Interpreting Fuzzy Linguistic Information in User Commands by Analyzing Movement Restrictions in the Surrounding Environment

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***Abstract*—Assistive robots for elderly and disabled people are being developed to uplift the living standard of the people. The idea of realizing the dream for a robot assistant obviously depends on the availability of human-human like interactions in human-robot interactions also. Humans prefer to use voice instructions, which have uncertain information such as "very little", "far" etc. in their daily interactions. Therefore, the ability of a robot assistant to understand the uncertain information is crucial. Therefore, our study proposes a method to interpret fuzzy linguistic information related to distance in user commands by evaluating the spatial information of the surrounding environment. Fuzzy logic based fuzzy linguistic information evaluation system (FLIES) has been introduced to interpret the fuzzy linguistic terms in user commands by analyzing possible movement restrictions in the surrounding environment. The proposed method has been implemented and tested on a Pioneer 3DX mobile robot. The experiment has been conducted in two different indoor environments and the experimental results of the system are presented.**

Keywords*—human friendly robot; assistive robots; spatial information; fuzzy linguistic information; human-robot interactions

I. INTRODUCTION

The population is growing older and it is found out that the percentage of aging population is significantly high in the world [1]. In addition to that, the number of disabled persons is also high because of casualties due to civil wars, injuries due to accidents etc [2]. They cannot perform their daily activities alone. Because of that, most of them need physical and cognitive assistance from a caregiver.

Nowadays, the society is getting complex and people have busy life styles, due to that human caregivers demand high wages and people do not like to have this kind of occupations. This leads to a shortage of well-trained caregivers for feasible rates and this will become a serious problem in the near future.

Well-developed robotic systems can be used as a solution for the above-mentioned matter [3], [4]. This has steered the trend of robotic research towards the development of assistive robots for elderly and disabled people and many assistive robots for elderly/disabled people have been developed [5]–[8]. However, the capabilities of those robots are far below compared to the capabilities of a human caregiver and a perfect assistive robot, which can compete with a human caregiver, is still a dream of robotic researchers. Therefore, the assistive robots require improvements in construction and behavior to provide assistance that is more sophisticated.

The idea of realizing the dream for a perfect assistive robot obviously depends on the availability of the human-human like interactions in human-robot interactions also [3], [9]. Human friendly robotics systems are preferred for assisting elderly/disabled people because they can provide more sophisticated assistant [10], [11]. A human friendly robot can be used as a caregiver or as an assistant for a human caregiver in a domestic environment.

Humans prefer to use voice instructions, responses, and suggestions including uncertain information involuntarily in their daily domestic activities. As an example, a person may instruct a caregiver to move inside a domestic environment by using a command such as "move little bit forward". In here, there is an uncertainty when interpreting the term "little bit" and such terms are referred as fuzzy linguistic information. The interpretation of a fuzzy linguistic information related to spatial information depends on the spatial information of the environment where the assistive task is being performed and the context. Therefore, the ability of the robot assistant to understand the uncertain information in context and environment dependent manner is a crucial matter.

Methodologies for controlling of a robot using information rich natural spoken language commands such as "move a very little forward" has been studied with the intention of handling natural language words with fuzzy implications while ignoring the redundant words in natural language [12], [13]. The concepts have been implemented for controlling a miniature wheeled robot and a redundancy manipulator using natural language voice commands. However, the interpretation is predefined because outputs of fuzzy linguistic information are defined as a linear modification factor based on the current state of the robot. Jayawardena et al. [14] introduced a concept called fuzzy coach-player systems, which can be used by

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a human user to train a robot using information rich voice commands. The system has been implemented based on the assumption that an actual quantitative distance to a qualitative distance command depends on the distance moved immediately before that command. The system has a fuzzy inference system for evaluating the linguistic terms and the membership functions are initially defined based on the expert knowledge. Therefore, the evaluation of the fuzzy linguistic terms is predetermined. In addition, in here interpretation of a linguistic term only depends on the immediate previous state. Jayasekara et al. [15], [16] proposed methods to adapt the perception of a robot on fuzzy linguistic information based on voice feedbacks of the user and improved by considering the willingness of the user in performing assistive tasks. Those concepts have been implemented on a robotic manipulator and the systems do not take any other sensory input from the environment than the voice commands and the feedbacks. Therefore, the systems are not possible to adapt according to the environmental changes. In all of the above-mentioned methods, interpretation of fuzzy linguistic information does not involve evaluation of the spatial information of the environment. The meaning of a fuzzy linguistic term heavily depends on the environment. Therefore, the above-mentioned methods have drawbacks when evaluating a fuzzy linguistic term.

