Information Integration and Mission Selection to Accomplish Dependable Perception for Service Robot

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Abstract— **One of the reasons why the most of current service robots are staying in laboratory is that they can not guarantee their dependability. Although many researchers have been developing human-robot interaction (HRI) components, such as voice recognition, understanding facial expression, and etc., however they can not be perfect in dynamic environment with uncertainty. For this reason, we propose a novel robotic architecture, referred to as a "Cognitive Robotic Engine (CRE)." The major features of CRE are the asynchronous/concurrent processing architecture, the integration of various perceptions, and the connection between perceptions and actions for more active collection of evidences. It makes it possible that a robot provides service in real environment using inexpensive/incomplete sensors or cameras. In this paper, we present how to integrate information to accomplish dependable perception and how to select and change the mission with consideration of the system resource mainly.**

I. Introduction

One of the major reasons most of service robots remain in research laboratories, instead of being on the market, is that the issue of robot dependability has not been solved yet. Much research has been done to solve this problem; But most research focused on human-robot interaction (HRI) components, e.g., understanding facial expression, voice recognition, etc. However they can not be perfect in real dynamic environment. In order to solve this problem, the "Cogniron" Project of the European Union (EU) studies advancement of component and multi-modal approaches [3][4][5]. A multi-modal interaction framework deals with the fusion of multiple human-robot interaction modules to reduce dependence on the single specified sensor data. But it does not address the robot behavior for more active collection of evidences. The robot BIRON has a three-layer control architecture containing a flexible control component. It provides flexibility for HRI, however it does not considering about uncertain situation. Although many researchers have been studying their researches with consideration of the uncertainty environment for robustness of robot[6][7], however, there has been minimal research regarding the uncertainty for the robot service/mission selection.

Therefore, in the previous works, we proposed the novel software architecture referred to as a "Cognitive Robotic Engine (CRE)" for dependable perception and action for service robot in dynamic environment[1][2]. The main features of CRE are explained as follows: 1) the spontaneous and self-establishment of perceptual missions in connection to sensing, 2) the choice of particular asynchronous and concurrent flow architecture of perceptual processes based on evidence structure, 3) and the incorporation of proactive action to reduce uncertainty. Especially, feature 3) indicates the main difference between multi-modal approach and CRE. These features make it possible that a robot provides service in real dynamic environment. And we expect that CRE can apply to intelligent building/vehicle, security system and so on.

In this paper, we will see how to integrate information and how to select the mission mainly. The robot has to select the mission naturally with consideration of the system resource. So, we implemented the mission manager for the robot, which is able to select the mission by oneself with the minimum of perceptual processes.

This paper is organized as follows: Section II introduces the CRE. Section III deal with the missions for service robot and how to select and change mission. Section IV shows that how to integrate information and how to estimate certainty. Software implementation and hardware configuration are described in Section V. And the result of experimentation is described in Section VI; Section VII concludes this paper.

II. Cognitive Robotic Engine

Before introducing the concept of CRE, let us consider how a human recognizes objects/people in the uncertain environment, e.g., a dark room, crowded and noisy party, etc. It is not easy for a robot to identify objects/people in such places. Because some objects seem very similar in a dark place and he or she is hard of hearing in noisy place. However, a human is able to identify them. In this situation, how is a human able to recognize them? What would he or she take action to recognize something/someone? If he or she heard his/her name from behind, but he or she was not confident because that place is so loud, he/she looked back in order to find who's calling. If someone is supposed to find a specific object in a dark room, but if there are several similar objects, he or she must approach the object, and then take some proper action such as touch to recognize the object. In order words, a human takes appropriate actions for gathering more information. In addition, a human makes a decision using not a specific sense but all the information. The concept of CRE like this, that is, CRE integrates information to accomplish dependable perception and recommends appropriate actions for gathering more information. It is regarded as a more general form of behavior based approach [8] that is extended to include perceptual behavior. Imitating the human dependability in perception, the main features and procedures of CRE is conjectured as follows:

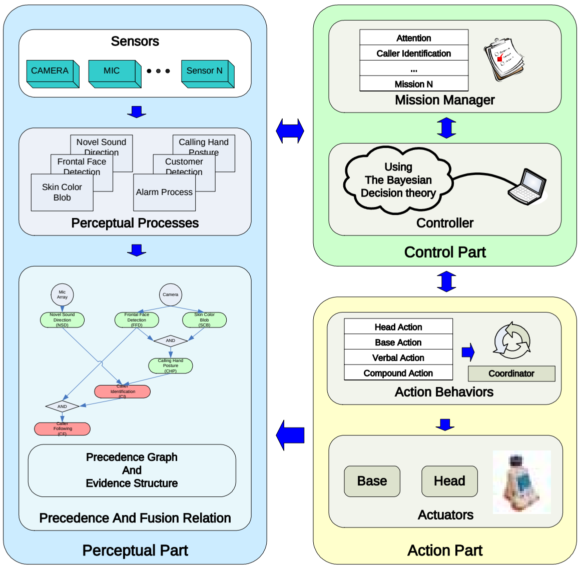


Fig. 1. Overall Architecture of Cognitive Robotic Engine

1) The spontaneous and self-establishment of ad-hoc perceptual missions in connection to particular sensing.

2) The choice of particular asynchronous and concurrent flow architecture of perceptual building blocks, out of a potentially huge number of possible flow architectures as the basis for deriving evidences to be fused together.

3) The incorporation of action blocks into the chosen asynchronous and concurrent flow architecture. This is a mean of proactively collecting new evidences for less uncertainty. The evidences trigger a dynamic reorganization of the flow.

4) The optimal process control at each sampling time, where the optimality is defined in terms of the time and computing resources for uncertainty reduction. Note that the control strategy may differ by individuals.

A. *Overall System Architecture*

Overall architecture of CRE system is shown in Fig. 1. CRE consists of three parts, perceptual part, control part and action part widely. Perceptual part is composed of sensors, perceptual processes which are processed asynchronously and concurrently, precedence and evidence fusion relations through which a robot perceives the environment like a human. Control part takes charge of invoke mission or mission transition and it controls behavior selection or behavior changing. Finally, action part is in charge of robot action. The system operating procedures are as follows: 1) the sensors receive and transmit external data, 2) the perceptual processes analyze the information, 3) the control part gathers all the information from perceptual processes, and then make a decision, 4) if there is any necessity the action part makes the robot to act.

TABLE I

DESCRIPTION OF PERCEPTUAL PROCESSES

NSD	Def.	When the sound volume exceeds the threshold, estimates the direction of source
	Source	Mic array (3 channel)
	Input	Raw data of sound
	Output	Direction of novel sound Calculated Certainty (CF) Spatial probability distribution (SP) Candidate of Action (AC) Processing Time (PT) Packet recording Time (RT)
FFD	Def.	Finds face region by image feature
	Source	Camera
	Input	Raw image from Camera
	Output	Coordinate, and size of detected face CF, SP, AC, PT, RT
SCB	Def.	Distinguishes skin region by RGB condition and makes others black in image
	Source	Camera
	Input	Raw image from Camera
	Output	Image of skin color segmentation Most probable direction that callers exist in. CF, SP, AC, PT, RT
CHP	Def.	Estimates calling hand by skin color in face adjacent area
	Source	FFD, SCB
	Input	Coordinate and size of detected face Skin segmented image
	Output	Direction, and distance of caller CF, SP, AC, PT, RT
CD	Def.	Estimates clothing color of a person who is detected by FFD process.
	Source	Camera, FFD
	Input	Coordinate and size of detected face
	Output	Estimated clothing color (Red/Blue) CF, SP, AC, PT, RT
AL	Def.	Send alarm signal at reservation time
	Source	Time check Thread
	Input	Current time
	Output	Alarm signal Information of reserved user CF, SP, AC, PT, RT

B. *Perceptual Process and Precedence Relation*

The perception process of CRE means basic building block for the entire perception. Table I represents the specification of all perceptual processes – Novel Sound Detection (NSD), Frontal Face Detection (FFD), Skin Color Blob (SCB), Calling Hand Posture (CHP), Color Detection (CD), and Alarm (AL). Normally, the output of individual perceptual process has calculated certainty (CF), spatial probability distribution (SP), action candidates that can improve the certainty factor (AC), processing time (PT), and packet recording time (RT).

