Automatic Programming for Industrial Robotics: A Cornerstone for Cyber-Physical System in Industrial 4.0

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Abstract. Although modern industrial robots have been largely improved in accuracy and precision, they still require much downtime of reprogramming for a new product. How to shorten the reprogramming downtime is a challenge in the industrial robots. Based on the Core Ontology for Robotics and Automation, this research proposes to apply knowledge driven approach to automate the programming of industrial robots. This research applies Protégé to model classes and to utilize its Semantic Web Rule Language (SWRL) to specify the knowledge rules. From a development perspective, four layers have been proposed: data, ontology, reasoning, and deployment. The instances been specified by the classes in the ontology through the real objects in the data layer are inferenced by the knowledge rules for further instances and facts in the reasoning layer. Then, the instances and facts are further composed into a robot program in the deployment layer.
This research applies the developed method in packaging farm products. The result demonstrates that a robot can automatically program for its designated tasks without human involvement.

Keywords: Core Ontology for Robotics and Automation, Knowledge Driven, Industry 4.0, Protégé

1. INTRODUCTION

An industrial robot is a combination of connected actuators. A robot program plays a role to translate each of the commands into function requirements of each actuator. Such a paradigm has not been challenged since the industrial robots were invented. However, huge downtime requirement for robot programming is not suitable as the batch size is getting smaller and the automation flexibility is becoming higher and higher. How to automate the robot programming becomes an issue.

This research observes a condition that usually a robot is designed to do similar tasks. To automate the robot programming, it relies on obtaining the knowledge of those tasks. Based on the knowledge, a robot program can be reasoned and then can be automatically coded for a new specific task.

2. LITERATURE REVIEW

This research review research in three fields: urgency for robot auto-programming, ontology for robotics and automation, and knowledge driven robotics. Literature in the three fields construct the necessity and basis for developing the modeling approach of this research.

2.1 Urgency for Robot Auto-Programming

Schlenoff et al. (2015) point out that even though the accuracy and precision of robots have been greatly improved, programming of robots still relies on a teach pendant. Not only the accuracy of the robot will be equal to the low accuracy of the operator of the teach pendant, the intolerable downtime for frequent reprogramming, through a teach pendant or not, due to the small order batch size is becoming a challenging issue.

Notwithstanding, in Industry 4.0, issues regarding cyber-physical system, internet of things, and intelligent equipment are all related with the quick changeover in accordance with the specific customer demand. If an industrial manipulator is unable to be quickly reprogramed, it is impossible to satisfy the dynamic customer demand.

2.2 Ontology for Robotics and Automation

A robot is situated in a designated conceptual environment. Unless the environment, the robot itself, and the task are described clearly, it is impossible to auto-program a robot. Ontology can be applied to fulfil such a need. Ontology defines the existence and the interrelationship of the entities (Sowa, 1995). Specifically, ontology is a collection of knowledge terms which include vocabulary, semantic interconnection, and logic inference (Hendler, 2001).

Suggested Upper Merged Ontology (SUMO) has been introduced as a high level ontology for robotics and automation systems (Niles & Pease, 2001). Prestes et al. (2013) further extend SUMO into Core Ontology for Robotics and Automation (CORA). Only when a robot's specific ontology developed based on CORA is defined, the robot program for the specific task in a specific environment can be automatically generated.

2.3 Knowledge Driven Robotics

Balakirsky et al. (2013) separate the motions of a manipulator by two directions: (1) sense→model→act and (2) domain specific information→ontology→planning language→robot language. The planning language in the second direction, they take Planning Domain Definition Language (PDDL) as the inference language. However, even though PDDL is similar to knowledge-based system, its interface with ontology and robot language is still a problem.