Schiffer et al. [17] proposed a method for qualitative spatial reasoning about positional information in a domestic environment. The basic idea of the concept is to combine qualitative distance and orientation based on fuzzy sets with the situation calculus [18], a framework for reasoning about actions and change. They introduced the concepts of frame, which is a framework to link positional fuzzy fluent with an associated positional context such as point of view or scale and unified way to transform qualitative positional information into different frames. The concept has been implemented and tested on an intelligent domestic service robot called CAESER [19]. However, the adaptation is entirely based on the size of the frame (bedroom, table, living room, etc.). When a robot is in a domestic environment, there may have movement restrictions for the movement of the robot in a given direction due to the spatial arrangement of the surrounding environment. For a better interpretation those spatial information also need to be accounted in the interpretation process. As an example, a situation of a person standing in front of a wardrobe inside a room is considered. When the person is standing 2 m away from the wardrobe the person may consider about 1.5 m distance towards the direction of the wardrobe as “far”. However, when the person is standing 50 cm away from the wardrobe the person may consider about 40 cm distance towards the direction of the wardrobe as “far”. Even though the room is unchanged, the person has different perception in the two occasions. Therefore, only the size of the room is not sufficient for the adaptation. Furthermore, for a maneuvering scenario the available free space plays a major role than the size of the environment. Jayasekara et al. [20] proposed a method for evaluating fuzzy linguistic information based on the visual attention. The proposed method is capable of effectively manipulating objects in the vision field by evaluating user commands, which have fuzzy linguistic information. A quantitative distance value for the fuzzy linguistic term is interpreted based on the average distance to the surrounding objects in the vision field. Therefore, the interpretation depends on the spatial arrangement of the objects in the attentive vision field and the system is capable of adapting its perception according to the environment. However, the above-mentioned method does not pay attention on possible limitations of manipulations due to the obstacles in the environment.

Our study proposes a method to interpret fuzzy linguistic information related to distances in voice commands by analyzing possible movement restrictions in the surrounding environment. As an example the robot, interpret a quantitative distance for a fuzzy implication “little bit” in the voice command “move little bit forward”. The possible movement restrictions are analyzed by evaluating the surrounding information such as distance to the nearest obstacle, which is in the direction of movement, the size of the room and the available free space.

The system overview is discussed in section II. Then the adaptable intelligent system for the user commands evaluation is explained in section III. Section IV discusses about the experimental setup and the results. Finally, the conclusion is presented in the section V.

II. System Overview

The proposed concept has been implemented on a Pioneer 3DX mobile robot [21]. The functional overview of the proposed system is shown in Fig. 1. It consists of a spatial information extraction module (SIEM), a voice recognition and understanding section, a fuzzy logic based fuzzy linguistic information evaluation system (FLIES) and a robot navigation controller. The SIEM calculates the spatial information related to the operating environment by analyzing the sonar sensor readings and the navigation maps, which can be created by using Mapper3 Basic software provided by Adept MobileRobot [21]. The robot navigation controller handles the low level controlling functionalities of the robot such as the robot localization and maneuvering tasks. It uses the Monte Carlo localization algorithm [22] to localize the robot within a given navigation map and it has capability to maneuver the robot to a given position and heading while avoiding the unmapped

