MULTISENSOR DATA FUSION BASED AUTONOMOUS MOBILE ROBOT WITH MANIPULATOR FOR TARGET DETECTION

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Abstract

This paper proposes a novel autonomous mobile robot in unknown environment navigating through obstacles by computing the shortest path. Flood fill algorithm is used for path planning of the mobile robot. The concept of minimum energy contour to perform the desired operation of robotic manipulator is achieved using Fuzzy algorithm. Object detection is done by utilizing a mobile robot with sensors and object recognition is achieved by image processing using Principal Component Analysis (PCA). This paper describes the implementation of multi sensor data fusion assisting a mobile robot to acquire a purposive behavior in the respective environment. This is achieved by directly integrating sensor information which helps the robot to successfully navigate and also enables fetch & retrieval operation of robotic manipulator. In this approach, information is taken from distance sensors, position sensors and image sensor. This work also aims to provide an optimal fusion of information from distributed multiple sensors using Kalman Filter.

Keywords: *Mobile robot navigation, flood fill, robotic manipulator, fuzzy algorithm, object detection, multi-sensor fusion, Principal Component Analysis, Kalman Filter.*

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1. INTRODUCTION

By autonomous robot navigation we mean the ability of a robot to move purposefully and without human intervention in environments that have not been specifically engineered for it. Autonomous robot is equivalent to a closed-loop control system in which the robot is the object to be controlled, the decision-making system is the system controller and the vision system performs the functions of detection and feedback loops. The visual system is mainly to capture, process and recognize images [7]. When the autonomous robot moves, it relies on artificial intelligence and target vision acquisition.

Important advances have been made in the last period in the robotic domain. The navigation of the mobile robots requires: the current position, the path planning and the obstacle avoidance. The environment around the robot is not known, so it must have decision-making capabilities [33]. Path planning is an important part of autonomous mobile robot, and according to some evaluation standards, it finds a collision-free path from original state to target state in obstacle environment [1]. The flood-fill algorithm is used primarily for path planning. It is used to plan an optimal (shortest) path to the nearest unexplored cell in the event that a repeated state is detected and it is also used to plan a path back "home" when the goal is reached. Fuzzy algorithm is implemented for the motion plan of robotic manipulator. The robotic manipulator adapts the shortest path to reach the target and follow a minimum energy curve to perform the desired function. Fuzzy algorithm provides solutions in a sufficiently short amount of time with minimum energy consumption.

In most of the mobile robotics navigation scenarios , for the robot to operate in an unknown dynamic environment, it is necessary to integrate or to fuse the data from different types of sensors so as to obtain useful information from the respective environment. The main advantage of using multi-sensor systems is the increase in reliability and flexibility provided by the redundant and diverse sensor information [31]. Here, multisensory data is fused using Kalman filter which enables a mobile robot to accomplish a given task by directly coupling multi sensor information and actions through interaction between the robot and its environment.

