The Fourteenth International Symposium on Artificial Life and Robotics 2009 (AROB 14th '09),
B-Con Plaza, Beppu, Oita, Japan, February 5 - 7, 2009

Robust Object Instance Registration to Robot-centered Knowledge Framework

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Abstract

Robot-centered knowledge enables a robot to perform complicated service tasks. It requires that robot knowledge robustly be instantiated for logical rigidness. However, there are some misidentifications in object recognition using a single camera. In this study, robust object instance registration method is proposed to detect misidentifications of object recognition. There are four types of properties for reasoning mechanisms: confidence of recognition of objects for statistical reasoning, inherent properties of object for ontological reasoning, spatial relation between objects for spatial reasoning and temporal relation of intervals between object detections for temporal reasoning. Validity of recognition of an object will be proved by using rules of reasoning mechanisms, since the object may not be assured to be correctly identified at the time of recognition. Additionally, action recommendation rules are applied to confirm the authenticity of object recognition when an object is not proved for a given period of time. To show the validity of proposed robust object instance registration method, several experimental results will be presented in an indoor environment.

1 Introduction

Semantic knowledge is required for a service robot to perform service tasks only with an object-based environment map. Suppose that you visit your friend's house and ask him/her where a cup is located. Then, he/she will answer, for example, "Go to the kitchen. A cup may be on a dinner table, or in a cupboard." In this case, Nobody says as follows; "a cup is at (x, y)." Humans will use semantic information instead of using such a metric data. In our previous works [1], we proposed robot-centered semantic knowledge framework, called Ontology-based Robot Knowledge Framework (OMRKF) which is developed for robot-centered knowledge representation. OMRKF includes four knowledge classes: perception, object, space, context, and action. And, in OMRKF, there are available domain specific rules to verify relations between knowledge classes. For robot-centered knowledge, it is required to robustly instantiate robot knowledge classes. Instances are often created by using object recognition algorithms. However, there will be some misidentifications such as false positives and/or false negatives because of imperfect object recognition algorithms. Also it is difficult to know if recognized objects are true positives or not. Inconsistent knowledge instances created from false recognition can prevent robot-centered knowledge from working for inference correctly.

There are research works that attempt to detect or control false data using rules-based [2] or randomization-based method [3]. Detection of misidentification in object recognition can be said to be one of uncertain problems. To cope with any uncertainty or vagueness using rule-based approaches, some methods are presented on various areas [4]. And there are also attempts to manage uncertainty in logic programming [5] [6]. For uncertainty, probability is considered to be the most useful approach. However it has some weaknesses, such as a scale problem that occurs when another new element is added to it. Rule-based system has advantages, such as locality, detachment, and truth-functionality. Thus, rule-based system such as expert system helps humans to make decision in a specific problem domain with rules which is gathered from expert's knowledge [7]. So, we consider cafefully object recognition in indoor environment, and extract rules to detect misidentifications.

Actually, at the time of recognition, nobody can assure that an object is correctly recognized. Therefore the recognized object cannot be registered at the time of recognition. Thus, we propose a robust object instance registration method for robot-centered knowledge framework, where the four types of properties

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are considered to be used in reasoning mechanisms: confidence of recognition of objects for statistical reasoning, inherent properties of object including mobility for ontological reasoning, spatial relation between objects for spatial reasoning and temporal relation of intervals between object detections for temporal reasoning. Object properties are designed by using ontology to assure the consistency of robot knowledge base. Spatial relations and temporal relations, as supplementary information, are employed to verify authenticity of object recognition. Additionally, for the case when an object is not proved for a given period of time, actions of a robot are recommended to confirm the authenticity of object recognition.

To verify the proposed approaches, some experimental results will be provided for an indoor lab environment, where 20 objects are distributed over the environments.

2 Ontology-based Robot Knowledge Framework (OMRKF)

From a need of semantic information for service robot, we proposed robot-centered knowledge framework, called OMRKF, which has four knowledge classes, such as perception, model, context and activity [1]. The robot-centered knowledge is integrated by using ontology from low level sensory-motor data such as visual feature, atomic behaviors to high level information such as objects, spaces, contexts, and service tasks. It ensures consistency for all instances created by using this scheme. And there are domain specific rules that support bi-directional reasoning means. OMRKF gives robots more opportunities to complete complicated missions. Fig.1 shows the system concept of OMRKF.

