MIRob: An Intelligent Service Robot that Learns from Interactive Discussions while Handling Uncertain Information in User Instructions

M. A. Viraj J. Muthugala and A. G. Buddhika P. Jayasekara
Robotics and Control Laboratory
Department of Electrical Engineering
University of Moratuwa
Moratuwa 10400, Sri Lanka
viraj@elect.mrt.ac.lk and buddhika@elect.mrt.ac.lk

***Abstract*—This paper presents about an intelligent service robot named Moratuwa Intelligent Robot (MIRob) that can acquire knowledge through interactive discussion with the user while handling the uncertain information in the user instructions. In order to facilitate this behavior, a finite state intention module has been introduced to manage the interaction between the user and the robot. A set of states has been defined to acquire and update the knowledge as well as in order to perform the actions required to satisfy the user instructions. Dialogue flows and patterns have been defined for each state in order to maintain the interaction with the user. The defined dialogue flows and the dialogue patterns are presented. Furthermore, the concept has been developed in such a way that the system is capable of updating a Robot Experience Model (REM) according to the acquired knowledge. In order to evaluate the performance of the system, experiments have been carried out in an artificially created domestic environment. The capabilities of the proposed system have been demonstrated and validated from the experimental results.**

***Keywords*—Understanding uncertain information; finite state acceptors; human-robot interaction; human friendly robotics; service robotics**

I. INTRODUCTION

An intelligent service robot is a machine that is able to gather information from the environment and use its knowledge to operate safely in a meaningful and purposive manner [1]. Nowadays, intelligent service robots are developed for emerging areas of robotics application such as caretaking and assitance [2], healthcare [3] and edutainment [4]. Especially, human friendly intelligent service robots are developed to use as assistive aids for elderly or disabled people [5], [6]. A human friendly intelligent service robot could provide both physical and cognitive assistance for the elderly or disabled peoples [7], [8].

Human friendly intelligent robots should have ability to interact with humans with natural human-human like communication abilities [9]–[11]. Humans mainly use voice instruction for the communication purposes between peers [10], [11]. Therefore, the human friendly robots should have ability to understand the voice instructions and appropriately responding to them. However, humans prefer to use voice instructions that have uncertain information and lexical symbols and notions rather than precise numerical information. As an example humans prefer to use commands such as "move little towards the table" instead of commands such as "move 45 centimeters with heading angle of 20 degrees". Therefore, human friendly robots should have ability to understand such uncertain information and lexical symbols. Furthermore, humans have ability to acquire knowledge about the unfamiliar facts by extracting the key information in voice instructions and responses of the peers.

Methods for acquiring knowledge through fuzzy voice commands have been developed [12], [13]. Those systems are capable of achieving a goal after learning from series of user commands given to the system. Concepts have been proposed to adapt the perception of uncertain information based on a series of user critics and user instructions [14]–[16]. However, those systems are proposed for controlling of ordinary robotic systems such as a fixed manipulator and the proposed system cannot acquire knowledge about heterogenous environments or lexical symbols and notions.

Methods for knowledge acquisition by multimodal human-robot interactions are being studied [17]. However, those systems are not capable of handling uncertain information. A method for teaching the natural language object references to a robot has been developed [18]. The method is capable of learning lexical symbols related to object identification with aid of a user reference. Jayasekara et al. [19] proposed a method for teaching behaviors for robots based on interactive dialogues. The system is based on a finite state machine and capable of learning new behaviors as a combination of primitive behaviors of the system. However, the system is not capable of learning lexical symbols and the environmental changes through the interaction with the user.

