Proceedings of the 2002 IEEE/RSJ
Intl. Conference on Intelligent Robots and Systems
EPFL, Lausanne, Switzerland • October 2002

Environmental Support Method for Intelligent Robots
- Movement Decision Method of Robots Based on Reliability and Trial Time-

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Abstract

Recently the activity of robots has been remarkable, and robots are branching out into general environment such as home or office. Although robots are active, planners uniquely decide the action method of robots when robots operate missions. Therefore, the most suitable approach is not assured. So, in this report we propose a method that we evaluate robots' actions from the viewpoint of both reliability and time, when robots operate missions. Then we calculate the most suitable approach for robots. To be concrete, by using a diagram we evaluate robots' actions and calculate the most suitable approach. In addition, we evaluate them not from all the actions immediately, but from the action units by making an evaluation index. So, we can shorten the time for evaluation. Finally, we realize the operations by a real robot with the most appropriate approach.

1. Introduction

Needless to say, the recent progress of robot industry has been remarkable, and robots do active work in structured environment such as factories. And now, we expect the activity of the robots in general environment such as home and an office. If the robots can operate instead of human beings, we can omit the everyday routine work. In order to realize it, the robots need to recognize environment precisely, and we need to establish an environmental support method to give robots' actions flexibility.

However, even if we say simply that we support environment, it is costly difficult to rebuild home and office environment for robots. And the present situation is that we cannot expect higher recognition ability to robots than human beings. Then, as environmental supports for work realization by robots, the authors of [1] guide a robot that communicates with an environmental side using IDC. In addition, guidance for a robot and operation by a robot are realized using a landmark on the environmental side in order to recognize environment [2][3]. However, in these researches, designers decide installation points of items such as marks and ID assisting the robot in recognizing environment on their way. Even if a work aim is given concretely, the designers do not discuss how to arrange the marks, and how to decide the movement of a robot, which lead to appropriate work realization.

On the other hand, there are researches that argued reliability or robustness, and demand or utility in the current situation in choosing movement for a robot [4][5]. In [4], the author designs to select and execute actions in response to the current state of the world, then interleaves planning and execution. This makes actions more responsive to unexpected changes. And in [5], the authors suggest a method to let a robot select an action of high demand and utility in the current situation. In these researches, the authors consider reliability of work, but don't consider work time. It is general that it takes time if we raise reliability, and reliability falls if we shorten work time because reliability and work time are relation of trade-off.

So, in this report, we decide an appropriate work approach, which considers both reliability and work time. And we include the arrangement of devices supporting recognition of the environment when a robot operates a mission. In other words, we deal with the problem of robot's action based on what kind of environmental support and what kind of sensor.

As the simplest method to choose a robot's action on the basis of reliability and time, it is considered that by general experiments we evaluate the reliability and time for all the approaches that can be considered. However, this method needs whole experiments for all the operations, and so it takes much time.

So, by evaluating reliability and time of common element work that is not dependent on specific work, we evaluate reliability and time of more complicated work. And we decide arrangement method of devices supporting recognition of the environment and suitable sensor for a robot in operating a robot. In this report, we use marks as devices which support recognition of the environment (The reason is mentioned in chapter 5.)

To be concrete, we classify a mission of a robot into the work realization approaches first. Next, we divide each work realization approach in action units (we call this unit Sub-Task), and describe the units as diagrams. Then, by doing fundamental experiments on each action unit, we calculate reliability and average trial time of each action unit and apply the result to each diagram. Finally, as a result, we can decide the most suitable approach method from the evaluation considering reliability and trial time.

In this report, we take up "Sliding Door Closing", "Faucet Turning off", and " Button Pressing" as concrete examples. And, we calculate the most suitable approaches, then actually accomplish the missions by the most suitable approaches with a real robot.

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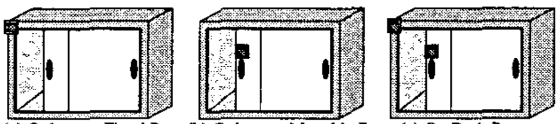
2. Classification of Work Realization Approach

When robots operate a mission, we classify the approaches using two methods: mark arrangement method, and robot control methods. We describe the classification method in this chapter.