Figure 1: System concept of OMRKF

3 Misidentification in Object Recognition

For the robot centered knowledge, it is required to robustly instantiate robot knowledge classes for logical ridigness. Instances in the robot-centered knowledge are often created by using object recognition algorithms. However, there will be some false object identification such as false positives and/or false negatives because of imperfect object recognition algorithms. Also it is difficult to know if recognized objects are true positives or not. We made robot taking snaps consecutively, recognizing objects and localizing by using the Evolution Robotics Software Platform (ERSP) [8] in an indoor lab environment, where objects are distributed over the environments.

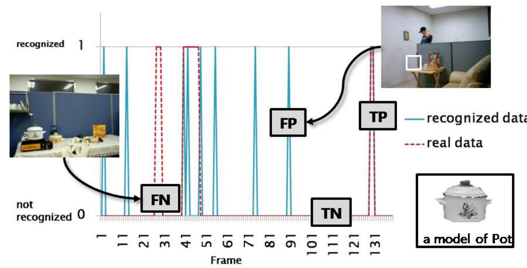

Figure 2: Object Recognition for Pot using ERSP

Fig.2 shows object recognition for pot and corresponding ground truth-data. The solid lines in this figure show the recognition of pot using ERSP vision module, and dotted lines show that there is a pot in the snaps for real. Here, there are misidentifications, such as false positives and/or false negatives, quite frequently in object recognition. Inconsistent knowledge instances created from false recognition can prevent robot-centered knowledge from correctly working for inference.

4 Overview of Proposed Rule-based Object Detection Method

4.1 System concept

To deal with misidentifications of object recognition, we propose a robust object instance registration method for the robot-centered knowledge framework.

Fig.3 illustrates system concept of our proposed method. We have designed rules to confirm authenticity of object recognition. For the rules, the following reasoning mechanisms are conidered: statistical reasoning, ontological reasoning, spatial reasoning and temporal reasoning. First of all, recognized objects are stored to buffers, such as p-buffer and/or n-buffer. Applying rules on the objects in buffers, the recognition of the objects is proved to be true or not. Finally,

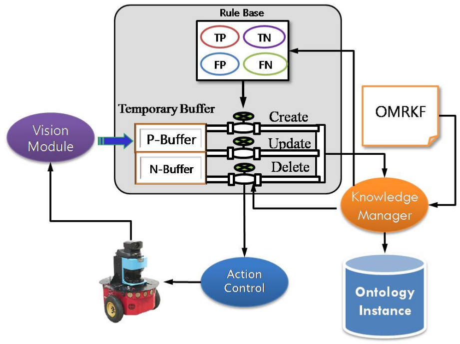

Figure 3: System concept of proposed object instance registration method

the proven objects will be settled into ontology instance database by Knowledge Manager through the three functions: create, update, or delete.

4.2 Temporary Buffers and Intervals

Because of misidentifications, the recognized objects cannot be registered at the time of recognition. To cope with this problem, two buffers, named positive buffer and negative buffer, are designed to store recognized objects until they are proved to be true or not. The buffers consists of fields of time string, object id, whether or not the object is recognized, localized x and y position. The recognized objects, before the objects are instantiated, are stored in the positive buffer (p-buffer). So are the objects recognized on different positions when compared to one in instance database. And the unrecognized objects that were registered and supposed to be recognized according to view of a robot are stored in the negative buffer (n-buffer). To confirm whether the recognition of the objects in the buffers are true or not, intervals are measured between instants at which the same object is or has to be recognized and localized. There are two types of intervals, named *is*-Interval and *has-to-be*-interval. all objects in the buffers have its own intervals. Those intervals are composed from buffers by a localized position. Fig.4 shows an example of buffers and intervals.

