are to be regarded for the automatic determination of suitable sensor configurations (F5): (1) Without domain knowledge or with only small not-expandable domain knowledge, an optimal position for a concrete test subpart shall be found/learned. (2) Domain knowledge is generated and learned, which can be generalized and used in different scenarios for the computation of suitable positions.

In the first approach, suitable configurations for a concrete test subpart shall be learned by trying. At this it is desirable to have to test only few sensor configurations. Therefore a strategy has to be developed, which chooses sensor configurations for testing under this aspect. A classifier, which maps sensor configurations to a qualification level, would be, simply implemented, just a table in which tested sensor configurations and their qualification levels are stored. To minimize the number of executed tests, the classifier should accept configurations as input, which have not been tested in a real inspection. The most promising configurations are tested in real and the results are integrated into the classifier. A Neural Network as classifier could be suitable here. With this kind of supervised learning the feedback of the vision system, directed to the host instance, would serve as input for an evaluation function for the classifier.

The second approach shall allow to generalize from formalized human knowledge and knowledge about already successfully determined sensor configurations, so that also for new tasks a sensor configuration can be found without many real tests. For this a suitable knowledge representation and reasoning rules must be found. Pairs of task description and suitable sensor configuration, already found, can be used for supervised learning of reasoning rules. An implementation of the first approach would provide such pairs of data in a format directly to be reused.

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