If the outputs of one or more processes are necessary as an input or inputs of another for processing, a relationship between the processes defines precedence relation. Each process is assumed independent as long as they are not under precedence restrictions. Fig. 2 shows the precedence relation of all perceptual processes.

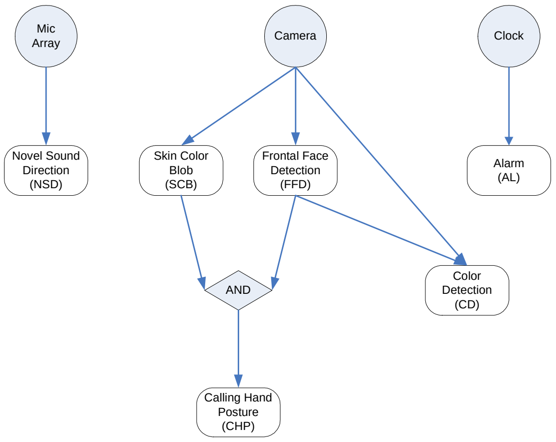


Fig. 2. The precedence relation of all perceptual processes – All the relations without AND mean OR

III. The Missions for Service Robot

A. The Robot Missions

In the present research, we implemented four missions for a service robot. All missions are made bring a current service robot platform into focus. Our analysis of current service robot's ability tell us that main objects of service robot are recognizing user and providing information to the user. So, we made the missions which are caller identification, customer identification, caller/customer following, and attention. Table II shows all executable missions and their definition.

B. Mission Manager for Cognitive Robotic Engine

Most of developed service robots recognize their mission by user's manual input. However, to provide advanced service, if there are several missions, the robot should be select mission naturally. Accordingly, we implemented the mission manager for advanced service of a robot. The mission manager should tell the mission with the minimum of perceptual processes. The roles of mission manager are detailed below:

1) The manager should be monitoring enabled perceptual processes.
2) If any change of environment stimulus some perceptual process, the manager has to recognizes all the missions which are related to the process. The connection relation between missions and perceptual processes should be pre-defined.

TABLE II
List of Missions And Definition

Mission	Definition
Attention	Gazes into Caller/Customer
Caller Identification	Seeks for the caller and then identifies the caller
Customer Identification	Seeks for the customer and then identifies the customer
Caller/Customer Following	Follows the caller/customer

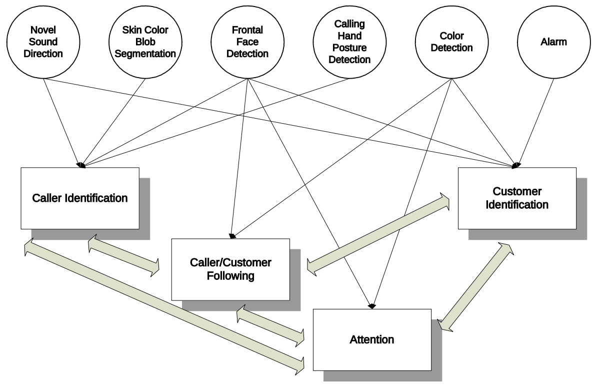


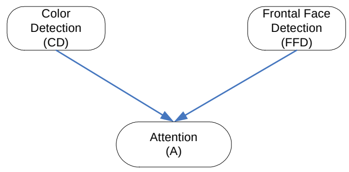
Fig. 3. Mission Manager for Four Missions

3) Since enabled perceptual processes are very primitive, some missions will remain and be invoked among the subset of missions, or the others may be removed. To recognize which of them to be selected, additional perceptual processes should be enabled.
4) If there is one mission selected, the manager performs it, while the number of mission is bigger than one, they are took into queue based on the priority of missions. Note that, simultaneous and multiple mission will be considered later.
5) Performing a mission, the manager should check if the mission is on going, or success, or fail
6) With succeed/failure of the mission, the manager should change the state of robot naturally.