Suppose that a robot was moving around from time T1 to T5, recognizing the object A that is not yet instantiated. A was recognized and localized on (150, 100) at time T1, then a region for A is created around localized position by threshold (here, the threshold is assumed as ±30.) The recognitions of A from T1 to T5 have been stored continuously in p-buffer. However, the recognized result of A at T3 is not included in *is*-interval of A at T5, because localized position at T3 was out of the region.

When an interval satisfys one of rules, the object in the interval will be settled into ontology instance database by one of functions; create or update for the object in *is*-interval, and delete for the object in *has-to-be*-interval.

4.3 Properties in Reasoning Mechanisms

Four properties are utilized in reasoning mechanisms to build rules in our proposed method: inherent properties of object for ontological reasoning, spatial reasoning, and temporal reasoning, and confidence of recognition of objects for statistical reasoning.

Object properties are designed by using ontology to assure the consistency of robot knowledge base. Mobility, spatial relations, temporal relations and confidence of recognition, as supplementary information, are employed to verify authenticity of object recognition. These properties are used for ontological reasoning, spatial reasoning, temporal reasoning and statistical reasoning. Object properties are placed in robot-centered ontology scheme and/or instance database. So they are provided to rules by Knowledge Manager(KM).

Mobility of each object represents how easily the object can be moved. In the case of cups, pots, and snacks, their values of mobility property are true. On the other hand, the values of mobility property are false for television, refrigerator, and desk.

Spatial relations among objects, such as left, right, above and so on, are generated from localized position between objects by spatial reasoning, when object instances are created. Spatial relations are used to provide additional information to efficiently prove the object recognition to be true or not.

Temporal relation represents relations of intervals between object detections using before, met-by, overlapped-by and so on. Temporal relations are used

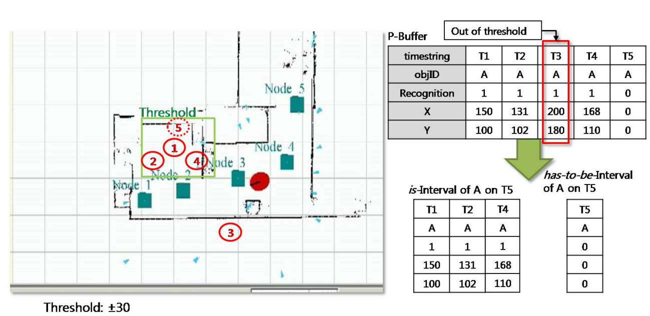

Figure 4: Example of buffers and intervals

for temporal reasoning which was proposed in [9] to reason about if some objects are recognized together or not for several periods of times.

Confidence of recognition is computed by interval-counter(γ) from recognition rate of each object to be used for statistical reasoning. Recognition rate of each object in the proposed method is obtained as follows: suppose that a robot took 100 snaps of object A while moving around. And A was recognized in 80 snaps. Then the recognition rate of object A is 80%. Recognition rates of objects in our method are supposed to be given by experts before rules are applied.

If the recognition rate of object A is x, (1-x) is the probability for that the recognition of A can be false. From that, (1-x)$^\gamma$ can be calculated to define probability when the vaues of γ consecutive recognition are all false. If the result of (1-x)$^\gamma$ is less than 5%, then it can be said that the recognition are reached 95% of confidence level. The interval-counter at that case is represented as follows;

$$\gamma : (1-x)^\gamma \geq 0.05. \tag{1}$$

Suppose that two objects A and B are recognized together and they have spatial reations to each other. Then we can measure confidence of recognition for multi objects and it can be expected to enable object recognition to be proved, although the confidence of recognition for multi objects is less than confidence recognition for each object. Interval-counter for multi objects, that makes confidence of recognition reached 95% of confidence level, is derived as follows;

$$\gamma_{multi} : (\Pi_{i=1}^{n}(1-x_{objI}))^{\gamma_{multi}} \geq 0.05. \tag{2}$$

Interval-counter for multi objects(γ_{multi}) will be used only to update or delete object instances in instance database.

5 Rules

Using the four properties, we have designed rules to confirm the object recognition. The rules can be clissified into three categories by reasoning mechanisms: statistical reasoning rules, spatial & temporal reasoning rules, and action recommendation rules. If objects which are already registered are recognized on the registered position, the recognized object will be considered to be proved as true.

