Neural Network Based Sensory Fusion for Landmark Detection[2]

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Abstract

NASA is planning to send numerous unmanned planetary missions to explore the space. This requires autonomous robotic vehicles which can navigate in an unstructured, unknown, and uncertain environment. Landmark based navigation is a new area of research which differs from the traditional goal-oriented navigation, where a mobile robot starts from an initial point and reaches a destination in accordance with a pre-planned path. The landmark based navigation has the advantage of allowing the robot to find its way without communication with the mission control station and without exact knowledge of its coordinates. Current algorithms based on landmark navigation however pose several constraints. First, they require large memories to store the images. Second, the task of comparing the images using traditional methods is computationally intensive and consequently real-time implementation is difficult. The method proposed here consists of three stages, First stage utilizes a heuristic-based algorithm to identify significant objects. The second stage utilizes a neural network (NN) to efficiently classify images of the identified objects. The third stage combines distance information with the classification results of neural networks for efficient and intelligent navigation.

1. Introduction

Mobile robot navigation based on landmark detection is an emerging area of research and is particularly significant for autonomous vehicles used to explore planetary surfaces. This becomes even more important if the mobile robot has to navigate in an unstructured, unknown and obstacle ridden environment. The additional intelligence incorporated in the navigational algorithm results in better path planning, avoidance of limit cycle operation (going to the same place or looping around a particular place) and hence lower power consumption. Traditional goal-oriented algorithms, which rely on accurate position and orientation determination, depend on a pre-planned path and consequently are unsuitable for this application. Implementation of landmark navigation using classical image processing techniques, however, poses several constraints. Recording hundreds of landmark images requires vast amounts of memory and storage space. Furthermore processing these images to identify landmarks is a computationally intensive task.

Neural networks (NN) have shown considerable promise in classifying images and require less memory. The classification of significant images as landmarks is performed in the learning mode of the neural network when it updates its neuron interconnection weights. Ultrasonic sensory data of the distances of the *significant objects* in a particular landmark is recorded. This serves as reaffirming information when the robot is trying to detect the already learnt landmarks. Detecting relevant objects and images is another problem. This we propose to approach using an existing

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U.S. patented technology developed for *Fuzzy Control of Video Printer.* This technology uses the fuzzy logic based algorithm to detect relevant objects to improve the quality of the color. This entire method of using neural network with ultrasonic sensory data warrants limited memory requirements and can be implemented in real-time as it is computationally less intensive. Incorporating the emerging technology of neural network for detecting landmarks is a new and innovative method with practical application. Ultrasonic sensors can be replaced by laser range finders or any other distance sensors if ultrasonic sensors do not work on some planetary surfaces (e.g. devoid of atmosphere),

2. Related Work

In 1996, NASA will launch the Mars Pathfinder spacecraft, which will carry an 11-kg rover to explore the immediate vicinity of the lander [1]. At present the rover navigation is divided into four major functions: goal destination, rover localization, hazard detection and path selection. There is significant room for improvement of the navigational algorithm by adding extra degrees of intelligence. This can be done by incorporating a landmark based navigation algorithm. Using fuzzy logic and neural network based methods, the efficiency, robustness, adaptability and accuracy of navigation can be vastly enhanced. This will allow autonomous operation without communication from the lander and reduction of power consumption by selecting shorter paths by avoiding limit cycle operation of the rover.

There are several approaches to local positioning of mobile robots using landmark detection. These approaches generally apply only to structured environments or pre-defined landmarks. Nishizawa, et. al. [2] describe a local positioning scheme using landmark detection where the landmarks are reflectors placed sparsely in the ceiling of the robot's work space. They then utilize the Maximum Likelihood Estimation technique to eliminate the gradual error accumulation caused by the integration of the odometer measurement. Fukuda et. al. [3] uses a fuzzy template matching to recognize edges of air conditioning outlets in the ceiling to be used as landmarks. A NN then determines if the object is an air conditioning outlet. This information is then compared with the map of the robot's work space in order to position the robot. In [4], Jung proposes a robot vision system modeled after human's, where peripheral vision and central vision are processed separately for a more efficient detection. Luo and Potlapalli [5] utilize fractals to recognize landmarks in an outdoor environment. Since fractals are inherently scale invariant, the algorithm is robust to changes in light intensity and viewing direction of the landmark. Krotkov and Hoffman [6] developed a quantitative model of surface geometry in order for a safe, power efficient locomotion over the natural, rugged terrain. Ricotta and Liotta [7] describe a real time visual landmark tracking system for mobile robots. They discuss image processing techniques to track "relevant" objects in the robot surroundings and keep desirable objects within the robot's field of view. In [8-10], other approaches to landmark detection in structured environments are discussed.