To conquer the above-mentioned issue, Balakirsky replace PDDL with XML to define the parameters, preconditions, and effects of the manipulator (Balakirsky, 2015). Then, he utilizes Region Connection Calculus (RCC) (Schlenoff, Kootbally, Pietromartire, Franaszek, & Foufou, 2015) to infer a manipulator's motions in time and space. He successfully develops a robot program in Canonical Robotic Command Language (CRCL) defined by National Institute of Standards and Technology (Proctor et al., 2016). Balakirsky's research (2015) is one of the very few research that can automatically inference the robot program. However, because the XML is not suitable for reasoning and domain-specific database query could hinder the applications of his research.

The other research developed by Navarro-Gonzalez et al. (2015) is based on a specific case study for arm movement. Their research is not applicable for the auto-programming of robots.

3. MODELLING APPROACH

There are four layers in our approach to model automate the programming process for a robot: data, ontology, reasoning, and deployment (Figure 1). In the Data Layer, this research utilizes machine vision system to capture the basic geometric data for the objects (in this research, fruit and package box). Ontology Layer is the core to configure the class (knowledge framework) and the knowledge rules by Semantic Web Rule Language (SWRL). In the Reasoning Layer, the Inference Engine based on Jess and Pellet reasons based on the facts of the environment, such that an action of the manipulator, in format of a robot code, can be specified and be deployed in the Deployment Layer by a Hiwin SCARA Robot. The Ontology and Reasoning Layers are developed by Protégé, an open-source ontology editor and framework for building intelligent systems (Protégé, 2016).

3.1 Object Model

This research takes a fruit packaging as a case example to illustrate the methodology. There are four sub-class under Object: Box, Fruit, Point, and Region. Coordinates and size limits of the Box and Fruits are also specified in the class model, as shown in Figure 2.

3.2 Perception Model

Detect is the sub-class of Perception Class. Detect has sub-classes: Box and Fruit. Fruit is specified by hasColor and hasFruitSize to associate with Color and FruitSize classes. The model is specified in Figure 3.

3.3 Position Model

A Position class is specified by two subclasses: Point and Region. The Point and Region of the Box and Fruit are specified by inferencing the given rules. The Region class defines the coordinates and edges of the Box. The Point class specifies of picking coordinate of the Fruit and the placing coordinates in the Box through reasoning. The class model is showed in Figure 4.

3.4 Robot Program Model

A Robot Program Class specifies the Program attributes that will appear in the fruit packaging task, as shown in Figure 5.

3.5 Robot Anatomy Model

A Robot Type Class has three subclasses: RobotGripper, RobotDriven, and RobotStructure. They specify the anatomy of a robot, as shown in Figure 6.

4. DEPLOYMENT

A detailed flow is illustrated in Figure 7. In the Data Layer, the Machine Vision capture the picture and feature attributes of the fruit to build the object. Then the coordinates of the objects (fruit and box) are translated from the relative coordinates of the robot and the camera into World Coordinate. The above process is realized by Labview and the data is stored in a MySQL database.

In the Ontology Layer, the data in the Data Layer were associated with the class properties in MySQL by DataMasterTab in Protégé to define the instances. Each instance has its individual attribute values. In the Reasoning Layer, by taking the instances and the SWRL rules, Jess API infers new instances and facts. Those instances and facts are the elements for the robot program. For example, we can have the following rule to designate a program format of the Hiwin SCARA robot.

```
Type(?x)∧RobotType(?x,"SCARA")∧Program(?y)
→Variable(?y , "#1") ∧ variable2(?y , "#3") ∧
variable3(?y , "#1")∧Math(?y , "=") ∧ Math2(?y , "=") ∧
Math(?y,"TO") ∧ Numerical(?y , 0) ∧
Numerical3(?y,1000)∧Numerical5(?y,8)∧
Numerical6(?y,0)∧Numerical7(?y,8)∧
Numerical8(?y,1)∧program(?y,"FOR")∧
program2(?y,"END_FOR")∧program3(?y,"SELECT") ∧
program4(?y , "END_SELECT") ∧
program5(?y , "W_MLC_O")
```

In the Deployment Layer, the instances and facts in the Reasoning Layer were composed into a robot program. The system is deployed in a Hiwin SCARA robot as shown in Figure 8 (a). The robot program can successfully trigger the robot to pick a fruit and place in a box, shown in Figure 8(c).