Muthugala and Jayasekara [20] proposed a method to adapt the perception of robots about the uncertain information based on the spatial arrangement of the environment and improved by introducing a concept called Robot Experience Model (REM) [21]. The REM organizes the knowledge of the robot

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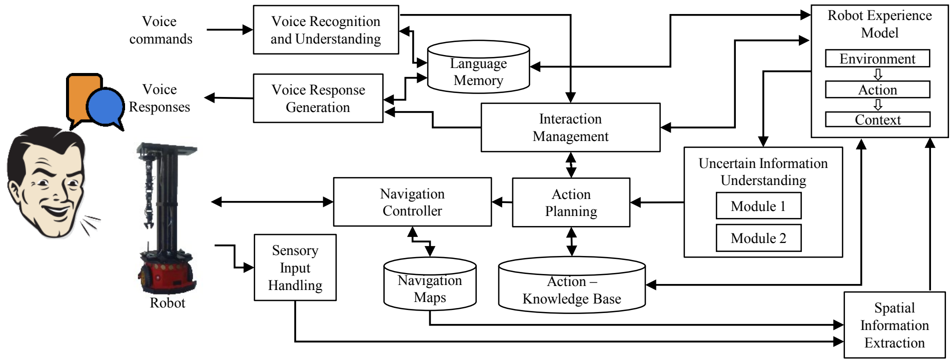

Fig. 1. Functional overview of the system.

about the environment, robot actions and context in a layered architecture. However, the system has not been demonstrated for acquiring the knowledge though interactive dialogues since the main focus of the study was to develop a method for interpreting uncertain information more effectively.

This paper presents about an intelligent service robot named Moratuwa Intelligent Robot (MIRob) that has ability to understand uncertain information and acquire knowledge about the lexical symbols and environment through interactive discussion. In order to enhance the interaction ability, the interaction between the user and the robot is managed with a finite state intention module. Furthermore, it facilitates the system to acquire knowledge through interactive discussions with the user while handling the uncertain information in voice instructions and responses. The functional overview of the system is discussed in section II. Hardware platform of the robot is explained in section III. Particulars of the REM are briefed in section IV. Section V explains the implementation of finite state intention module. The experimental results are presented and discussed in the section VI. Finally, the conclusion is presented in section VII.

II. System Overview

Overall functionality of the system is depicted in Fig. 1 in a modular format. The aim of the system is to facilitate the knowledge acquisition through interactive dialogues between the users and the robot and appropriately responding to the user instructions with uncertain information. Interaction between the user and the robot is managed by the Interaction Management Module (IMM). The IMM has been implemented with a finite state intention module. Voice Recognition and Understanding section converts speech into text using Speech Recognition 3.1 speech to text converter. Then the converted text is tokenized and analyzed with the language memory. Voice Response Generation section is a text to speech converter implemented using Microsoft Speech API. Uncertain information in user instructions is interpreted by the Uncertain Information Understanding Module (UIUM). It has two-sub modules. The Robot Experience Model (REM) is used in order to organize the knowledge of the robot. The knowledge of the REM is utilized by the UIUM and IMM for interpreting the uncertain information and managing the interaction. The UIUM and REM are implemented as explained in [21]. Required sequence of robot actions for a particular user command is decided by the Action Planning Module based on the action knowledge base and the output of the IMM. Navigation controller has been implemented for low level controlling of the robot and it is capable of navigating and localizing the robot within a given navigation map. The required navigation maps can be created by using Mapper3 Basic software. Inputs of the inbuilt low-level sensors of the robot such as sonar and bumpers are handled by the Sensory Input Handling Module. Key spatial information retrieved from the sensors of the robot and the navigation maps are extracted by the Spatial Information Evaluation Module. Then the extracted information is fed into the REM.