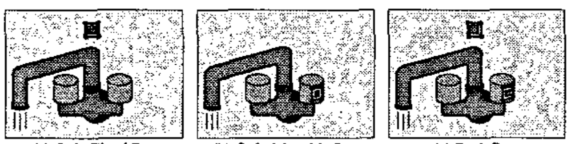
2.1 Mark Arrangement Method

There are a fixed part and a movable part in an operation target. So, as a primitive arranging method for marks to accomplish a mission by a robot, three ways are considered; (a) we place the mark only on the fixed part of an environmental side, (b) only on movable part (the point where a robot approaches), (c) on both parts (one fixed part and one movable part).
The mark arranging methods for "Sliding Door Closing", and "Turning off a Faucet" are shown Fig. 1 and Fig. 2 as examples. But in this report, we assume that we do not argue about a geometric mark arrangement.



(a) Only on a Fixed Part (b) Only on a Movable Part (c) On Both Parts

Fig. 1: *Mark Arrangement methods for "Sliding Door Closing" Mission*



(a) Only Fixed Part (b) Only Movable Part (c) Both Parts

Fig. 2: *Mark Arrangement methods for "Faucet Turning off" Mission*

2.2 Robot Control Method

If the mark arrangement is decided, the work realization approach is also decided. When mark is set only one part like (a) and (b) in Fig. 1 or Fig. 2, the robot needs a force sensor to complete the work. The time to search a mark can be shorter when there is one mark, but in case of (a), work becomes impossible in case that a door moves unexpectedly. In addition, the working speed and precision fall because the work is based on a force sensor. In case of (c), though it takes time to search two marks, we have a merit that the Position Control only by camera measurement is possible.

And so, we can consider two ways to control a robot. The ways are as follows.

(1) A method based on only camera measurement: Vision sensor-base

(2) A method based on camera measurement and a force sensor: force sensor-base

2.3 Classification of Work Realization Approaches

From three ways of mark arrangement methods and two ways of control methods mentioned above, we can consider totaled six ways of work realization approaches. But when we arrange the mark on one part (either the fixed part or the movable part), robots cannot operate by the position control based only on camera measurement. Robots need a force sensor. In other words, we need to use a force sensor to realize robots' operation. Therefore, work realization approaches are classified as Table 1.

Table 1: *Classification of Work Realization Approaches*

	On a Fixed Part	On a Movable Part	On Both Parts
Vision sensor-base	×	×	Method A
Force sensor-base	Method B	Method C	Method D

Table 1 shows that we need only four classifications. We will discuss the most suitable approach in these work realization approaches in Chapter 3 and 4.

3. Division of Work Realization Approach

3.1 Reliability Prediction Method of System

There is a psychological prediction method (a grade method) as one method to evaluate reliability of a system. This method is that an engineer who has experience and knowledge divides a system into suitable elements. Then he rates the divided elements, and predicts reliability of the whole system.

We evaluate the approaches using this reliability prediction method to them.

3.2 Division of Work Realization Approach

We divide each work realization approach in action units (Sub-Task) based on the psychological prediction method mentioned above, then express as diagrams. As an example, we show a diagram of method A of "Sliding Door Closing" in Table 1. It is shown in Fig. 3.

We set each action unit (Sub-Task) as S_i, reliability (success rate) of S_i as R_i, and time to need for one time of trial of S_i as t_i ($1 \leq i \leq n$). Then, we express Success as S and Failure as F. And a designer describes this diagram.

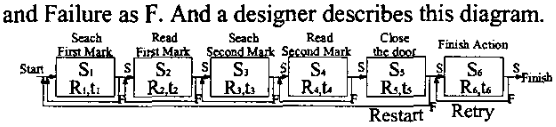


Fig. 3: *Diagram of Method A in "Closing a Sliding Door"*

When the Sub-Task mentioned above fails, in case that the mission must be repeated from the beginning, it is looped back in the beginning position as Restart. And in case that the Sub-Task can be retried or the mission can be repeated from any point on its way, it is looped back in the position as Retry.

If we describe the diagram in this way, we can consider that the mission will succeed in finite time unless the reliability of Sub-Task somewhere on its way is 0. We show in Fig. 4 an example of such a diagram which is generalized.