5. CONCLUSION AND FUTURE RESEARCH

Today's industrial robots still rely much on the teach pendant for programming. Such a programming approach demands large downtime and does not meet the various needs with a small order batch size. The frequent reprogramming on the robot also demands a large number of engineers. Hence, it is necessary to develop an automatic-programming approach, so each industrial robot can program by itself to complete the task requirements.

As a robot is usually designed to a group of similar tasks, this research applies ontology oriented approach to describe the knowledge of objects, positions, robot program, and robot anatomy. In addition, the knowledge rules in accordance of the real situation are specified. This research applies Protégé, an ontology software system, to describe the knowledge and rules.

This research develops a system with a four-layer structure (data, ontology, reasoning, and deployment) to realize the auto-programming. The system include capture a picture from a machine vision, and then detect the required coordinates to let the classes in the ontology layers can specify the instances. Based on the rules, the instances can inference further instances and facts as the elements of a robot program. Finally, the deployment layer combines the elements into a robot program for the specific task. The system has been successfully applied in a fruit packaging example.

Based on the study in this research, there are two future research directions:

(1) Developing a canonical model for integrating the pictures from the machine vision, so the associated objects can be efficiently and intelligently input into the ontology classes.
(2) Applying the approach to other operations, e.g., arc welding, to prove the feasibility of the four-layer model.

ACKNOWLEDGMENTS

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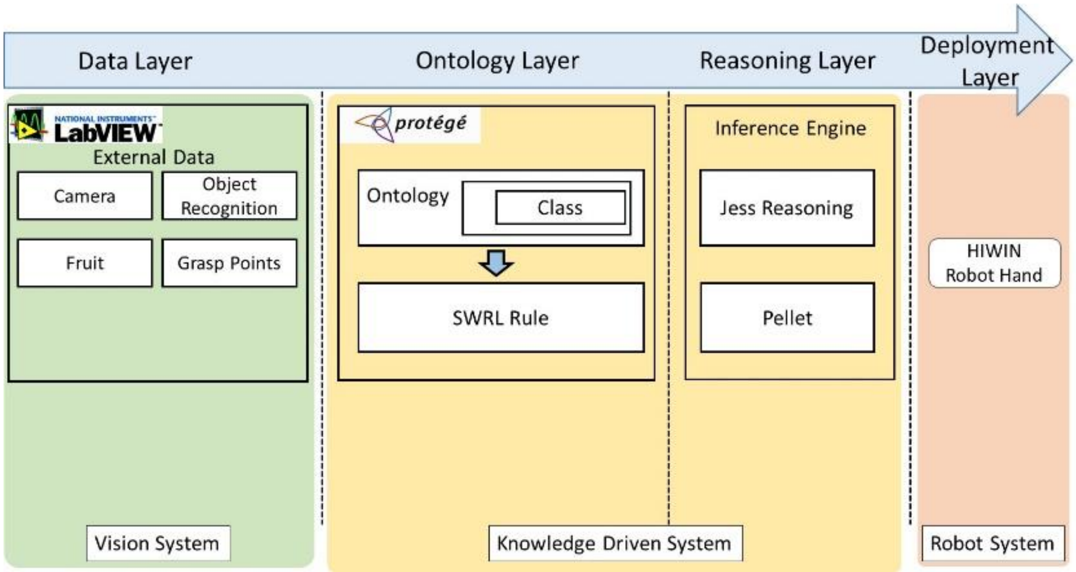