III. Hardware Platform

Moratuwa Intelligent Robot (MIRob) has been developed as a domestic service robot. The base of the MIRob consists with a Pioneer 3DX mobile robot platform. It is a differential drive mobile robot with 500-tick encoders. The robot has two sonar sensor arrays one in the front and one in the back. Each sonar sensor array consists with eight sonar sensors, which have sensitivity range from 10 cm to 5 m. The base can reach maximum speed of 1.2 ms^{-1} and carry a payload of up to 17 kg. In addition to that, it has an inbuilt gyroscope for error correction in navigation. A mobile robot especially when operating in human populated environments, needs to avoid possible damages to furniture or humans because of collisions and has to be safe in this regard. As a further safety measure, it is fixed with front and rear facing bumpers to detect collisions. An aluminum structure has been placed on top of the base to increase the height of the robot to a match the height of human beings. Total height of the MIRob is 110 cm. Cyton Gamma 300 manipulator is installed on the robot to handle objects. The manipulator has 7- DOFs and 1 DOF gripper. It can handle a maximal payload of 300 g. Full reach of the manipulator is 53.4 cm and the maximum opening of the gripper is 3.5 cm. On the very top of the robot, a binocular vision system has been mounted with a self-assembled pan-tilt unit. The pan tilt unit facilitates gaze changes of the robot. The MIRob is shown in Fig.2.

The embedded motion controller of the robot automatically performs velocity control of the robot and provides robot state and control information including a position estimate of the robot in space, battery charge data, sonar range sensing data etc. An embedded PC with 2GB RAM and Intel® Core™ 2 Duo 2.26 GHz processor has been integrated into the robot base for performing high level processing and controlling such

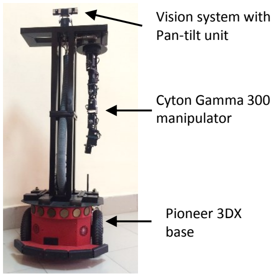

Fig. 2. Moratuwa Intelligent Robot (MIRob).

as, image processing, voice recognition and understanding, tasks planning and decision making. For communication, a WLAN adapter capable of using IEEE 802.11a/b/g has been installed. In addition to that, the robot consists with stereo speakers and microphones to play sound and voice recognition. The robot is powered by three hot-swappable 9Ah sealed led acid batteries and the battery power lasts for approximately 3 h continuous operation at full charge.

IV. The Robot Experience Model (REM)

The Robot Experience Model (REM) [21] organizes the knowledge of the robot about the environment, robot actions and context in a hierarchical architecture. The environment layer is responsible for organizing the knowledge about the heterogeneous domestic environments in a hierarchical graphical model as shown in Fig. 3. It has 3 layers namely room layer, primary object layer and secondary object layer. Those layers are responsible for maintaining the knowledge about the rooms, primary objects and secondary objects respectively. Furthermore, it facilitates the system to identify the relationships between them. As an example from the environment layer given in Fig. 3, the robot can identify that the vase is on the table of the kitchen. Knowledge of the action layer is used to identify the required robot actions for fulfilling a particular user instruction. In here, five types of robot actions have been defined. Robot action type I is used to fulfill the requirements of motional commands with direct directions such as “move little forward”. Then robot action type II is defined for motional commands, which the direction is given with respect to a reference. As an example, “move little towards the table” can be considered. Robot action type III is defined for fulfilling positional commands such as “move near to the table in the kitchen”. However, there can be situations where the current room of the robot and the room of the reference are not the same. In such situations first, the robot has to perform a type IV robot action to navigate to the room of the reference. Secondly, the robot has to perform a type III robot action. Robot action type IV is defined as just room-to-room navigation task without having uncertainties. Robot actions type V is defined for actions that involve only the voice responses such as notification of an erroneous command and asking clarifications from the user.

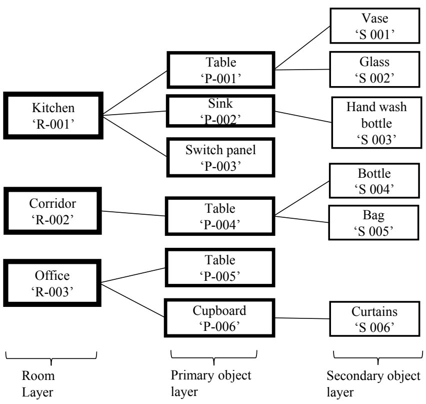

Fig. 3. Environment layer of the REM.