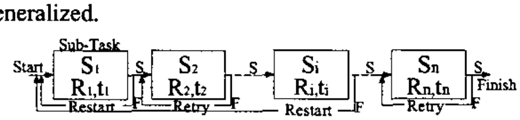


Fig. 4: *Generalized Diagram*

4. Evaluation of Work Realization Approach

4.1 About Evaluation of Work Realization Approach

We set the time that the Sub-Task (S_i) is accomplished as $F_i(t)$ for each work realization approach. And we set the average time when the whole work is accomplished (the time that the last Sub-Task is accomplished) as $F_n(t)$, and then we choose the work realization approach for the smallest $F_n(t)$ as the most suitable solution.

If the most suitable one is selected in this way, we can consider both reliability and time.

4.2 Derivation Method of Work Accomplishment Prediction Time

We set the time that a Sub-Task (S_i) is accomplished as $F_i(t)$. The time of the following Sub-Task is calculated as follows.

(i) When the mission must be repeated from the beginning as Restart shown in Fig. 5 because of the failure of the Sub-Task, $F_{i+1}(t)$ is expressed as equation (2) using probability equation (1).

$$F_{i+1} = \lim_{n\to\infty}\left\{\sum_{k=1}^{n}(F_i(t)+t_{i+1})(1-R_{i+1})^{k-1} - (F_i(t)+t_{i+1})n(1-R_{i+1})^{n}\right\} \quad (1)$$

$$F_{i+1}(t) = (F_i(t)+t_{i+1})/R_{i+1} \quad (2)$$

(ii) When the Sub-Task can be retried as Retry shown in Fig. 6 even if the Sub-Task fails, $F_{i+1}(t)$ is expressed as equation (4) using probability equation (3) like (i).

$$F_{i+1} = F_i(t) + \lim_{n\to\infty}\left\{\sum_{k=1}^{n} t_{i+1}(1-R_{i+1})^{k-1} - t_{i+1}n(1-R_{i+1})^{n}\right\} \quad (3)$$

$$F_{i+1}(t) = F_i(t) + t_{i+1}/R_{i+1} \quad (4)$$

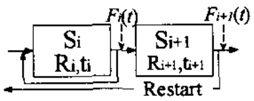


Fig. 5: Accomplishment Time Calculation (i)

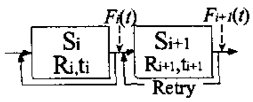


Fig. 6: Accomplishment Time Calculation (ii)

(iii) When all the following continuous k elements can be repeated from a point, and considered to be one loop shown in Fig. 7, $F_{i+k}(t)$ is expressed as equation (5).

$$F_{i+k}(t) = F_i(t) + \{((t_{i+1}/R_{i+1}) + t_{i+2})/R_{i+2} + \cdots + t_{i+k}\}/R_{i+k} \quad (5)$$

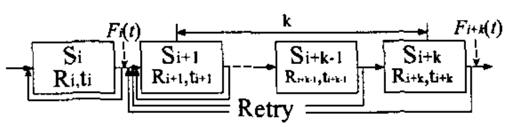


Fig. 7: Accomplishment Time Calculation (iii)

We can predict the mission accomplishment time $F_n(t)$ by calculating each $F_i(t)$ as above. When there exists another loop that is different from the examples mentioned (i)-(iii), we only have to calculate $F_n(t)$ up to the diagram.

4.3 Calculation for Reliability: R_i and Trial Time: t_i

We explain a calculating method of reliability: R_i and trial time: t_i of each Sub-Task. R_i and t_i are given by fundamental experiment for every Sub-Task. For example, R_i and t_i for searching marks can be expressed using searching distance: x_m and movement velocity of a robot: V_m as equation (6) and (7).

$$\begin{cases} R_i = f_{Ri}(x_m, V_m) & (6) \\ t_i = f_{ti}(x_m, V_m) & (7) \end{cases}$$

R_i and t_i for working movement can be expressed as equation (8)-(11) using working distance: x_w and movement velocity of a robot: V_v or V_f (V_v: robot velocity based on Vision sensor-base, and V_f: robot velocity based on Force sensor-base).