Figure 1 Four Layers in the System

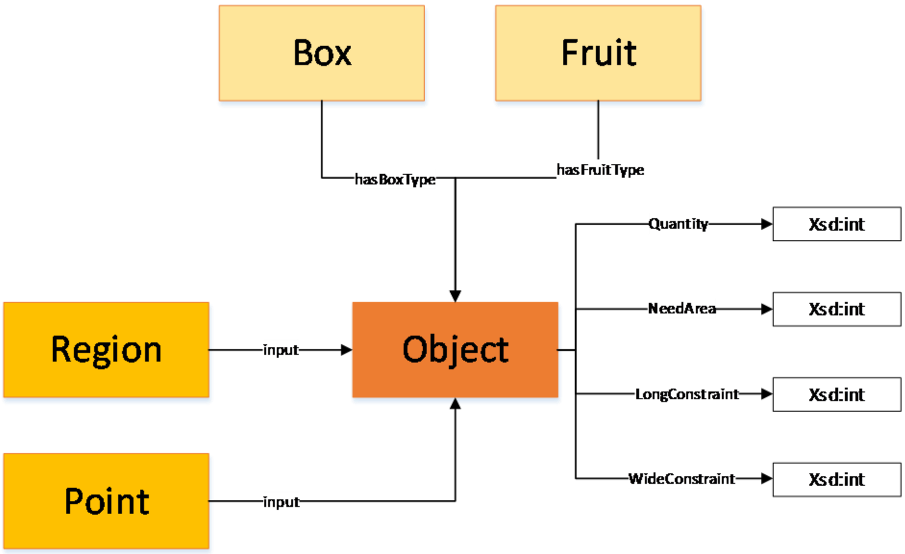

Figure 2 Object Class Model

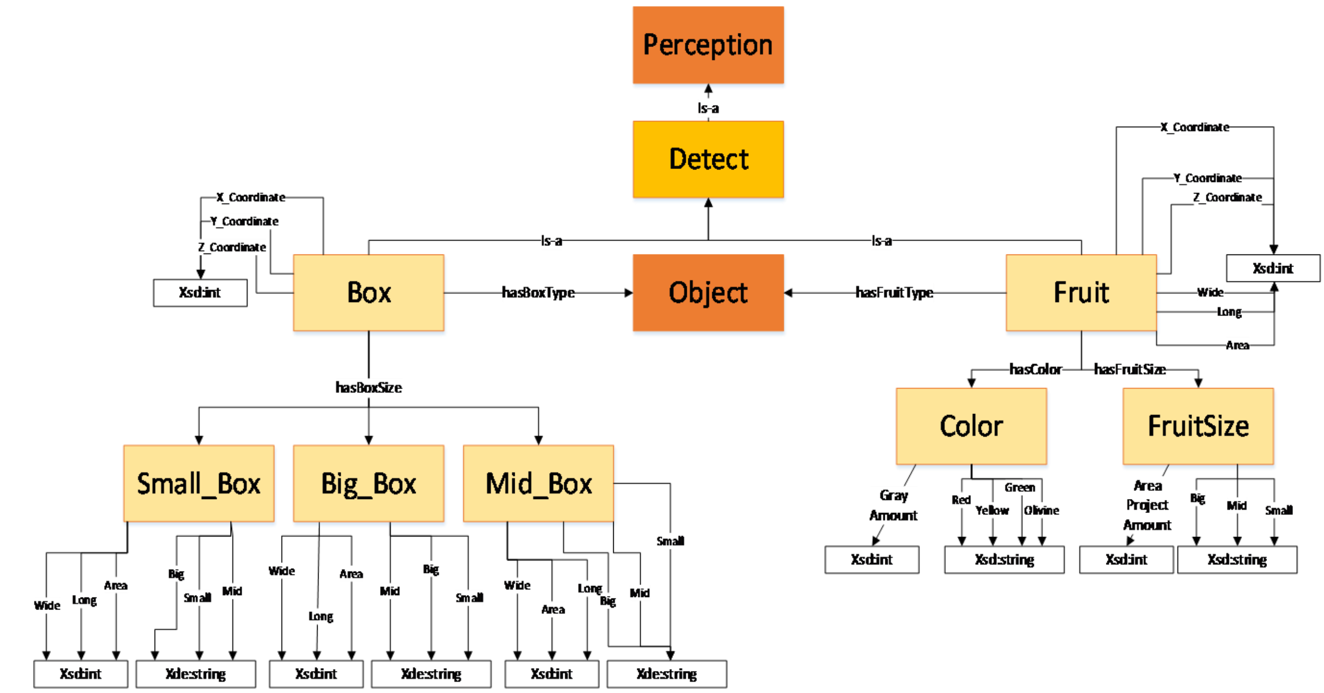

