KNOWLEDGE BASED ROBOTIC SYSTEM, TOWARDS ONTOLOGY DRIVEN PICK AND PLACE TASKS

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Abstract - The paper proposes an ontology driven framework to define a machine used for automatic pick and place robotic tasks. The developed framework was successfully simulated and validated in an automotive manufacturing environment where seals have to be placed in a cable plug terminal. The developed framework builds on the IEEE ORA standard, which defines the Core ontologies for Robotics and Automation (CORA). Specific contributions were developed to extend the previous ontologies to the presented application case, e.g., for interaction with environment and robot movement. Moreover, a database of seal patterns is implemented in the cloud to be fetched, as needed, by the robot. Based on the tasks/processes obtained from the developed framework, the robot will seal a batch of cable terminals, automatically. The system was implemented in a simulated scenario, in V-REP, using a 3 dof. Scara Robot. Using the knowledge base, specially defined for the developed framework, based in CORA, reasoning actions can be performed to obtain valuable data for production and maintenance at the factory level.

Keywords: Industrial Robotics; Automation; Knowledge Representation; Ontologies; Simulation.

1. Introduction

Robotic manufacturing systems are widely used in industry. However, in specific industries, e.g., automotive cable industry the robot has not been deployed with great success, as of other branches of automotive industry, e.g., car assembly. The main reason for this issue is the complexity of existing tasks and its large number. For automotive plug sealing, of the produced car cables, robot cells do exist, but its programming is not adequate to an agile manufacturing system. In fact, the work cell program must be developed by scratch for each new plug of the various cables produced in factories. As such, hundreds of sealing patterns can exist in the factory database.

The paper proposes and ontology driven framework to define the tasks needed for the robotic cell to operate for a given seal pattern. From the robot, environment, and process knowledge, the knowledge model, i.e., the ontology is obtained. Part of the knowledge model is stored in the cloud, making the system modular and more flexible. Moreover, special tools were developed to communicate from the cloud and the machine. The latter is built from the core ontologies and also from the manual process that is currently in place at the factory.

The paper presents the application scenario in section 2, where the complete process to be automated is presented. Section 3, presents a simulation scenario of the system where a 3dof scara robot is used. The Application of the Core Ontology for Robotics and Automation is presented in Section 4, and the following section, 5, depicts the ontology application domain where the main tasks were defined. In section 6 are presented results on reasoning with the ontologies and are also discussed. Finally, some conclusions are drawn in section 7.

Figure 1: Simulation Scenario. Two conveyors for each type of seal. One 3 dof robot. Three cable terminals.

2. Application Scenario

The application scenario, depicted in figure 1, consist on the placement of two different types of seals in a plug terminal with 56 holes, isolating those who do not receive electric cables. One type of seal is placed...
manually and the second is placed automatically by the robot.

The operator, before starting the process must verify the machine electricity and compressed air power supplies. Also, must be checked if the security doors are closed and the emergency buttons are disabled.

First, must have to be set the power of the machine. After the power being set, “Homing” must be performed, that enables the localization \((X, Y)\) of the “Gripper” in relation to a reference point \((X_0, Y_0)\) in the robot workspace.

In the next step, the operator starts by creating or selecting the seal pattern to be produced. After selecting the seal pattern, press the button “Start” and triggers the three-phase motor that will rotate the base of the plug terminals in the robot workspace. The motor of the basis stops when its inductive sensor provides a signal to the robot controller.

A vibrating reservoir carries the seals, through vibratory waves, to a feeding line, which in turn, also via similar waves, forwards these to the feed zone of the “Gripper” machine, triggering a fiber optic sensor that indicates to the robot controller that the seal is in position to be picked by the robot.

This feed zone consists of two cylinders. A cylinder \((X)\) preparing the seal for placement in the “Gripper” and a second one \((Z)\) laying the seal within the “Gripper”. This is fixed due to the frictional force caused by the double cylinder \((Z)\) which is the “Gripper”. The \((Z)\) cylinder is the vertical motion of the grip depicted in figure 1.

After the seal is within the gripper, the robot, will move the “Gripper” in the \((XY)\) plane to the desired position and place the seal in the cable plug terminal.

After positioning the “Gripper”, the cylinder containing the seal is activated, approaching the hole (where the seal will be placed). Subsequently, the other cylinder is actuated a first time to put the seal into the hole and a second time to ensure the correct placement of the seal in the hole. Finally, the “Gripper”, return to the feed position.

When completed the seal pattern for a plug terminal, the robot controller expects a new button press “Start” by the operator, for continuing the process.

The next section presents a simulation of the above described process, where the feeding zone and the vibratory reservoir are simulated by two conveyors.

3. Simulation Scenario

To simulate the developed machine a simulation scenario was built using a physical robotic simulation environment (V-REP) and Matlab. The needed software modules were developed, that included the communication layers, between Matlab and V-REP, and also between a MySQL database, to store the knowledge to the system, related to the sealing patterns.

As such the full system comprises, as depicted in figure 2:
- a 3 dof scara robot, two conveyors, two types of seals and the plug terminals, simulated in V-REP;
- the robot controller, calibration and GUI interface, simulated in Matlab;
- the MySQL database;
that will be depicted in the next subsections.

V-REP Simulation Components

The V-REP [1] simulation consists of the following parts:
- a 3 DOF robot, figure 1, with two rotational joints (with planar motion) and one prismatic joint with vertical motion, to pick and place the seals (figure 3, right);
- two conveyors, depicted in figure 1, to transport the two types of seals;
- three cable terminal plugs, as depicted in figure 3 left, where the seals are to be placed;

The Matlab Environment Components

The Matlab environment components consists of the following parts:
- the robot controller;
- the Matlab communication to V-REP;
- a System Calibration based on a vision module, not presented in this paper.