In case of Vision sensor-base

$$\begin{cases} R_i = g_{Ri}(x_w, V_v) & (8) \\ t_i = g_{ti}(x_w, V_v) & (9) \end{cases}$$

In case of Force sensor-base

$$\begin{cases} R_i = g_{Ri}'(x_w, V_f) & (10) \\ t_i = g_{ti}'(x_w, V_f) & (11) \end{cases}$$

By accumulating these values as database, even in case of a new mission, we can easily calculate the average work accomplishment time in each work realization approach of the mission.

4.4 Examples of Diagram for "Sliding Door Closing"

In case of "Sliding Door Closing", we can describe the diagram of Method A as Fig. 3 (we show classification of work realization approaches in Table 1). And the diagram of Method B or C is described as Fig. 8. The difference of Method B and C is the Sub-Task: S_3 although both methods are based on the force sensor. In case of Method B, the work can be realized only when the condition of the door is on the fixed mark. Moreover, because the position of the sliding door is not certain, the work realization may be impossible, and so reliability becomes lower.

On the other hand, the diagram of Method D is shown in Fig. 9. The difference of Method A and D is the Sub-Task: S_5. In case of D, the closing action is realized by camera measurement and force sensor, while in case of A, it is realized by position control using only camera measurement. As a result, in case of D, Closing Task: S_5 can be described as Retry if the task fails, because the robot recognizes where the sliding door is until the robot has closed the door. Compare with Method D, we can describe Method A as Restart because the robot turns out that it cannot recognize the position of the sliding door, if the Closing Task fails.

4.5 Decision of Reliability, Accomplishment Time and Work Realization Approach

Reliability: R_i and work trial time: t_i of each Sub-Task (S_i) are given by the repeated inspections with an actual robot. By using the provided values, we can calculate work accomplishment prediction time $F_n(t)$ on the basis of a diagram. And we can choose the least one as the most suitable work realization approach.

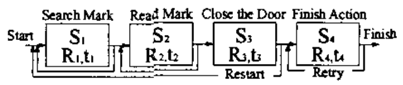


Fig. 8: Diagram of Method B or C for "Sliding Door Closing"

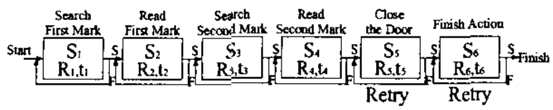


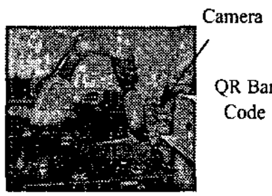
Fig. 9: Diagram of Method D for "Sliding Door Closing"

5. Experiment

In this chapter, we calculated reliability: R_i and trial time: t_i of each Sub-Task of each work realization approach for "Sliding Door Closing", "Faucet Turning off", and " Button Pressing". Then, by using the diagram mentioned in chapter 3 and according to the decision method of work realization approach mentioned in chapter 4, we decide the most suitable work realization approach, and realize the approach with an actual robot.

5.1 Abstract of Experimental Device

In this experiment, we used a manipulator of 6 degrees of freedom with two parallel grippers developed by DENSO WAVE Inc. The manipulator has also a camera over the grippers to recognize environment. Fig. 10 shows the figure of the manipulator.



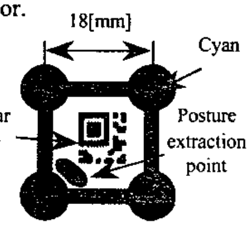


***Fig. 10:** DENSO Robot [DENSO WAVE Inc.]* ***Fig. 11:** Mark used in this experiment*

And we use a mark to assist a robot to recognize the environment, which is shown in Fig. 11. The reason why we use this mark is that we want to calculate the position and the posture relation between the robot and environment. We can easily observe the relation by measuring four tops of this mark. And by mentioning the shape, the size, and the state of the object and the workshop in the two dimensions' (QR) bar code at the center of the mark, we assist the robot to recognize the object and the task.

5.2 Sliding Door Closing

We calculated the rough values of reliability: R_i and trial time: t_i of each Sub-Task for "Sliding Door Closing" with the fundamental experiments. Table 2 shows the result. Then, from these values, we calculated the average work accomplishment time $F_n(t)$ for each work realization approach of this mission, which is shown in Table 3. We decided the most suitable approach. And the sliding door used in this experiment is shown in Fig. 12.