Figure 3 Perception Class Model

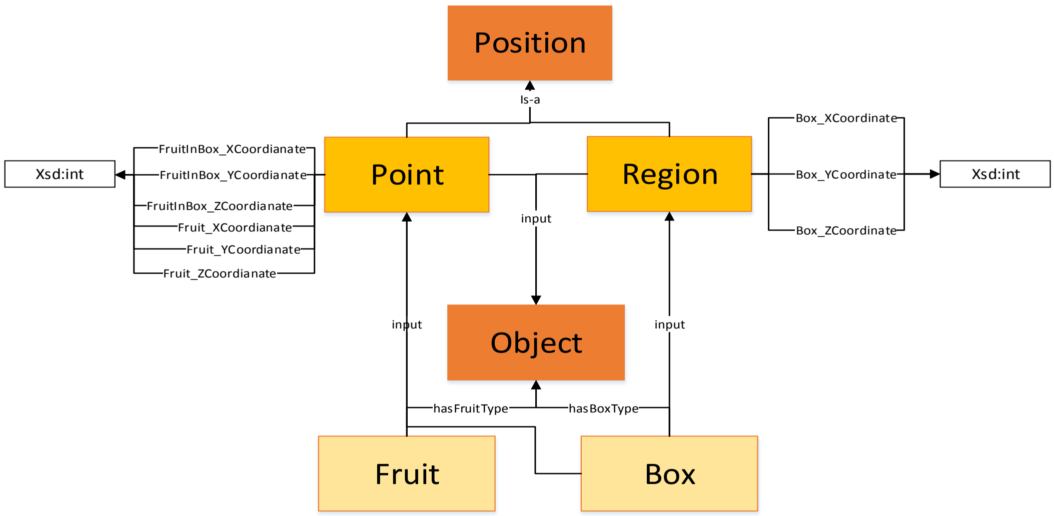

Figure 4 Position Class Model

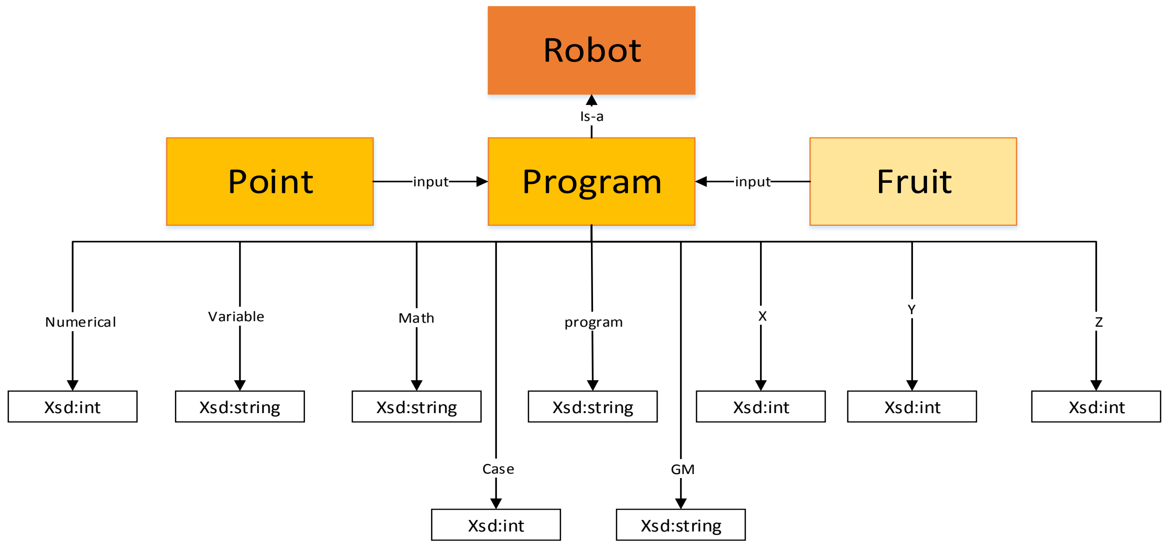