5.1 Statistical Reasoning Rules

Rules in this category are called as statistical reasoning rules, used for most cases in object recognition. The statistical reasoning rules are used for the first instantiation of objects, update of instances caused by object mobility, or unrecognized objects that were supposed to be recognized according to view of a robot. Recognized objects are stored in buffers with lapse of time as a robot is moving over and over, and magnitude of intervals becomes growing. When *is*-interval of an obejct reaches over some confidence level, the recognition of the object is proved to be successfull. The statistical reasoning rules given above will look like;

```
IF an is-Interval of TV AND
  length of the Interval is over 3
  (interval-counter of TV)
THEN The data are proved as true.
```

5.2 Spatial & Temporal Reasoning Rules

Rules in this category are used to update or delete object instances in instance database. If an object A is identified and, there are spatial relations or temporal relations with other objects B's, and B's are recognized with same spatial or temporal relations with A, then recognition of object A can be proved by applying γ_{multi} even at a confidence level which is lower than the confidence level employed in the first remedy described above. Rules given in this category will look like;

```
IF An is-Interval of Clock AND
  DeskLamp has spatial relation with Clock AND
  DeskLamp also has is-interval AND
  the intervals are overlapped AND
  length of the overlapped intervals is over 2
  (interval-counter for the objects)
THEN the recognitions are proved to be true.
```

5.3 Action Recommendation Rules

There are cases that an object is not proved for a period of time with the above-mentioned rules. It is necessary to handle with this object. Therefore, in the proposed method, actions like an object re-searching are used with object properties. Action is special property of robot, which makes robot different from regular computer. There are three types of action recommendation rules.

First, when an object is not proved for a given period of time, magnitude of the intervals will be growing

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over and over. To deal with this object, actions of a robot and mobility of objects can be utilized. For example, if the object does not have mobility, we can think the *is*-intervals are true, because the obejct is recognized on one position for a given period of time and it is hard to be thought that the object could be moved frequently for that moment. In the case when the object has mobility, it cannot be proved easily, so it is necessary to re-search the object around the localized position. These kinds of rules will look like as follows;

```
IF length of all Intervals of Cup is over two
  times of 5 (interval-counter for Cup) AND
  Cup has mobility
THEN re-search around Cup.
```

Second, there could be a case where object A has been proved as true negative but A does not have mobility. In this case, it could be either that object was truely moved or not. The object could not be recognized by other reasons. We cannot easily be sure of the reasons. Therefore, re-searching the object could be useful for correcting additional information to confirm the result. These rules will look like as follows;

```
IF Fridge has been proved as TN AND
  Fridge has not mobility property
THEN re-search around Fridge.
```

Third, we can come up with some cases where object A has been proved as true negative but object B which has spatial relation with A has been considered as true positive. In this case, A could not be recognized from a variation of view caused by position of a robot. Through the actions refering spatial relation between the objects, the result of A can be confirmed. These rules can be represented as follows;

```
IF Keyboard has been proved as TN AND
  Monitor that has spatial relation
  with Keyboard has been proved as TP
THEN re-search around Monitor.
```

6 Experiment

6.1 Experimental Environment

Our experimental environment is made up of a kitchen and a living room. We made models for 20 objects and assumed that there is only one object for each object model in the environment. The recognition rate of each object is derived from the recognized object data in 213 snaps. A robot took snaps with a single camera attached on the robot and recognized the objects using ERSP vision module, as moving along with nodes.