V. Finite State Intention Module

The proposed system is capable of acquiring knowledge through the interactive communication with the user while handling the uncertain information. In order to facilitate this the IMM has been implemented as a finite state intention module. Functional overview of the IMM is shown in Fig. 4 as a finite state acceptor diagram.

The default intention state is set as “Waiting”. In this state robot is waiting for a user instruction to perform a task. If the received user instructions is compliance with a robot action of type I or II or III or IV. Then the state is changed to “Action planning”. In the “Action planning” state, the sequence of the required robot actions is decided. When the action going to be performed is a robot action type IV action then the state is changed to “Perform” state. In the “Perform” state robot perform an action of robot actions type I-IV. When the required action is an action of robot action type I or II or III then the state is changed to “Uncertainties interpretation” state. In this state robot interprets quantitative values for the uncertain terms in the user commands. After the interpretation process is finished then the state is changed to “Perform” state. After performing a robot action, the state is changed back to “Action planning”. If update of the REM is available then the state is changed to “Updating REM”. After finishing the updating, the state is changed back to the “Action Planning” state. After finishing the required sequence of the robot actions, the state is changed back to “Waiting”.

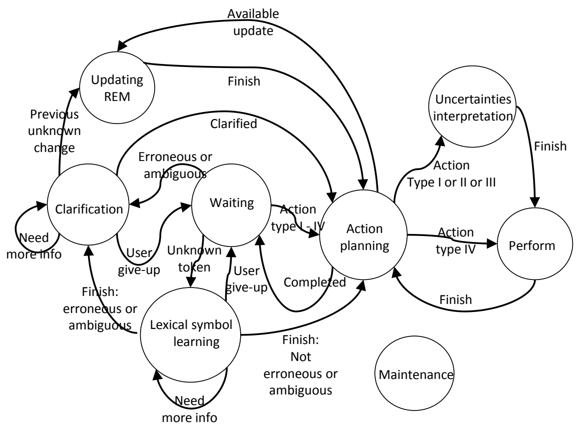

Fig. 4. Finite state acceptor diagram of the system. It is possible to change the state to “Maintenance” from any other available states if there is a requirement of a maintenance work of the robot such as low battery condition.

If the user command is erroneous or ambiguous according to the existing knowledge of the robot, the state is changed to "Clarification" state. In this state, the robot seeks the help of the user to clarify the ambiguity of the command or further enquire about the possible yet unknown changes in the environment. If the user intention is not to give clarification, the state is changed back to "Waiting". After successfully clarifying the ambiguity the state is changed to "Action planing" state. If an unknown change is identified during the clarification, the state is changed to "Updating REM". After finishing the updating, state is changed to "Action planning" state to plan the required sequence of actions.

If there is an unknown token in the user instruction, the state is changed to "Lexical symbol learning" state. In this state the robot seeks the help of the user to learn the unknown token. If the user give up the learning process then the state is changed back to "Waiting". After the unknown token is learned, the state is changed to "Action planning" if the command is compliance with an action of type I-IV. If the command is erroneous of ambiguous, state is changed to "Clarification" state for further clarifications.

A set of predefined dialogue flows and patterns are used in order to acquire the knowledge while maintaining a smooth interaction with the user. The predefined dialogue flows of the "Lexical symbol learning" and "Clarification" states are given in the Fig. 5 and Fig. 6 respectively. The dialogues of the robot are given as a letter code in the diagrams and the corresponding dialogues for the letter codes are given in the Table I. During the listening process, if no voice is recognized within 300 seconds or if the same listening process consecutively runs more than 5 times, the state is changed to "Waiting" with the voice response M or C respectively.

The state is changed to "Maintenance" if there is a requirement of a maintenance work of the robot such as recharging or hardware failure. It is possible to change the state to "Maintenance" from any other available states. During this transition robot gives speech output N.