Figure 5 Robot Program Class Model

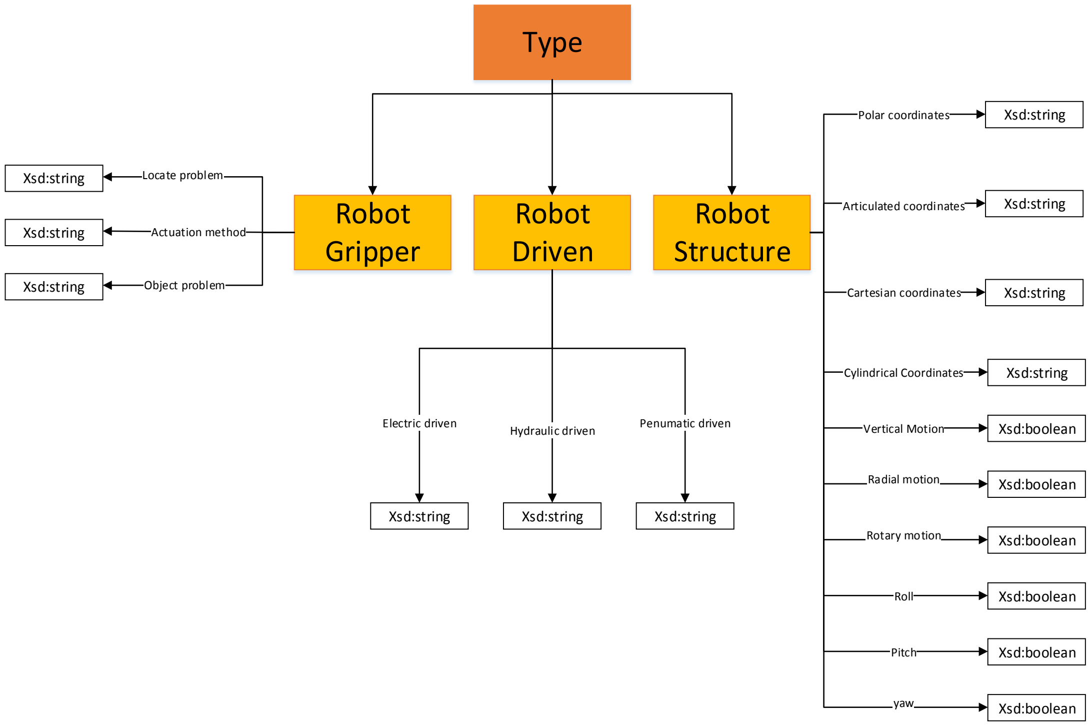

Figure 6 Robot Anatomy Class Model

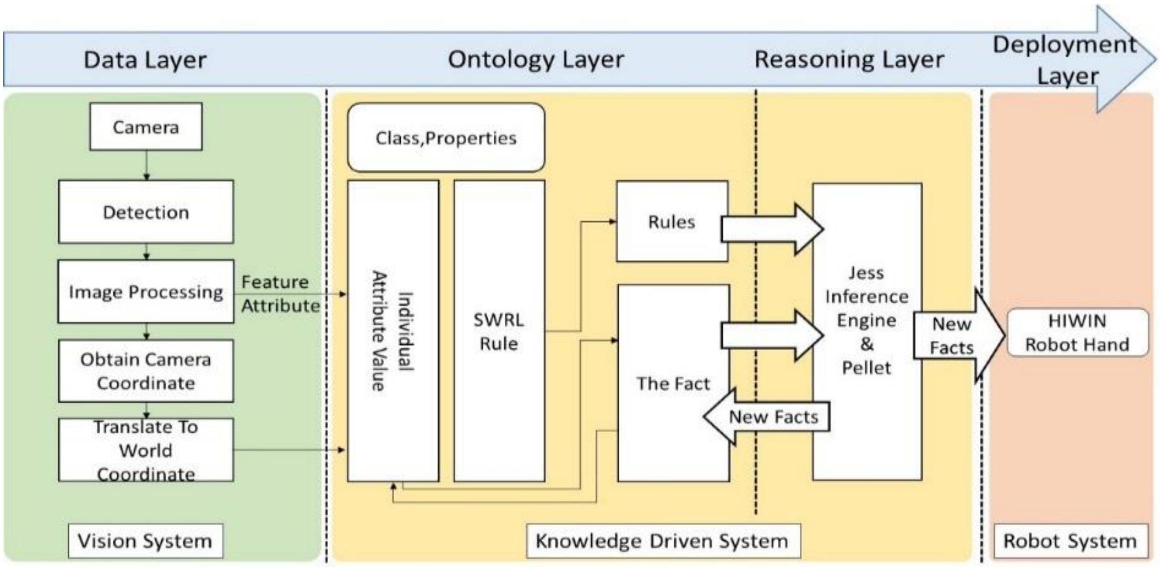