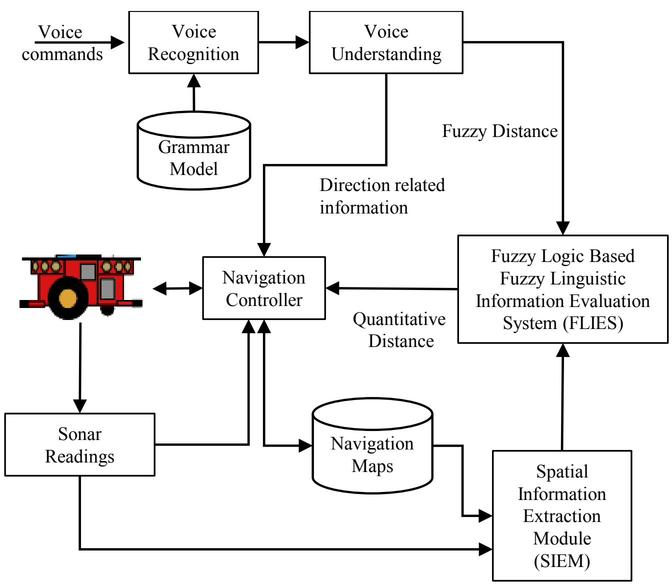

Fig. 1. System overview.

obstacles. Voice recognition and voice understanding section performs the user commands identification. Voice recognition capability has been implemented by using Voce API [23]. Voice recognition accuracy has been improved by using a grammar model in the memory. Direction related information in a voice command is directly sent to the navigation controller and the fuzzy information related to the distance is sent to the FLIES. The FLIES evaluates the fuzzy linguistic term by adapting the perception according to the spatial information of the surrounding environment.

III. User Commands Evaluation

A. Structure of the User Commands

The user commands are assumed to be structured as "action" + "action modifier" + "direction". The possible sets of terms for those components are shown in Table I. As an example command, "go far forward" can be considered. In this kind of a voice command, distance related information has a fuzzy implication and the direction related information is fixed. The directions are defined with respect to the robot.

B. The Grammar Model

The accuracy and the efficiency of the speech recognition have been increased by adding a grammar model to the memory of the robot. A grammar model is a structured collection of words and phrases bounded together by rules that can be recognized by the speech recognition engine. The grammar model has been defined by using Java Speech Grammar Format (JSGF) [23]. The structure of the grammar model is given below.

<command> = go <actionModifier> <direction> ;

<actionModifier> = (little | medium | far);

<direction> = (forward | backward | left | right);

C. Interpretation of Fuzzy Linguistic Information

The fuzzy linguistic information evaluation system (FLIES) has been implemented by using a Mamdani type [24] fuzzy inference system to evaluate quantitative distances to distance related fuzzy implications in user commands. This evaluation should be adapted according to the spatial arrangement of the working environment. The action modifier of the user command (vc) and the available free space (sf) are used as the inputs of the fuzzy logic controller. The output (d) is the quantitative distance, which needs to be travelled by the robot. Centre of area method is used for the defuzzification of the output. The membership functions for the inputs and the output are shown in the Fig. 2. The fuzzy labels are defined as S: small, M: medium, L: large, VS: very small, S: small, M: medium, L: large and VL: very large. The input membership function for the available free space is adjusted based on the room size (S). The output membership is adjusted according to the distance to the nearest obstacle (D) in the direction, which needs to be travelled. For the sake of simplicity in implementation, triangular membership functions with overlapping boundries have been used to represent the natural human perception.

TABLE I. Possible Sets of Terms for the User Commands

Action	Action modifier	Direction
go	Little Medium Far	Forward Backward Left Right

Mobility of a person increases with the available free space of the environment. As an example, a person who is in a playground has a higher mobility than a person who is in a shopping mall. However, inside of a domestic environment there may be restrictions for a movement in a given direction. Therefore, the mobility of a person in a given direction does not totally depend on the available free space inside of the room and it depends on the possible movement restrictions in the given direction. As an example, a person who is standing far away from a wall has higher mobility towards the direction of the wall than a person who is standing very close to the wall. The rule base has been defined by considering that natural tendency of human beings. The rule base of the fuzzy inference system is shown in the Table II.