This result is in case that the interval of the sliding door is 250 [mm]. And the unit of t_i is [s]. From Table 3, we can judge that the work realization approach by Method A (using two marks and based on the vision sensor) is the most appropriate. So, we made the robot close the sliding door with Method A. Fig. 13 shows the execution.

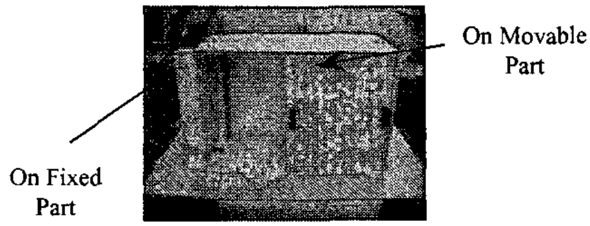


Fig. 12: The Sliding Door Used in This Experiment

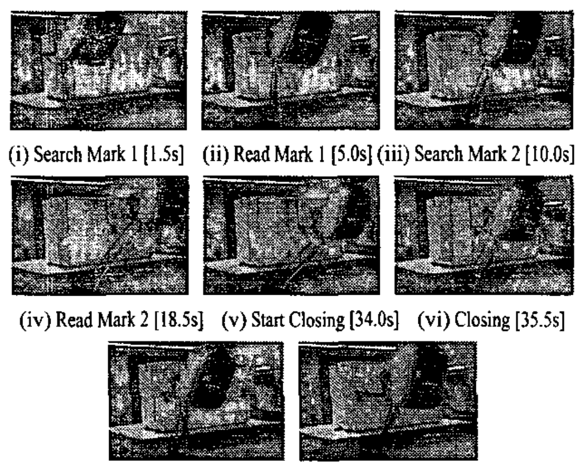
Table 2: Result of Fundamental Experiment for Sliding Door Closing

	R_i	t_i		R_i	t_i
Search Mark Method A&D 1st	0.95	4.0	Search Mark Method A&D 2nd	0.95	12.0
Search Mark Method B	0.95	4.0	Search Mark Method C	0.95	12.0
Close Action Method A	0.95	12.7	Close Action Method B	0	-
Close Action Method C	0.75	18.0	Close Action Method D	0.75	12.7
Read Mark	0.90	3.8	Finish Action	1.00	21.4

The unit of t_i is [s], Frequency of trial is 20.

Table 3: The Average Work Accomplishment Time [s]

Method A	61.39	Method B	Impossible	Method C	67.87	Method D	63.62



(i) Search Mark 1 [1.5s] (ii) Read Mark 1 [5.0s] (iii) Search Mark 2 [10.0s]

(iv) Read Mark 2 [18.5s] (v) Start Closing [34.0s] (vi) Closing [35.5s]

(vii) Finish Closing [37.3s] (viii) Finish Operations [54.0s]

Fig. 13: Sliding Door Closing by Method A

5.3 Faucet Turning off

The diagrams for "Faucet Turning off" and "Sliding Door Closing" have a lot in common basically. However, in case of "Faucet Turning off", the different condition of the faucet may need the robot passing action during the movement to turn off the faucet. In such a case, we should change Turning off Task (in case of only one mark

Sub-Task: S_3 in Fig. 8, and in case of two marks Sub-Task: S_5 in Fig. 3 or Fig. 9) to the diagrams in Fig. 14. Force sensor-base or Vision sensor-base decides the changes. And the faucet used in this experiment is shown in Fig. 15.