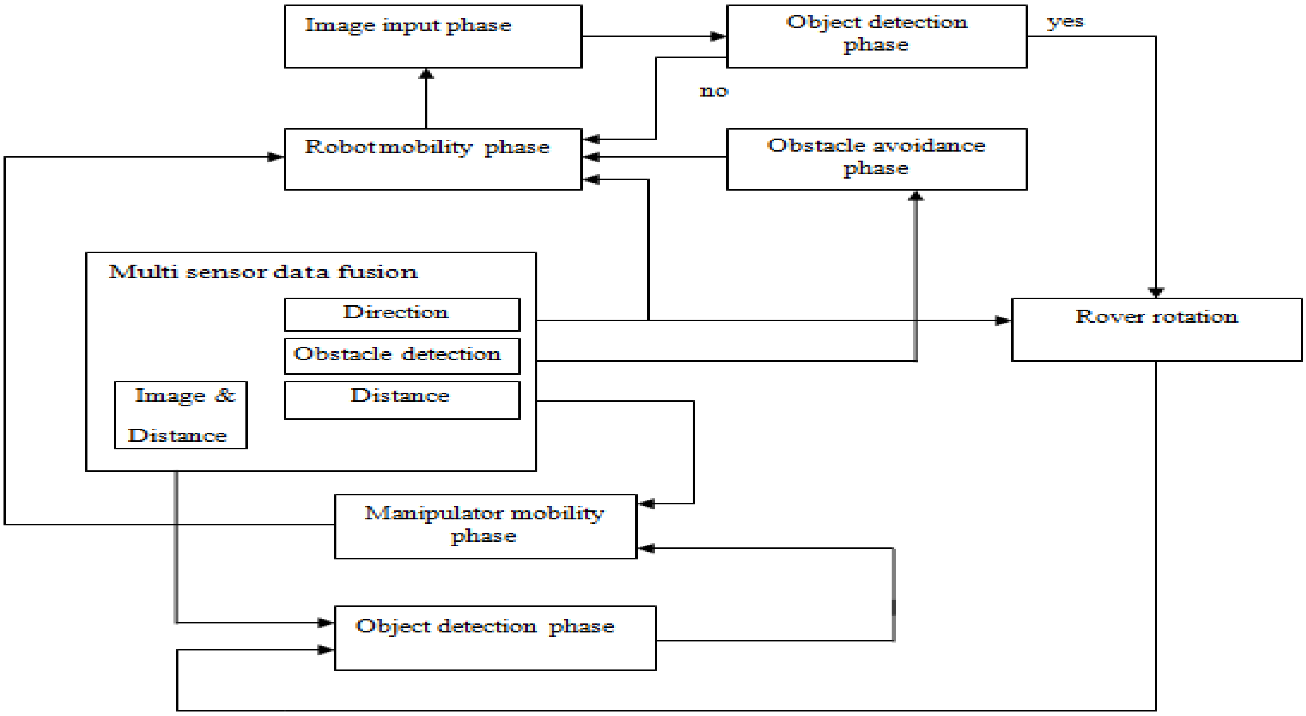

Fig 1 Overall system block diagram

When the autonomous mobile robot moves, it depends on vision system to catch the targeted objects. So vision system is one of the key technologies for intelligent robot. Principal Component Analysis has been investigated for appearance-based object recognition[24]. This method has been found attractive as it compresses the data.

2. ALGORITHM

2.1 Path Planning

Autonomous robots which work without any human intervention are required in robotic fields. The robot has to move in any environment even in the one it has never seen before. This robot is essentially designed to move on a floor. When a robot moves in the given environment from starting point to the target point it is necessary to plan an optimal or feasible path. It must avoid obstacles coming on its way. In this paper the well known Flood fill algorithm is implemented to make the mobile robot navigate. After reaching the target position, it finds the shortest path from target position to an initial position.

The entire unknown environment is divided into grids with static obstacles. The robot moves within the unknown environment by sensing and avoiding the obstacles coming across its way towards the target. When the mission is executed, it is necessary to plan an optimal or feasible path for itself avoiding obstructions in its way and minimizing a cost function such as time, energy, or distance [1].

Flood fill algorithm is one of the most efficient maze solving algorithms. The flood fill algorithm is derived from the "Bellman Ford Algorithm". Using this method complex and difficult mazes can be solved efficiently. The algorithm works by assigning values for all cells in the maze, where these values indicate the steps from any cell to the source cell. It is a very efficient method to solve even a complicated maze. Here flood fill algorithm has been used to drive the robot to solve a real environment as in our case. This robot uses various sensors that help in navigation.

The algorithm consists of two phases. In the initial phase, the unknown maze like environment is divided into equal sized grids and the cells are flooded with default value of -1 initially. The values in the cell changes as the robot start moving. The flooded weighted value of a cell represents the number of steps that would be required to reach that particular cell from the initial cell. As the robot starts exploring the maze and obstacles in each cell, it has to update the weighted value because the number of steps from source cell to reach that particular cell would change. The shortest path will be in the decrementing order of the grid values which is the shortest path.

Proposed pseudo code for executing the process of updating the weighted value of each cell.
a) Start scanning from the start node(0,0)
b) Scan in determined pattern
c) Is sensors detected obstacle? do step d or e
d) No →go to step h
e) Yes → turn and move the robot for the next available position and go to step h.
f) Object detected? and do step f or g
g) Yes → Stop
h) No →go to step h
i) Change the cell to the value of the cell +1, if the robot moves in up or right direction, and Change the cell to the value of the cell -1 ,if the robot moves in down or left direction, go to step b

2.2 Robotic Manipulator

Robotic manipulators are becoming multifunction programmable manipulation devices designed to do different tasks in various fields. An efficient algorithm based robotic manipulator is necessary to increase the accuracy in various fields. The well known fuzzy algorithm is implemented for the motion plan of robotic manipulator[5]. The robotic manipulator finds the shortest path to reach the target and follows a minimum energy contour to perform the desired function. Path planning of robotic manipulator based on fuzzy algorithm provide solutions in a sufficiently short amount of time with minimum energy consumption

Robotic manipulator uses sensors to determine position of object within its working envelop. Visual sensor is used to identify shape, position and orientation of object. The controller accepts the sensor data to acquire the desired position of robotic manipulator. It will also ensure that the robotic manipulator is correctly positioned to initiate the object acquisition. Controller provides the necessary signals for controlling the manipulator motors. Manipulator feedback sensors ensure smooth manipulator and grip operation without any collision or miss hit.