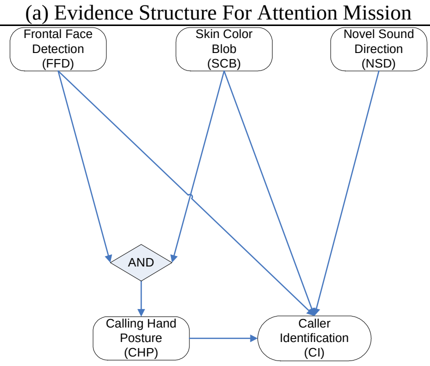
IV. Integration of Information and Certainty Estimation

A. Evidence Structure for the Robot Missions

CRE aims at combining or fusing multiple evidences in time for dependable decision. In order to integrate multiple evidences, we needed another relation graph for certainty estimation. Although, above mentioned precedence relation graph shows the input-output relation of each perceptual process nicely, however it is not suitable for certainty estimation.

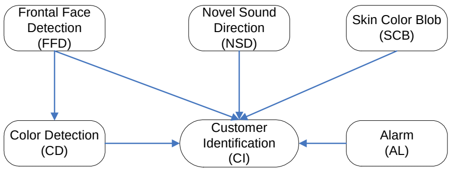


(a) Evidence Structure For Attention Mission

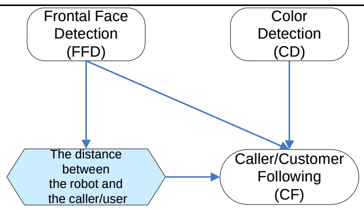


(b) Evidence Structure For Caller Identification Mission

Fig. 4. Evidence Structure For Each Mission



(a) Evidence Structure For Customer Identification Mission



(b) Evidence Structure For Caller/Customer Following Mission

Fig. 5. Evidence Structure For Each Mission.

Because to calculate certainty of the mission, the robot applies difference shape of calculate expression to each mission. But if some missions are extended in the future, it is difficult to design architecture graph to extended missions. Therefore, we define the "evidence structure" for certainty estimation.

The evidence structure described by Fig. 4 and Fig. 5 is equivalent to a Bayesian net, except that we consider explicitly the conjunctions of evidences that becomes sufficient for proving the truth of another evidence and represent them with AND operations. This is to make it easier to define the joint conditional probabilities required for the computation of certainties based on the Bayesian probability theorem. The actual implementation of computing certainty update is based on the Bayesian net update procedure.

B. Certainty Estimation based on Bayesian Theorem

In this paper, we calculate the mission certainty based on Bayesian theorem.

$$MissionCertainty(Mission) =$$
$$P(Mission \mid Evidences) = \frac{1}{1 + \dfrac{P(Evidences \mid \overline{Mission})P(\overline{Mission})}{P(Evidences \mid Mission)P(Mission)}} = \frac{1}{1+\alpha}$$
$$\therefore\ \alpha = \frac{P(Evidences \mid \overline{Mission})P(\overline{Mission})}{P(Evidences \mid Mission)P(Mission)} \tag{1}$$

(1) shows that the formula of the mission certainty estimation. In here, α is calculated differently in each mission. Under assumption that each evidence is independent, from the evidence structures, we are able to calculate α. For example, if the caller identification mission is selected, α is calculated by formula (2).

$$\alpha = \frac{p(FFD \mid \overline{CI})\,p(SCB \mid \overline{CI})\,p(NSD \mid \overline{CI})\,p(CHP \mid \overline{CI})\,p(\overline{CI})}{p(FFD \mid CI)\,p(SCB \mid CI)\,p(NSD \mid CI)\,p(CHP \mid CI)\,p(CI)} \tag{2}$$

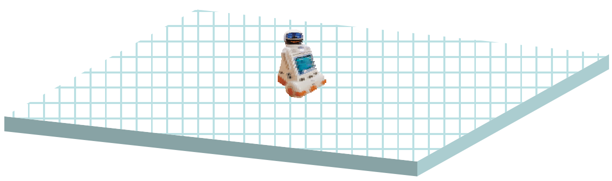


Fig. 6. Interaction Space of the Robot for Certainty Representation.