The MySQL Database Components

The MySQL Database components consists of the following parts, depicted in figure 4:
- a software module in Matlab to connect to the Robot controller;
- the ‘id’ and ‘code’ for each seal pattern, e.g., the ‘id’ is the name of the seal pattern and the ‘1’ and ‘0’ states if there is to be, or not, a seal a given plug terminal position;
- the GUI interface, figure 5, that comprises an interface, from the Matlab environment to the MySQL database, communicating in both directions;
In 2015, IEEE Robotics and Automation Society produced its first ever standard [2]. The standard was related to ontologies and was focused to represent the basic knowledge related to the robotics domain to be used by the community [3]. From the represented knowledge is then possible to reason in robots, the environment and human co-workers, to jointly perform tasks. Moreover, the standard provides tools for a formal reference vocabulary to be used in the communication between humans and/or robots. In this paper is applied the standard towards the representation of the machine knowledge, in its levels, i.e., the machine components, processes, and environment. The first part, will be addressed in this section. The processes and environment parts, will be addressed at the application domain level in the next section.

For the machine components was applied directly the IEEE standard, i.e., the Core Ontology presented in [2] where the Robot Main Parts and relations were properly defined.

In figure 6 is presented directly the definitions in the standard, where is depicted that a robot is a device and also an agent that can reason, based on knowledge. Moreover, in figure 6, are also depicted several types of devices that can be part of a robot, e.g., a sensor, a mechanical link, etc.

From the Knowledge based built, all the components from the machine are instantiated. For the pneumatic actuators present in the gripper, the instances were named: AC-02 and AC-01, as depicted in figure 7. In the same figure the instance SE-01 is a sensor that is equivalent to the sensor classes: proximity sensor, switch sensor, inductive sensor. The Robot is named ‘3dofRobot’ and the GriperEffector class have an instance named ‘PlaceSealGripper’. For the sensors and actuators, the instance names in the knowledge base are exactly the same that are present in the electric circuits, which is very useful for maintenance.

Figure 7: Instances of the CORA ontology when applied to the application scenario

Figure 8, presents the physical components of the robotic system, i.e., a close up of the real ‘PlaceSealGripper’ and the two pneumatic actuators and the sensor to detect the cylinder back position.

Figure 8: Physical implementation of the gripper for seal placement, with two actuators and one sensor
The main sensors and actuators are present in the knowledge model depicted in figure 9, where all the instances are present. Moreover, several information can be inferred from the diagram. The actuator ‘AC-09’ is attached to ‘LinkX’ that is also attached to the ‘3dofRobot’, being the latter an instance of the class ‘Robot’. Similar inferences can be drawn for the sensor, e.g., ‘SE-08’ is attached to the ‘SealFeederBase’.

5. Application Domain Ontology

In this section are presented the tasks that the robot must perform to achieve the goals defined in section 2, i.e, to place the seals in the cable plug terminal.

Figure 9, presents the main sub-processes within the main class defined in CORA ‘RobotMotion’. The tasks are high level defined in the ontology and have a low level implementation in the robot controller.

The Tasks defined are directly related to the actuators. The tasks ‘ReleaseSeal’ and ‘CaptureSeal’ use the pneumatic actuator. The task ‘RotateBase120’ use a 3 phase electric motor to rotate the base where the cable plug terminals are to be located, for seal insertion. All the other tasks use the two DC motors of the robot joints to move the robot in the XY plane.
6. Results and Discussion

In this section are presented the results of using the knowledge model defined in the ontology. The main results were obtained by reasoning with the ontology, and by using the GUI interface to program the robot controller in the simulation scenario, and also to interface with the cloud with the sealing patterns.

Reasoning

Using the ontology and description logic queries is possible to is a straight forward way to obtain, to obtain the following information:

- Sensors on the end-effector of the robot, as depicted in figure 10.
- Actuators on the end-effector of the robot, as depicted in figure 11.
- Devices that are needed in a defined task, as depicted in figure 12.
- A clear explanation for some of the information given on a query, as depicted in figure 13, for the query depicted in figure 12.

Figure 10: Query about sensors on the end effector.

Figure 11: Query about actuators on the end effector.

Figure 12: Query about devices involved in a task.

Figure 13: Explanation why AC-10 is involved in a task.
In figure 14 is presented the robot in operation, using V-REP, where the sealing pattern defined in figure 15, was stored in the cloud.

![Figure 14: Sealing Machine in Operation, V-Rep Simulation.](image1)

The developed framework was built based on the IEEE ORA standard. Specific contributions were developed to extend the previous ontologies to the presented application case, e.g., for interaction with environment and robot movement. Moreover, a database of seal patterns is implemented in the cloud to be fetched, as needed, by the robot. Based on the tasks/processes obtained from the developed framework, the robot will seal a batch of cable terminals, automatically.

The system was validated by the implementation in a simulated scenario, in V-REP, using a 3 dof, Scara Robot. The knowledge base, specially defined for the developed framework, based in CORA, was also validated by performing first order logic reasoning actions to obtain valuable data for production and maintenance at the factory level, namely information about sensors, actuators, and its purpose in the tasks defined in the ontology.

![Figure 15: Sealing Machine in Operation, Matlab GUI interface.](image2)

### 7. Conclusions

The paper proposed an ontology driven framework to define a machine used for automatic pick and place robotic tasks. The developed framework was successfully simulated and validated in an automotive manufacturing environment where seal have to be placed in a cable plug terminal.

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8. References