Fuzzy logic has already been applied to data fusion. Murphy [11] describes a sensory fusion effects architecture for robot navigation. Also, he discusses the utility of biological and cognitive insights for sensory fusion. Abidi, et. al. [12,13] use fuzzy logic to integrate several sensory data and to enhance the recognition capability of an autonomous system by yielding meaningful information which are otherwise unavailable or difficult to acquire by a single sensory modality. Zhang et. al. [14] applied fuzzy logic for integration of deliberative and reactive strategies, where

programming at the task level in a partially known environment is divided into two consecutive steps: sub-goal planning and sub-goal guided plan execution. In [15], Song et. al. describe an integration routine for an ultrasonic sensor and a CCD camera. They utilize an extended discrete Kalman filter to fuse raw sensory data and to provide a more reliable representation for environment perception.
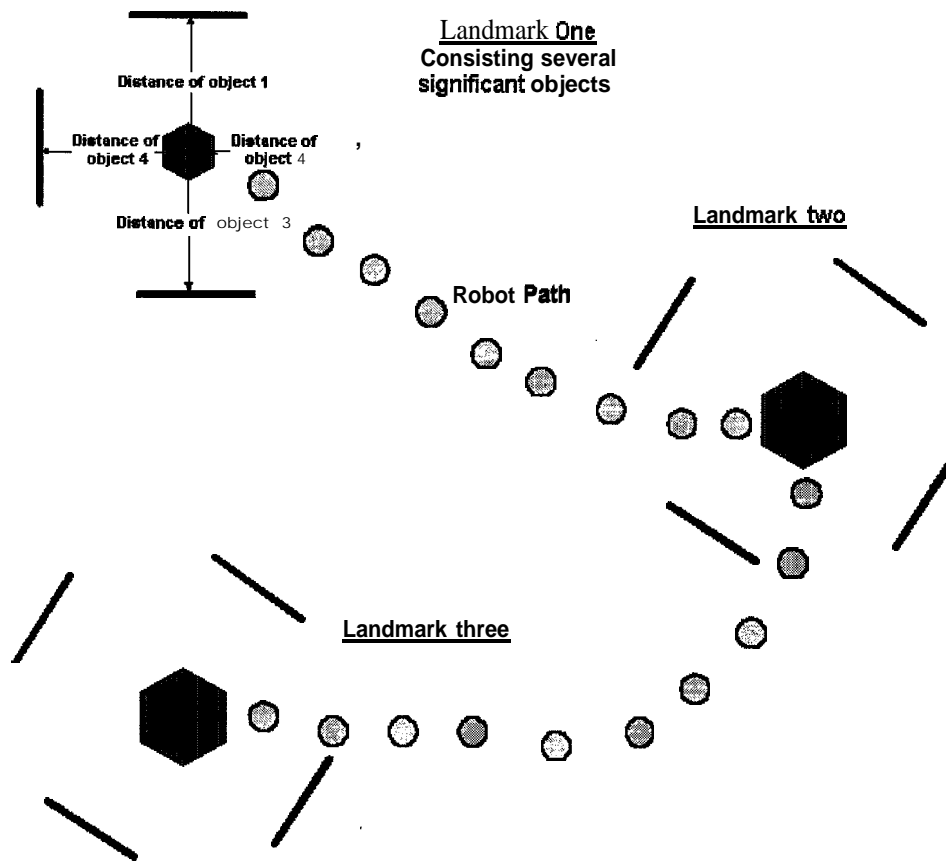

Figure 1: Landmark, significant object and robot path

3. Fusion of information for landmark detection

3.1 Significant Objects and Landmarks

The primary function in this method of landmark detection is to identify relevant or significant objects. The digital image frame from the camera is used as an input to a fuzzy logic based object identification algorithm. This algorithm decides whether the image can be classified as a distinguishable significant objects. This information depends on the environment in which the mobile robot is supposed to navigate. Such significant objects are represented by a sharp contrast or color variation in the image. In the actual settings, these landmarks need to be reaffirmed by other sensory information such as distance measurements. This can be done by using ultrasonic sensors or laser range finders. This means the object can only be considered for a landmark only if the position sensor can determine the distance from the object. A landmark can be a single object or a collection of several significant objects. By having several objects the identity of the landmark can be made unique. A sensory fusion algorithm based on fuzzy rule-sets can be used to fuse the information on a particular landmark. Figure 1 shows a landmark consisting of several

objects. We propose the use of ultrasonic sensors for implementation of the landmark detection algorithm. Figure 1 describes the significant object, landmark and mobile robot path. As the robot is traversing the unknown path, it continuously monitors the terrain. It looks for significant objects which can be considered as landmark.