6.2 Experimental Result

Fig.5 shows how proposed method works to confirm misidentifications and correct them. (a) in Fig.6 is about detection of false negative in recognition of TV using statistical reasoning rules. The recognitions of TV were stored in *p*-buffer. And two *is*-intervlas and a *has-to-be*-interval are generated for TV from the *p*-buffer. Interval counter(γ) for TV was measured as 3 in our experiment. The positive results of TV in buffers are proved to be true from the sec-

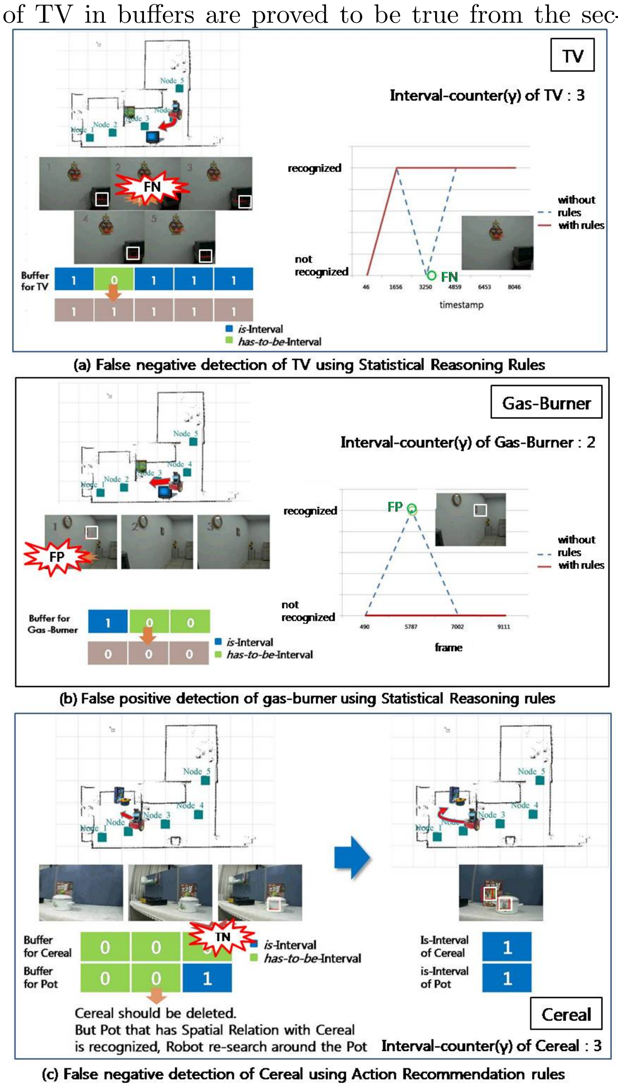

Figure 5: The results of object recognition using the proposed method.

Table 1: Misidentification rate

	without rules	with rules
TV	19.67%	9.83%
Cereal	23.80%	4.76%
Gas-burner	46.15%	23.07%

ond is-interval as it is reached the confidence level by applying statistical reasoning rules. Thus the negative results in *has-to-be*-interval at the second frame is considered as false and it is corrected to be true.

(c) in Fig.5 shows detection misidentification of cereal instance using action recommendation rules. Spatial relation between pot and cereal instances were generated when the instances were created. When the robot was watching the position where the pot and the cereal were, the cereal happened to be considered as true negative because it was patially shaded by the pot. At the moment when the cereal was proved as true negative, the pot was considered as true positive, so that the robot was asked to re-search around the pot by action recommendation rules. Finally, from changing the view by actions of robot, the cereal instance was found and the negative results of the cereal were ignored, then the instance of the cereal was kept in instance database.

Table 1 shows the rate of misidentifications about TV, gas-burner, and cereal without and with rules. From the result in table 1, we showed that the misidentification rate were reduced through the proposed method.

7 Conclusion

We proposed robust object instance registration method to robot centered knowledge framework, where statistical reasoning rules, spatial and temporal reasoning rules, and action recommendataion rules are employed. To verify authenticity of object recognition that cannot assure an object is correctly recognized at the time of recognition, buffers, named *p*-buffer and *n*-buffer, and intervals, named *is*-interval and *has-to-be*-interval, are designed. In addition, we showed that misidentifications in object recognition can be detected and corrected by using the proposed method, so that robot centered knowledge framework can be managed robustly.

Acknowledgements

This work was performed by a grant of the Second Stage of BK21 Research Division for Advanced IT Education Program on Industrial Demand, and for the Intelligent Robotics Development Program, one of the 21st Century Frontier R&D Programs funded by Korea Ministry of Knowledge Economy.

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