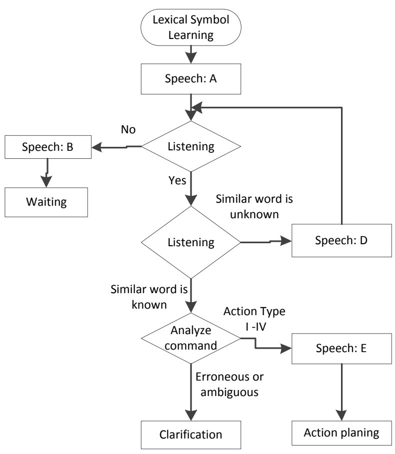

Fig. 5. The dialogue flow of the "Lexical symbol learning" state. The voice responses of the robot is given as letter code and corresponding voice outputs are given in Table I. During the listening process, if no voice is heard within 300 seconds or if the same listening process consecutively runs more than 5 times, the state is changed to Waiting while robot gives the voice response M or C respectively.

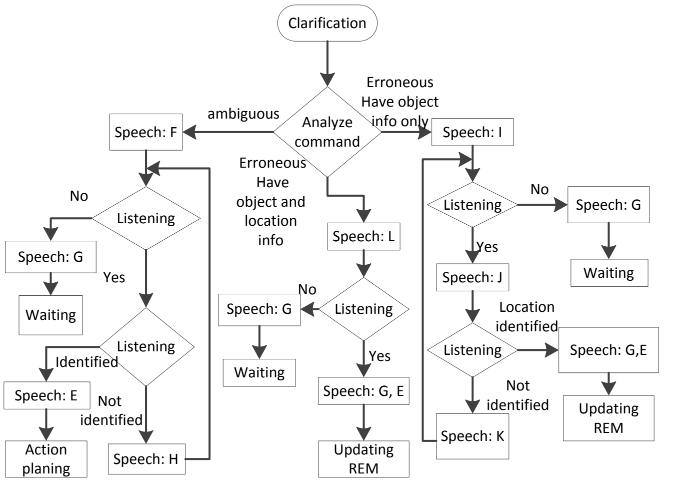

Fig. 6. The dialogue flow of the "Clarification" state. The voice responses of the robot is given as letter code and corresponding voice outputs are given in Table I. During the listening process, if no voice is heard within 300 seconds or if the same listening process consecutively runs more than 5 times, the state is changed to Waiting while robot gives the voice response M or C respectively.

TABLE I. DEFINED DIALOGUES OF THE ROBOT

Code	Speech output
A	I haven't heard the word $< unknown\ token >$ before. Can you give a similar word for $< unknown\ token >$?
B	What can I do ?
C	I am sorry I couldn't understand your requirement. Do you need any other help?
D	Sorry, I don't know that one also. So can you give me another similar word for $< unknown\ token >$?
E	I will do it.
F	There are more than one $< object >$ in $< location >$. Can you help me to select the correct one?
G	OK
H	Can you give me another clue?
I	According to my knowledge, there is no $< object >$ here. Is there any change ?
J	Where is it?
K	Can you provide more information ?
L	According to my knowledge, there is no $< object >$ in $< location >$. Is there any change?
M	Sorry I couldn't hear anything. Do you need any other help?
N	$< Hardware\ status >$ I require maintenance work.

VI. RESULTS AND DISCUSSION

Experiments have been conducted in an artificially created domestic environment inside the laboratory facility for verification of the capabilities of the Moratuwa Intelligent Robot (MIRob). As the experiment, a series of user commands has been given to the robot and the responses of the robot have been recorded for the analysis. In order to enhance the voice recognition accuracy a wireless headset with a microphone was given to the user to issue the commands. A selected segment of dialogues between the robot and the user during the experiment is given below.