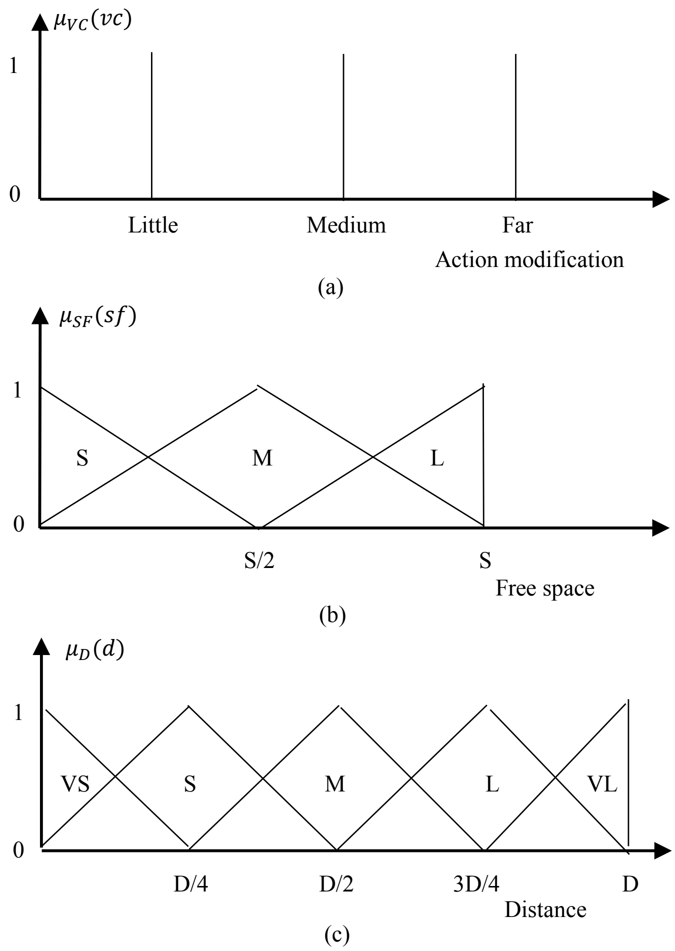

Fig. 2. (a) and (b) represent the input membership function for the user command and the available free space respectively. (c) represents the output membership function for the distance to be travelled.

IV. Results and Discussion

A. Research Platform

The proposed concept has been implemented on a Pioneer 3DX mobile robot [21]. 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 distance information provided by the sonar sensors are utilized to find the distance to obstacles. As a safety measure, the minimum clearance between the robot and an obstacle is set to be 20 cm. Therefore as the distance to the nearest obstacle in the direction, which needs to be travelled, is calculated by reducing the minimum clearance value from the sonar readings. The required navigation maps have been created by using Mapper3 Basic software [21]. The robot has some navigational errors. When the robot moves linearly, the error in the distance is 0.05 mm per 1 mm distance traveled. When the robot rotates, the error in the rotational angle is 0.05 degrees per 1 degrees angle turned. When the robot moves linearly, it can also affect its orientation. This drift is 0.0025 degrees per 1 mm distance travelled.

B. Experiment

The robot was placed in different locations of an indoor environment and the robot was moved by using commands of a human user. The distance to the nearest obstacle and the robots initial and final positions have been recorded for each case. The user was asked to give a feedback about the distance traveled by the robot compared to his/her expectations in each scenario. The user was asked to give a feedback whether the movement is “too small” or “too large” or “OK”. Likewise, the experiment was carried out in two different indoor environments. The required navigation maps had been created before and the maps were in the memory of the robot during the experiment. The robot in a test scenario is shown in the Fig. 3.

C. Results

The experiment has been carried out in two different environments. The sizes of the environment 1 and 2 are 31.955 m^2 and 32.4 m^2 respectively. The environment 1 has 17.673 m^2 of free space while the environment 2 has 28.624 m^2 of free space. The main difference of the two environments is the available free space. Initial and final positions of the robot in each test case have been marked in the maps shown in Fig. 4 and Fig. 5 for the environment 1 and the environment 2 respectively. Triangles of different colors have been used to mark the orientation and the position of the robot. The initial positions of the robot are marked in shaded colors and the final positions are marked in solid colors. The colors of the triangle markers for the test cases are given in Table III along with the other important information such as user command, initial and final positions of the robot, distance to the nearest obstacle, quantitative output distance of the FLIES, user feedback etc.