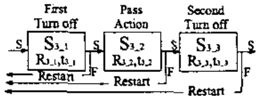
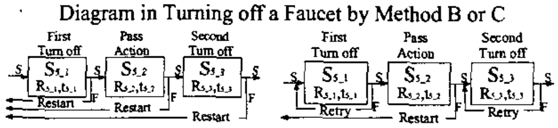


Diagram in Turning off a Faucet by Method B or C



Diagrams in Turning off a Faucet by Method A and D (left: A, right: D)

Fig. 14: Diagrams for Faucet Turning off with Passing Action

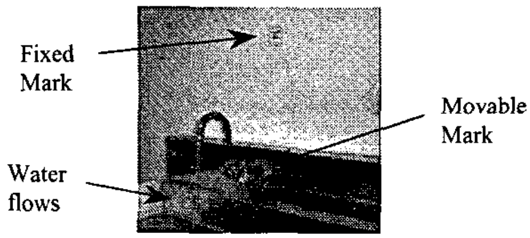


Fig. 15: The Faucet used in This Experiment

Table 4 shows the result of the fundamental experiments in this mission. Through the experiments, the values newly calculated are only reliability and trial time of Turning off Task. On the other hand, the other values are calculated by substituting the distance to search the marks and the velocity of the robot in this mission for the equation (6) to (11).

In this "Faucet Turning off" experiment, we slowed the robot velocity for safety, so the trial time took more than another experiment.

***Table 4:** Result of Fundamental Experiment for Faucet Turing off*

	R_i	t_i		R_i	t_i
Search Mark Method A&D 1st	0.95	33.0	Search Mark Method A&D 2nd	0.95	57.3
Search Mark Method B	0.95	33.0	Search Mark Method C	0.95	70.0
Turn off Action 1 Method A	0.95	118.2	Turn off Action 1 Method B	0	-
Turn off Action 1 Method C	0.75	150.0	Turn off Action 1 Method D	0.75	118.2
Turn off Action 2 Method A	0.95	15.0	Turn off Action 2 Method B	0	-
Turn off Action 2 Method C	0.75	24.0	Turn off Action 2 Method D	0.75	15.0
Read Mark	0.90	3.8	Finish Action	1.00	62.1
Pass Action	0.85	82.2	-	-	-

The unit of t_i is [s], Frequency of trial is 20.

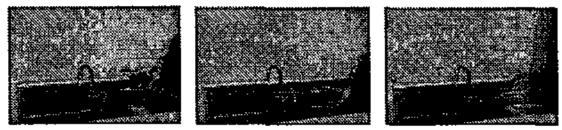
From this result, we calculated the average work accomplishment time $F_n(t)$ for each work realization approach of this mission. Table 5 shows the result.

***Table 5:** The Average Work Accomplishment Time [s]*

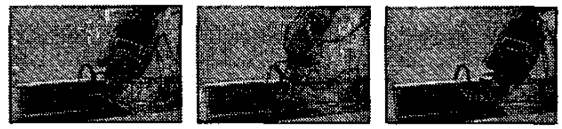
Method A	468.68	Method B	Impossible	Method C	699.71	Method D	481.77

From Table 5, we can judge that the work realization approach by Method A (using two marks and based on vision sensor) is the most appropriate. So, we made the robot turn off the faucet with Method A. Fig. 16 shows the execution.

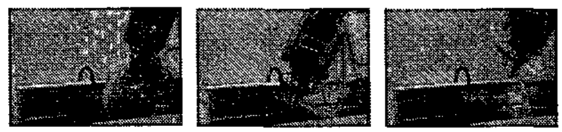
(i) Search Mark 1 [19.0s] (ii) Read Mark 1 [36.0s] (iii) Search Mark 2 [61.5s]



(iv) Search Mark 2 [81.0s] (v) Read Mark 2 [91.0s] (vi) To Grasp Position [133.0s]



(vii) Grasp Faucet [165.6s] (viii) Turn off Faucet [208.8s] (ix) Passing Action [244.0s]



(x) Grasp again [298.8s] (xi) Finish Turning off [308.7s] (xii) Finish Operation [350.0s]

Fig. 16: Faucet Turning off by Method A

5.4 Button Pressing

The diagrams for "Button Pressing" and "Sliding Door Closing" have also a lot in common basically. In this mission, we change Closing Task to Pressing Task. And the newly needed experiment is only Pressing Task. On the other hand, the other values are calculated by substituting the distance to search the marks and the velocity of the robot in this mission for equation (6) to (11). Table 6 shows the result.