1) ***User:*** *Move near to the tv*
2) ***Robot:*** *According to my knowledge, there is no tv here. Is there any change?*
3) ***User:*** *Yes*
4) ***Robot:*** *Where is it?*
5) ***User:*** *On the office table*

6) ***Robot:*** *OK. I will do it*
7) ***User:*** *Move near to the sink*
8) ***Robot:*** *I will do it*
9) ***User:*** *Move close to the table*
10) ***Robot:*** *I haven't heard the word close before. Can you give a similar word for close?*
11) ***User:*** *Yes. Near*
12) ***Robot:*** *I will do it*
13) ***User:*** *Move little left*
14) ***Robot:*** *I will do it*
15) ***User:*** *Move close to the tv*
16) ***Robot:*** *I will do it*

Variation of the states of the robot during the execution of this command sequence is illustrated in Fig. 7. The position of the robot during execution of the command sequence is marked on the map shown in Fig. 8. Initially the robot was at the location marked as '0' on the map and the state of the robot was "Waiting" as illustrated in Fig. 7. The user issued the command "Move near to the tv". Environment layer of the robot at that time is shown in Fig. 3. According to the knowledge of the robot at that time, there was no TV in the home. Therefore, the robot considered that the user command was erroneous and the state was changed to "Clarification". Then the robot responded with dialogue 2 to clarify that from the user. Then the user responded with the dialogue 3 that there had been a change of the environment which the robot had not known yet. Then the robot asked the possible location of the TV by using dialogue 4. Then the user replied with the dialogue 5. Then the robot replied with dialogue 6 and the state was changed to "Updating REM" to update the REM according to the newly acquired knowledge. The updated REM is shown in Fig. 9. After finishing the updating, the state was changed to "Action planning". At this stage, the current room and the room of the reference object were different. Therefore, first the robot had to perform an action of robot action type IV for fulfill the requirements, the state was changed to "Perform". After finishing it, the state was changed back to "Action planning". Then the robot had to perform type III action and then the state was changed to "Uncertainties interpretation" state to interpret a quantitative value for the uncertain term "near". After finishing the interpretation, the state was changed to "Perform". After performing the action, state was changed back to "Action planning". All the required sequence of actions had been already completed at this stage to fulfill the command issued by the user in dialogue 1 and because of that, the state was changed to "Waiting" and the robot was waiting for a new instruction from the user. At this stage robot settled at the location '1'. Captured snapshots of the robot while executing the command sequence up to this point are shown in Fig. 10.

In dialogue 7, the user asked the robot to move near to the sink. Then robot moved to the position '2'. In dialogue 9, the user asked the robot to go close to the sink. At this stage, the robot was not aware of the meaning of the token "Close". In order to learn the meaning of this lexical symbol, the state was changed to "Lexical symbol learning" and the robot asked a similar word for "close" in dialogue 10. Then the user gave a similar word in dialogue 11. Then robot learned that the meaning of the unknown token "close is similar to "near. Then it moved to position '3'. The robot moved from position '3' to '4' to obey the user instruction given in dialogue 13. In dialogue 15, the user asked the robot to move close to the TV

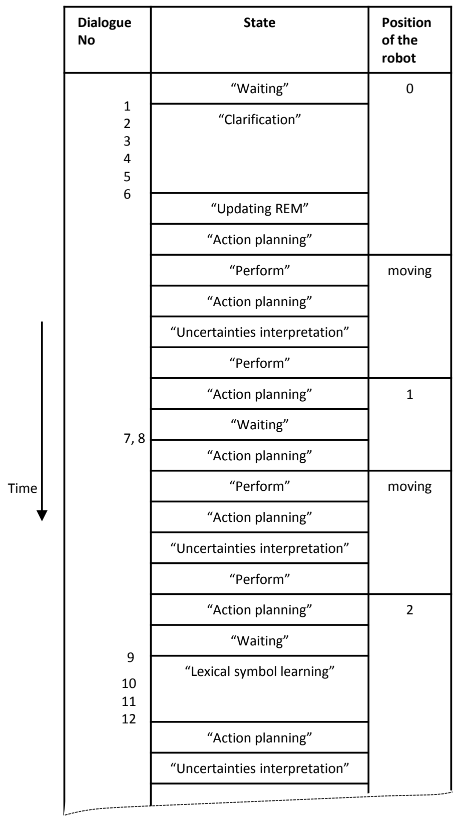

Fig. 7. Variations of the dialogues, states of the robot and the position of the robot during the execution of the command sequence. It should be noted that the time axis is not drawn to a scale and states which involve only computation such as "Action planing" and "Updating REM" may take less than a fraction of a second.