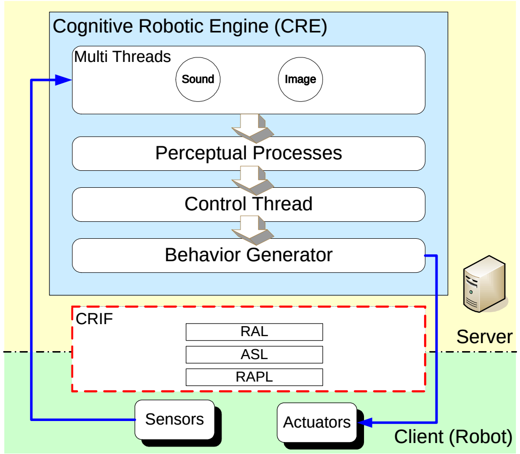


Fig. 7. Overall Architecture of the System. (RAL: Robot API Layer, ASL: API Sync Layer, RAPL: Robot API Presentation Layer)

C. Certainty Estimation with Considering Space-Time

In this research, we implemented all perceptual processes with considering the two-dimensional interaction space of the robot. Fig 6 shows that interaction space of the robot. The interaction space is represented by 81(9*9) cells and each cell has around 50cm*50cm size. Since all processes have the information of two-dimensional space, each mission certainty $P(Mission \mid Evidences)$ is also represented by two-dimensional space and it is calculated for each cell. Therefore, the robot has spatial information. The spatial probability distribution is changed according to the robot behaviors and is estimated according to evidences continually.

Moreover, in order to provide time-related service, we implemented alarm process (AL). Using this process, the robot is able to provide service such as delivery information for the customer at specific time.

V. Implementation of Hardware and Software Architecture

A. Hardware Specification

The approach outlined above has been implemented on the mobile robot iRobi. The specification of single-board-computer has Intel Pentium mobile processor 1.40GHz, 1GB RAM. And the Robot has three channel microphone for estimates the direction of sound source. Logitech Quickcam Pro 3000 camera as imaging sensor has approximately 60° horizontal-field-of-view (HFOV) and 320*240 square pixels.

B. System Architecture and Software Design

Overall architecture of the CRE system is presented in Fig. 7. As seen in the figure, the system is composed of server and client. In here, client means the robot and the robot and the server communicated by Common Robot Interface Framework (CRIF). It provides TCP/IP wireless connection so that CRE system could be adapted to another platform easily. Two multi threads in the server request image and sound continuously. A perceptual process is called when a thread get sensing information from robot. There procedures are operated asynchronously and concurrently.

VI. EXPERIMENT RESULTS

In the experimentation, we try to test the capability of mission manager and the proper propagation of estimated certainties in the interaction space of a robot. Experimental results of the reasonable selection and convergence of behaviors to accomplish the given mission are already shown in previous work [1] and [2]. So, this paper didn't mention the selection of behaviors.

We assume that the robot has four missions described in table 2, and verify the certainty of each mission shown in the interaction space of the robot as missions changed.