TABLE II. Rule Base of the Fuzzy System

Input Memberships		Available free space		
		S	M	L
User commands	Little	VS	S	M
	Medium	S	M	L
	Far	M	L	VL

The zones shaded in grey color represent the objects in the environment such as tables, chairs etc. The robot positions are given in (X mm, Y mm, Heading angle in degrees) format with respect to the marked origins of the maps. The maps have been drawn to a scale and they can be used to visualize the arrangement of the robot and the environment in the test scenarios.

Altogether, in two different surrounding environments 10 test cases have been carried out. In 6 cases out of 10 cases the user has accepted the movement of the robot. In 3 cases out of 5 cases in the environment 1, the user has rated the movements of the robot were “too small” according to the expectation of the user. In the environment 2, the user has accepted the movements of the robot in 4 cases out of 5 cases and in one case the movement of the robot has been rated as

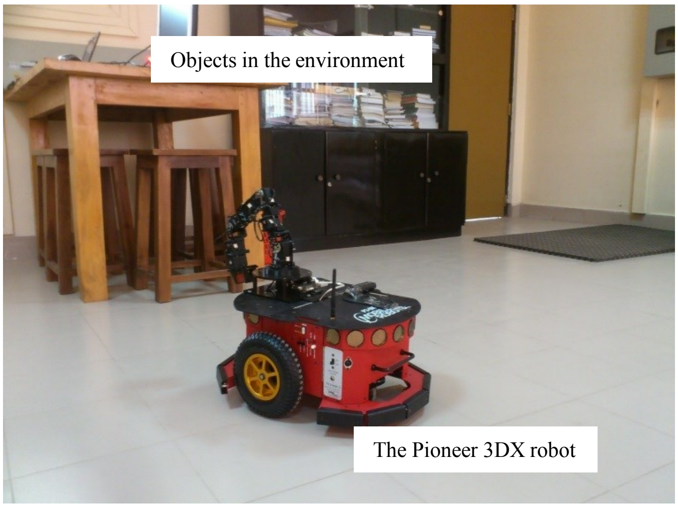

Fig. 3. The robot in a experiment scenario.

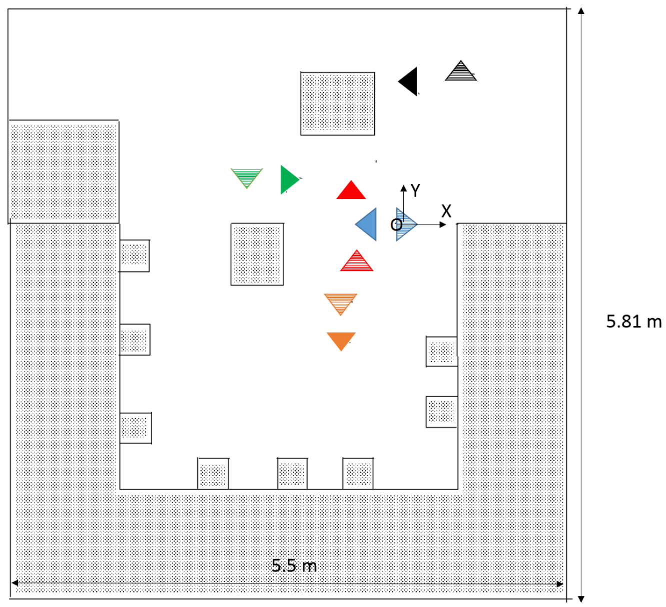

Fig. 4. The initial and final positions of the robot for the test cases in the environment 1 are shown in triangles with the shaded colors and the solid colors respectively. The map has been drawn to a scale.