3.2 Classification of landmarks using Neural Network

A multi-layer perception Neural Network (NN) has been extensively used to classify images. Once the fuzzy logic algorithm detects a valid object, the NN is trained to recognize this a particular object. Several images associated with the landmark is trained to the NN's memory by a back-propagation training algorithm. After the NN has successively learnt a landmark the robot can look for another landmark. The NN is trained to recognize several landmarks while the robot is traversing a terrain. Although there is no set size for the NN for learning a particular set of landmarks, it is generally based on the size of training data; the NN size increases as the number of images to be classified increase. In this proposed method a multi-layer network with two hidden layers. The number of neurons in the input layer is determined by the number of pixels in the image. The output layer neurons would correspond to the maximum number of landmarks to be detected.

Even though the usage of neural networks allows for reduction of memory requirements in identification of landmarks compared to actual storage of images, a large number of landmarks require an increased network size. Therefore, the mobile robot's allotted onboard memory will dictate the network size and consequently the number of landmarks which can be detected.

Figure *2* shows the flowchart of the comprehensive landmark detection algorithm. A combination of visual image and distance information is used to detect a landmark. A fuzzy logic based algorithm identifies significant objects. At the same time the sonar measures the distance of the object. If the distance can be accurately measured then the neural network starts the learning algorithm and classifies the significant object as a landmark. For any particular landmark several nearby objects are classified and the distance and orientation information are measured. A landmark thus is determined by fusion of image information with the distance information by a fuzzy logic based fusion algorithm.

3.3 Hardware and Software

The facilities at NASA ACE will allow us to develop the software for simulations as well as for future experimental validation. The digital camera will be directly interfaced with a Pentium-based personal computer. We have access to several possible platforms of mobile robots which includes an in-house built mobile robot, *LOBOT, a Cybermotion's NAVMASTER,* and *Angelus Research's WHISKERS Intelligent Autonomous Vehicle.* These mobile robots are equipped with several sensors including ultrasonic sensors. Visual C^{++} will be used for basic software development. We will use an adaptive fuzzy logic control algorithm, *Dynamic Fuzzy,* which has already been developed. *Lab Windows* will provide a user friendly visual interface.
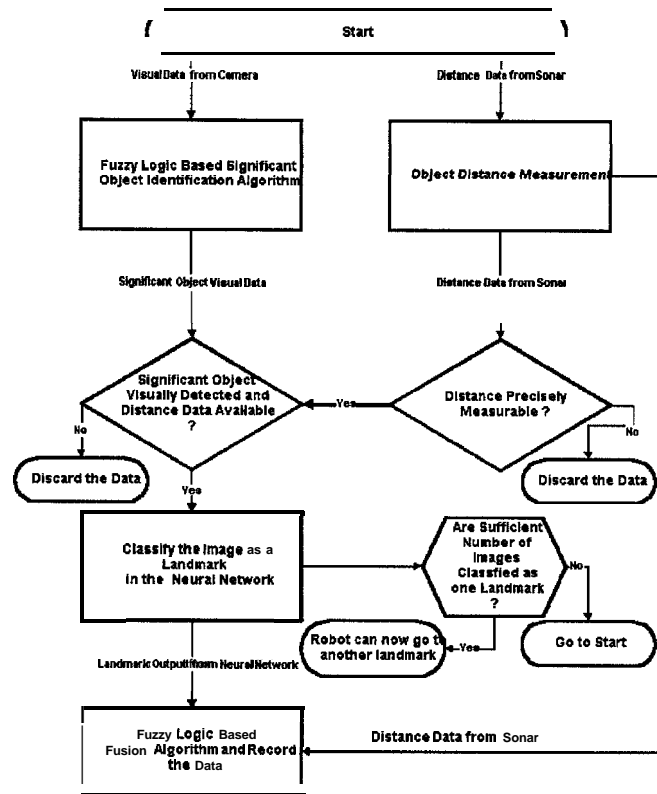
Figure 2: Flow Chart of the Landmark Detection Algorithm

4. Conclusions

This paper discusses a proposal to identify landmarks using a combination of fuzzy logic based significant object recognition algorithm and a neural network for classifying the landmarks. The landmarks are detected and defined by a combination of visual and distance information which are fused together for effective navigation. The proposed scheme will be implemented on real-time using the available mobile robot test-beds. An additional application of this method is related to robots on the factory floor. Using this method, the robots can identify parts in an assembly line to decide on a particular task. This eliminates the necessity of positioning the parts accurately which in turn allows a more flexible robotic assembly.

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