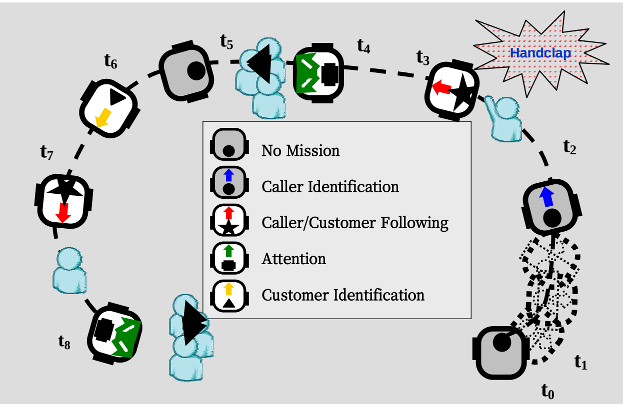


Fig. 8. Experimentation of the muti-mission management and the certainty estimation of Cognitive Robotic Engine

Initially, control part of CRE enables only NSD[1], FFD, AL processes (refer to table 1 to find names of processes). At this moment (t_0), the caller called the robot at the back by handclap. Then, the certainty [2] of caller identification mission arisen as Fig. 9 by NSD process output, and the mission started (t_1). As the caller identification mission started, SCB and CHP processes activated to collect more evidences. Fig. 10 is certainty of the mission, just after turning to the caller, and the certainty increased when FFD and CHP processes detected caller's hand motion (Fig. 11). At this moment (t_2), the mission manager changed the mission to caller tracking. So, FD and CD processes [3] activated, and started to move to the caller (t_3). Fig. 12 shows the certainty of caller tracking mission at t_3. In Fig. 13, the certainty of frontal spaces of the robot is high enough to change the mission to attention (t_4). Fig. 14 shows the certainty of attention mission. Generally, the service robot can convey information to the caller while doing attention mission. After a communication with the caller, mission manager of the robot dismissed attention mission like initial state. After for a while, the customer identification mission started by AL process, so the robot try to find customer who wears red shirt (reserved mission like timer). The certainty of customer identification mission is shown Fig.15 (t_4). When the robot found the customer, the certainty changed like Fig. 16, then, attention mission started (t_8).

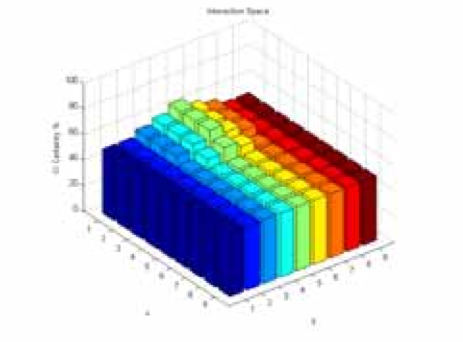


Fig. 9. Certainty of the caller identification mission (t_1)

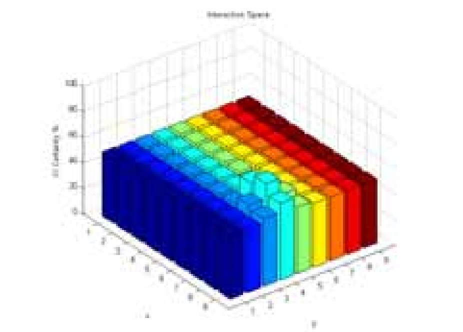


Fig.10. Certainty of the caller identification mission (t_2, before calling hand posture detected)

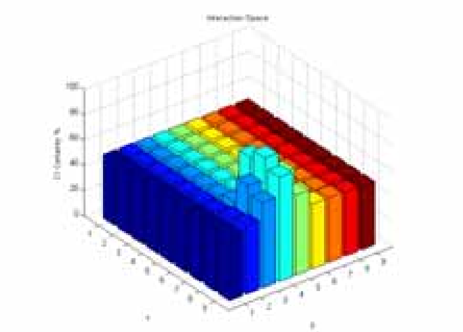


Fig. 11. Certainty of the caller identification mission (t_2, after calling hand posture detected))

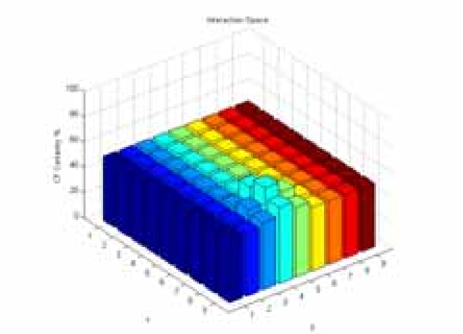


Fig.12. Certainty of the caller/customer tracking mission (t_3)

[1] NSD: Novel Sound Detection, FFD: Frontal Face Detection, SCB: Skin Color Blob, CHP: Calling Hand Posture , CD: Color Detection, AL: Alarm.