Figure 7 Deployment flow chart

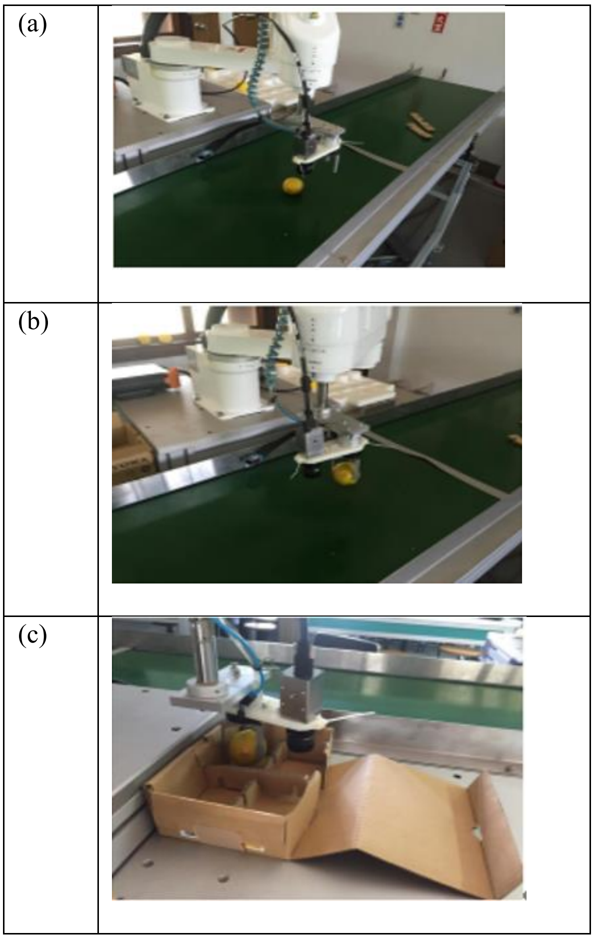

Figure 8 The robot program is successfully deployed in fruit packaging