1) Path planning of Robotic Manipulator: Fuzzy algorithm provides solutions in a sufficiently short amount of time with minimum energy consumption. [35]The entire workspace scanned by camera can be utilized. If target is detected, fuzzy units are fed with the x and y coordinates of target within workspace. If no target is detected, the fuzzy unit is informed that the target is far away. The output variable of each unit is the motor command .The motor command is given to the link motor which is fed to the manipulator at each iteration.

2) Fuzzification: Fuzzification module performs two tasks. Input normalization, mapping of input values into normalized universe of discourse. Transformation of crisp process state values into fuzzy sets, in order to make them compatible with antecedent parts of linguistic rules that will be applied in fuzzy interface engine [5]. Before path planning work space of robotic manipulator is divided equally

Then fuzzification of distance in x coordinate and y coordinate done.

a. Fuzzification of y coordinate
Manipulator can detect an object within a certain range of distance in Y axis from 0-30 cm. Membership function for distance can be expressed in cm.

3 fuzzy sets:-
L-LOW
M- MEDIUM
H-HIGH

b. Fuzzification of x coordinate
Manipulator can detect an object within a certain range of distance in x axis from 0-30 cm. The membership function for distance can be expressed by 3 fuzzy sets:-
SL = SMALL LEFT
LL = LARGE LEFT
C = CENTRE
SR = SMALL RIGHT
LR = LARGE RIGHT

3) Fuzzy Interference Rules: In a fuzzy interface system, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion.

4) Fuzzy Rule Table

Y \ X	LL	SL	C	SR	LR
H	LLH	SLH	CH	SRH	LRH
M	LLM	SLM	CM	SRM	LRM
L	LLL	SLL	CL	SRL	LRL

Fig-2: Fuzzy rule table

Rules can be constructed as follows
- **If** X distance is LL and Y distance is H **then** control action is LLH,
- **If** X distance is LL and Y distance is M **then** control action is LLM

5) Defuzzification: The last step in the fuzzy inference process is defuzzification. Fuzzification helps us to evaluate the rules, but the final output of a fuzzy system has to be a crisp number. The input for the defuzzification process is the aggregate output fuzzy set and the output is a single number. There are several defuzzification methods, but probably the most popular one is the centroid technique.

$$COG = \frac{\int_a^b \mu_A(x)x\,dx}{\int_a^b \mu_A(x)\,dx} \quad (1)$$

2.3 Sensors

When designing a system using multiple sensors, it is important to understand the advantages and limitations of each of the sensors such as tri- axis accelerometer, tri-axis magnetometer, infrared sensor, ultrasonic sensor, visual sensor[32]. An accelerometer measures acceleration (change in speed) of the moving platform. Accelerometers are very important in the sensor world because they can sense such a wide range of motion. They are Analog Sensors capable of measuring acceleration on three axes (up/down, left/right, and forward/ backward) at the same time. This data could allow the robot to calculate its velocity or react to collisions and avoid hit.

The magnetometer senses the earth magnetic field (0.5Gauss–0.6Gauss). In static conditions, the projection of geomagnetic field on the three axes allows to compute heading angle.An algorithm is proposed to detect orientation in three dimensions. The inertial measurement unit (IMU) is composed of a tri-axis accelerometer, and a tri-axis magnetometer. A Kalman filter is implemented to yield the reliable orientation. The raw data from each sensor need to be calibrated. To calibrate these data, scale and bias must be taken into account. The bias represents how far the centre of data is from the zero. The scale means how much larger the range of data from the sensor is than the real meaningful data.

Proximity/distance sensors seem to be quite appealing for their acceptable cost-to performance ratio, as compared to that of more expensive sensing techniques, e.g., vision or laser range finding. Among proximity/distance sensors, ultrasonic (US) and infrared (IR) detectors are particularly interesting in real-life applications. Our Robot is equipped with simple ultrasonic sonar for detecting obstacles and an active infrared communication and localization system. Also our approach aims to construct an autonomous agent in which both the functions “perception for action” and “action for perception” emerges simultaneously by means of the integration of distance and visual sensor data to accomplish the task of navigation and pick & place by manipulator. Distance sensor is used to avoid obstacles and a visual sensor is used to recognize what the object is.