[2] In the interaction space, the robot located at (5,5), center of space, and frontal direction is increasing direction of x axis.

[3] The robot detects the color of caller's shirt to distinguish the caller from other people.

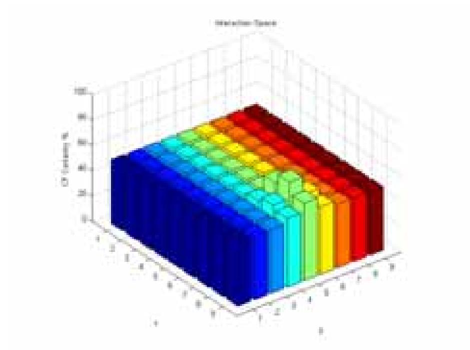


Fig. 13. Certainty of the caller/customer tracking mission (t_4)

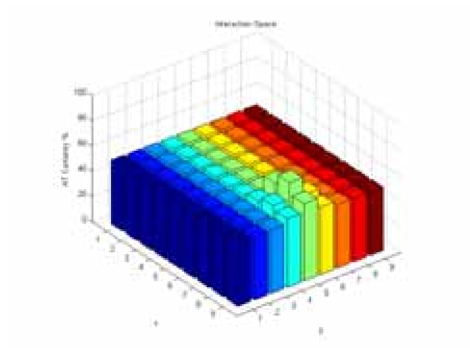


Fig.14. Certainty of the attention mission (t_4)

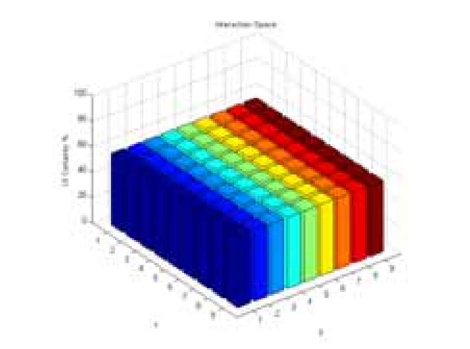


Fig. 15. Certainty of the customer identification mission (t_6)

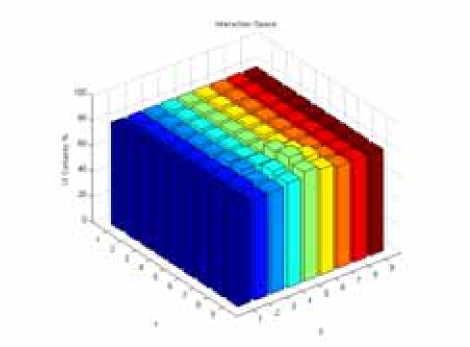


Fig.16. Certainty of the customer identification mission (t_7)

We recorded the results several times of experimentation, the results shows that missions started, stopped and changed automatically based on variation of the certainty, and by defining the certainty of each mission in the interaction space, behavioral parameters can be easily obtained. Basic rules to choose behavior is that select one behavior among candidates suggested by perception processes to increase their certainties. [1][2]

VII. Discussion and Conclusion

In this paper, we described the robotic architecture for dependable perception and action for service robot in dynamic environment. This architecture is organized to accomplish perception mission in spite of the integration of imperfect perception processes, and updated for managing multi-missions.

From the experimental results, we can see following feasible properties of the proposed architecture.

1) According to mission selection, all processes are enabled/disabled, the robot made the efficient use of system source.
2) Probabilistic certainty estimation in interaction space of a robot based on Bayesian theorem increase robustness to noisy output of each process of perception.

Acknowledgment

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