TABLE III. RESULTS OF THE EXPERIMENT

User command	Initial position (X,Y, Heading)	Distance to the obstacle	Output distance of the FLIES	Final position (X,Y,Heading)	User feedback	Color of the markers in the diagrams
For environment 1						
Go medium backward	(-1,0,0)	823 mm	429 mm	(-368,13,178)	Too small	Blue
Go medium forward	(-575, -761, -87)	944 mm	492 mm	(-565, -1192, -89)	OK	Brown
Go far forward	(-443,-384,98)	989 mm	742 mm	(-541,285,96)	Too small	Red
Go far left	(532, 1458, 96)	733 mm	550 mm	(52, 1376, -176)	Too small	Black
Go little left	(-1531, 457, -92)	1701 mm	463 mm	(-1137, 451, -1)	OK	Green
For environment 2						
Go medium right	(-243, 783, 177)	746 mm	501 mm	(-217, 1221, 84)	OK	Blue
Go little right	(-862, 662, 174)	892 mm	385 mm	(-824, 987, 85)	Too large	Brown
Go far forward	(-824, 987, 175)	1874 mm	1534 mm	(-2290, 1120, 179)	OK	Red
Go far backward	(-1214, 2434, 3)	2537 mm	2076 mm	(-3219, 2288, -176)	OK	Black
Go little left	(-3219, 2288, - 176)	809 mm	342 mm	(-3219, 2288, - 176)	OK	Green

"too large" according to the expectation of the user.

Limitations of the robot may effect the performance of the proposed concept in some scenarios. As an example, the navigational errors of the robot may drift the position and the orientation of the robot from the position and orientations commanded by the navigation controller. The available sonar sensor arrays cannot locate objects which are more than 5 m away from the robot. Therefore, if no object is detected by the sonar sensors, the distance to the nearest obstacle is assumed as 5 m. As a safety measure the robot always try to maintain 20 cm clearance with obstacles. Therefore, the robot cannot be navigated to a position where this clearance is less than 20 cm.

V. CONCLUSION

A method has been introduced to interpret fuzzy linguistic information related to distance in user commands by evaluating spatial information of the surrounding environment. The main improvement of the proposed method over the existing systems is the system is capable of analyzing movement restrictions in the surrounding environment to evaluate fuzzy linguistic information.

This system can be further developed to adjust the perception of the robot to match the willingness of the user based on the user feedbacks. However, the proposed method is suitable for navigating an assistive robot in a domestic environment by using user commands with fuzzy implications.

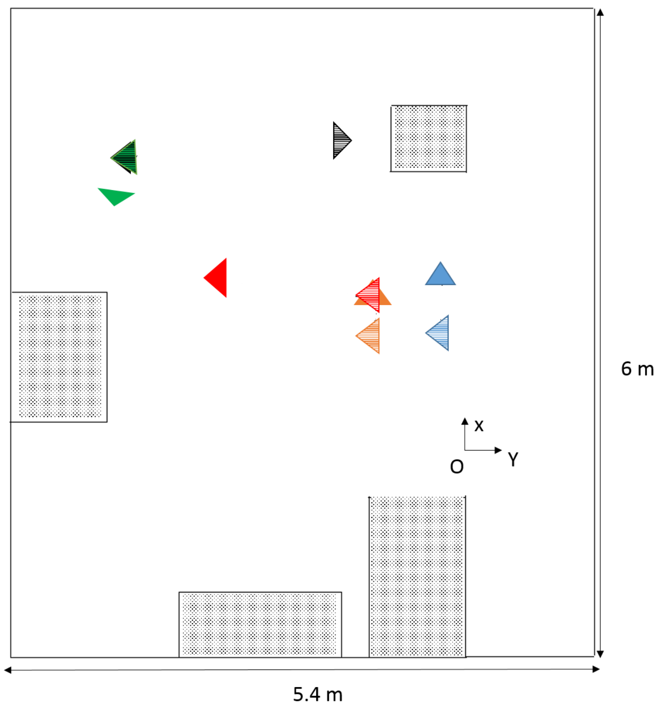

Fig. 5. The initial and final positions of the robot for the test cases in the environment 2 are shown in triangles with the shaded colors and the solid colors respectively. The map has been drawn to a scale.

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