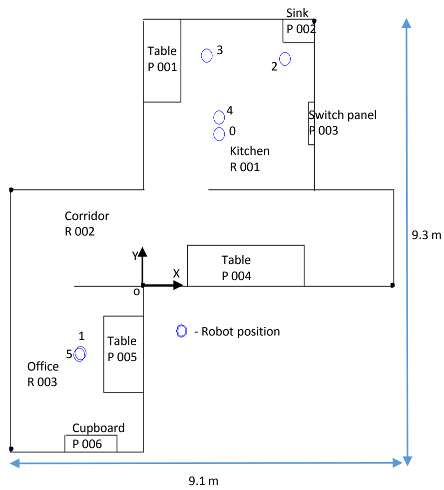

Fig. 8. Positions of the robot during the execution of the command sequence is marked here. The map is drawn to a scale. However, the markers do not represent the actual size of the robot.

set. At this instance, the robot had already known that there is a TV set on the office table as well as the meaning of the word "close" is similar to "near". Therefore, it moved to the position '5'. This validates the ability of the robot in acquiring the knowledge about the environment and learning of unknown lexical symbols.

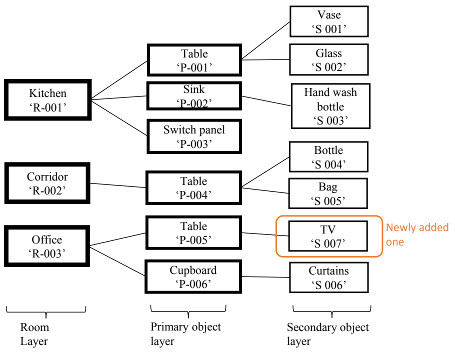

Fig. 9. Environment layer of the REM after acquiring the knowledge about the TV set. 'S-007' has been added to the secondary object layer.

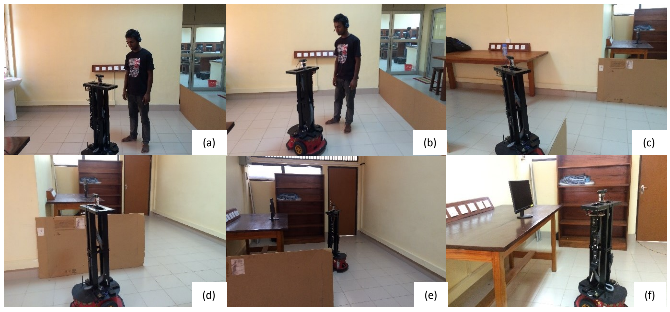

Fig. 10. Captured snapshots of the robot until the dialogue no 7. (a) has been captured when the user and the robot was having the conversation (dialogues 1-6). In (b), MIRob started to move. (c) shows the passing of the MIRob through the door way of the kitchen. Approaching of the MIRob towards the doorway of the office room is shown in (d). (e) shows the moving of the robot inside the office room. (f) has been captured after settling the robot near the TV set.

VII. Conclusion

An Intelligent service robot named Moratuwa intelligent Robot (MIRob) has been developed. The developed robot is capable of acquiring knowledge through interactive discussion with the user while understanding the uncertain information in the user instructions.

Interaction between the robot and the user is managed by the Interaction Management Module (IMM) that has been implemented with a finite state intention module. A set of states have been defined in order to acquire the knowledge from the user using a set of predefined dialogue patterns.

Experiments have been carried out in an artificially created domestic environment in order to validate the performance of the system and the obtained results show that the system is capable of learning unknown lexical symbols and acquiring knowledge about the working environment. Furthermore, the concept is capable of updating the Robot Experience Model (REM) according to the acquired knowledge and the changes due to the performed actions of the robot. This has been demonstrated and validated from the experimental results.

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