2.4 Kalman Filter

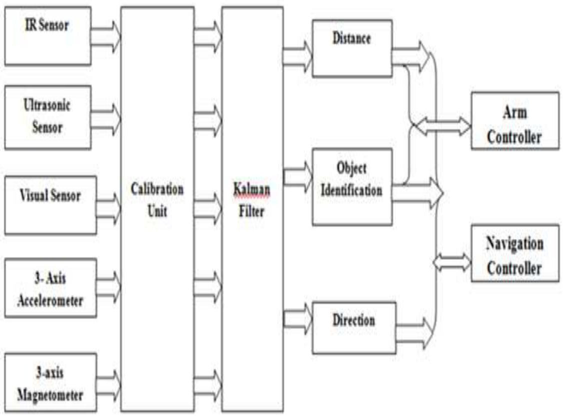

Fig-3: Block for sensor data fusion

Kalman filter has traditionally been used extensively in the solution of tracking, estimation and signal extraction problems. Kalman filtering is an optimal recursive data processing algorithm that is based upon state space concepts. The recursive nature of the algorithm makes it suitable for systems without large data storage capacities.

The Kalman filter [15] is used in sensor fusion and data fusion. Typically real time systems produce multiple sequential measurements rather than making a single measurement to obtain the state of the system. These multiple measurements are then combined mathematically to generate the system's state at that time instant.

The following steps are implemented [15] in discrete Kalman filter:
1) State prediction:
2) Prediction of error covariance:
3) Calculate the constant gain and update
4) Update error covariance:

In this case, the input value to the Kalman filter is z_d(state) corresponding to the distance between the camera and the object. In (1) and (2) the $z_d$value and covariance is predicted to the next step. In (3), (4) and (5) the equations correct the discrete Kalman filter. In (3), a new gain of Kalman is calculated. (4) and (5) calculate a new value of z_d predicted, and new covariance of error, respectively.

2.5. Object Detection

In this paper, PCA is applied for object detection. Principal component analysis (PCA) is a typical approach in pattern recognition. PCA is a way of identifying patterns in data. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analyzing data. The other main advantage of PCA is that once you have found these patterns in the data, and you compress the data, ie. by reducing the number of dimensions, without much loss of information. Edge detection and color detection is in the forefront of image processing for object detection. The main steps include

- Get Image data
- Subtract the mean from each vector to get a set of vectors
- Calculate the Covariance Matrix
- Find the normalized Eigenvectors and Eigen values of
- Arrange the Eigenvectors according to Eigen values from highest to lowest
- Find the Feature vector *F* using the transpose of Eigenvectors.

There are 2 phases for object detection.

- In Training phase, the image of the target is fed to the PC. Features are extracted and PCA is done.
- In detection phase, feature extraction and PCA is done and matched with already available result to detect object.

3. IMPLEMENTATION

Figure shows the entire system including the sensors, camera and robotic platform.

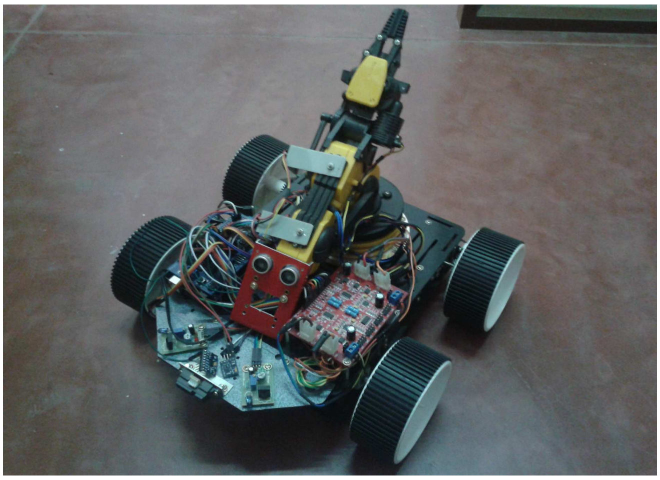

Fig-4: Robot Model

4. CONCLUSIONS

The mobile robot under development has robustness of conventional path planning techniques. This is by using Flood fill algorithm for path planning and Principal Component Analysis for object detection. An efficient target acquisition and faster mission completion can be achieved by sensor data fusion through Kalman filtering. Better performance of robotic manipulator can be achieved through fuzzy path planning algorithm. Fuzzy algorithm provide solutions in a sufficiently short amount of time with minimum energy consumption

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