***Table 6:** Result of Fundamental Experiment for Button Pressing*

	R_i	t_i		R_i	t_i
Search Mark Method A&D 1st	0.95	4.0	Search Mark Method A&D 2nd	0.95	4.0
Search Mark Method B	0.95	4.0	Search Mark Method C	0.95	8.0
Press Action Method A	0.95	10.7	Press Action Method B	0.90	12.0
Press Action Method C	0.90	12.0	Press Action Method D	0.95	10.7
Read Mark	0.90	3.8	Finish Action	1.00	7.7

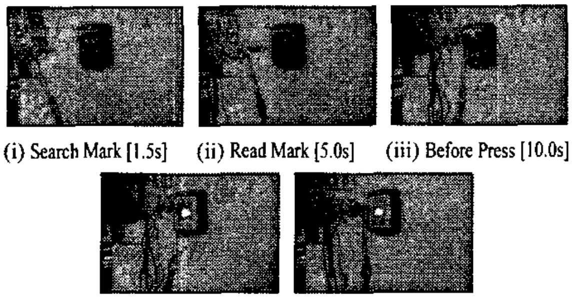
The unit of t_i is [s], Frequency of trial is 20.

From this result, we calculated the average work accomplishment time $F_n(t)$ for each work realization approach of this mission. Table 7 shows the result.

Table 7: The Average Work Accomplishment Time [s]

Method A	36.72	Method B	30.40	Method C	35.08	Method D	35.83

From Table 7, we can judge that the work realization approach by Method B (using only the fixed mark and based on the force sensor) is the most appropriate. So, we made the robot press the button with Method B. Fig. 17 shows the execution.



(i) Search Mark [1.5s] (ii) Read Mark [5.0s] (iii) Before Press [10.0s]

(iv) Just After Press [18.5s] (v) Working Start [34.0s]

Fig. 17: Button Pressing by Method B

5.5 Another Mission

Even in case of other new missions, the basic diagrams are almost the same. And we can easily calculate the reliability and trial time of Sub-Task of similar work by making database from the previous fundamental experiment results. Then, we can choose the most appropriate work realization approach. When there is no similar result of the Sub-Task, we experiment fundamentally only for the Sub-Task.

5.6 Evaluation of Experiment

In this chapter, we actually made a manipulator operate a series of work. As a result, the time and failure probability of each action unit were almost equal to those which are calculated as Sub-Task by fundamental experiment in advance. This fact applied to all the missions we tried.

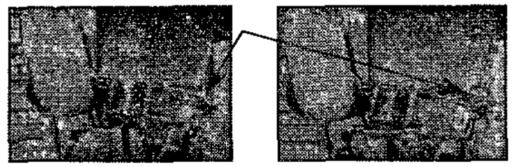
From this result, we can say that this proposition method is effective. When we decide the most appropriate work realization approach of a mission, we can use this method as easy and reliable one.

6. Extension of Proposed Method

In this report, we decided a work approach of a robot according to the mark arrangement methods. However, even in case of the same mark arrangement, there are cases that work realization approaches of a robot vary. For example, in case of "Faucet Turning off", we can consider two ways for the work realization approaches of Turning off Task. One is to turn off by grasping a faucet like (a) in Fig. 18, and the other is to turn off by pushing like (b) in Fig. 18 (we show these figures with a model of a faucet).

In such a case, we describe a diagram for each approach in the same way mentioned above, and calculate each reliability and trial time. Then, we calculate average work accomplishment time, and compare them. As a result, we can choose the shortest one in accomplishment time as the most appropriate work realization approach.

If we consider in this way, even in case of missions of robots with no marks, by making diagrams for robots' approaches which can be considered and calculating each average work accomplishment time, we can decide the most appropriate work realization approach.



(a) Grasping version (b) Pushing version

Fig. 18: Difference of Approaches in Turning off a Faucet

7. Conclusion

In this report, we propose that we classify the mission of a robot into the work realization approaches. The arrangement method of marks decides the approaches, when a robot operates a mission. We divide each work realization approach in action units (Sub-Task), and describe them as diagrams, then evaluate them from the viewpoint of work time and reliability.

From this proposed method, when reliability and work time of each action unit are known and made into database by fundamental experiments for each action unit with a real robot, we can easily predict the most appropriate work realization approach. Even if a new mission appears, we can predict the most appropriate approach. There is no need to experiment all the approaches. And we can decide the most appropriate approach from the values of reliability and work time of the similar action unit.

8. References

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