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Study on Types of Neural Network Algorithm for Autonomous Robot Navigation

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Abstract—*This paper revolves around the study of different types of neural network algorithms, used over the years, for autonomous navigation of mobile robots. The navigation system in mobile robots has been used for numerous applications till now, some of them being, navigating autonomously out of a maze (i.e.to reach a destination from the source), to detect forest fires, to navigate safely in an unacquainted environment. Thus the basic principle behind any of the above stated application is same, which is, autonomous planning of path along with identifying and avoiding obstacles along the path in an unacquainted environment. Almost all the researchers have focused on two cruxes while developing such a system: Dynamic and unacquainted navigational environment; Robot's learning credentials. The information about the former is obtained by using various on-board sensors (Ultrasonic range finder, SONAR etc.) and for the latter, different neural network algorithms are devised which exploits the information collected by sensors and instructs the robot to move in a particular direction. Irrespective of the NN algorithm used, the flow of events for developing a neural network controller remains the same, which are, Initialization of Neural Network, Training and Testing. But each algorithm used has its own set of advantages, disadvantages and application areas. Most of them have been thoroughly listed in this paper.*

1. INTRODUCTION

Since a few years, a number of studies have been performed that revolves around machine learning and its application in the field of mobile robots [1, 2]. This application involves building an autonomous mobile robot used for navigational purposes. An intelligent mobile robot with a number of sensors, to detect external environment, constitutes an autonomous robotic navigation system [3].

Navigation is a major issue in the designing of a mobile robotic system. Navigation is defined as the capability of a mobile robot to reach a destination location from a source location while avoiding collisions along its way. Therefore, as said by Umar in [4], robot navigation consists of two main concepts- Hurdle avoidance and goal reaching within its environment.

Several approaches have been observed to solve the issues of both static and dynamic environment. Some of them are wall following method [5, 6], edge detection approach [7, 8], Potential Fields Method [9] and Virtual Force Field Model [10].

However, the environment is complex, uncertain, unbounded and dynamical. Thus, to reach the goal location while avoiding obstacles, the robotic system must be equipped with decision making, obstacle avoidance and data processing and learning capabilities. For example, the data obtained by various sensors helps the robot in understanding the dynamic and unrecognized environment.

The knack of applying these features on a system comprises of some key concepts of artificial intelligence. Humans are consistently trying to reproduce this type of intelligence to build intelligent systems, specifically autonomous mobile navigation system. [1]

Neural Network is one such artificial intelligence technique that provides the desirable solution to navigational problems because they are capable of learning complicated non-linear relationship among input sensor data and output variables [4].

The two aspects to achieving an acceptable degree of autonomy in a mobile robot system are: sensing (to understand the complex unknown environment) and decision making (on the basis of an algorithm used) [1]. For sensing, an onboard sensory system is used and for decision-making capability, different types of neural network algorithms are devised that exploits the data captured from sensors and generates appropriate commands. Using neural network, robot attains the capability to avoid obstacles in an anonymous environment. Also, it acquires learning capabilities due to which it learns lessons from past experiences so as to avoid hitting the obstacle again in a similar scenario.

In this paper, different types of neural network have been classified and a study of similar papers has been done according to the type they fit in. In other words, the paper includes a short description of different neural network algorithms that have been used till now to solve the navigational problem of an autonomous mobile robot. Also, the general method of navigation while avoiding obstacles has been shown in fig. 1.

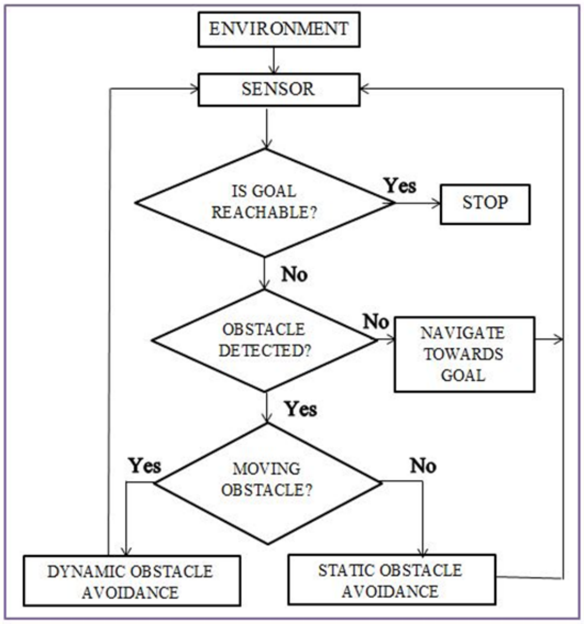

Fig. 1: General procedure of avoiding obstacles [34]

The paper is organised as follow: section 2 consists of types of NN learning algorithms; section 3 covers short reviews on individual papers depending on the type they fit in. Finally we conclude this paper in section 4.

2. TYPES OF NEURAL NETWORK- BASED ON NETWORK TOPOLOGY

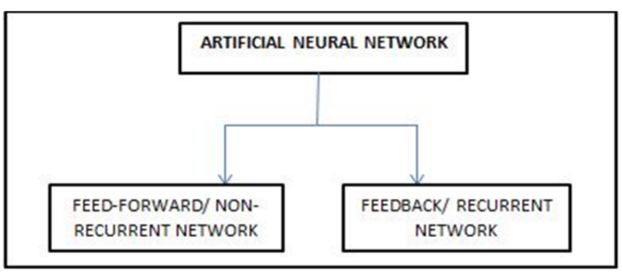

Fig. 2: Types of Neural Network [35]

Feed-Forward Artificial Neural Networks

It is the simplest ANN in which information flows in one direction only, that is, the forward direction. Information moves from input node to output node via hidden nodes. The output layer doesn't influence the input of the same layer. Hence, loops/cycles do not exist in the network. Single layer perceptron and multilayer perceptron are the examples of feed-forward ANN.

Feedback Networks/ Recurrent Neural Network

In this, the information flow is bi-directional unlike feed forward network where unidirectional flow exists. Data can propagate from subsequent processing stages to initial stages via loops/cycles. Thus, it contains both forward and backward connections. Hopfield model, Kohonen maps etc. are the examples.

2.1 Types of Neural Network Learning Algorithms [35]

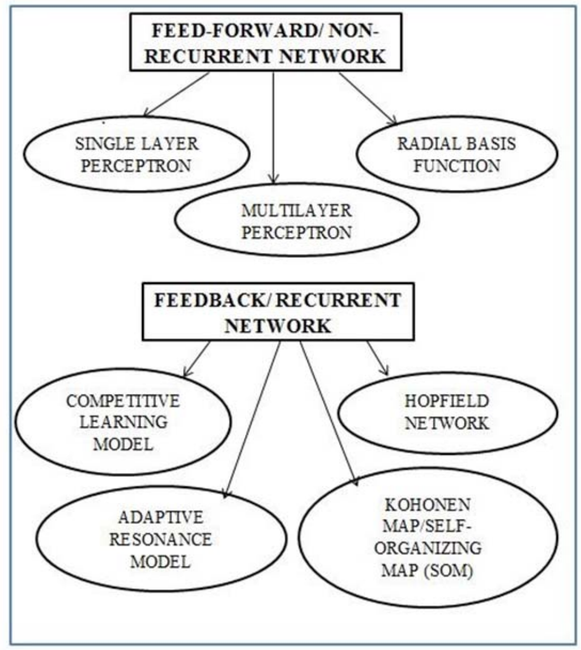

Fig. 3: Neural Network Learning Algorithms [35]

Single Layer Perceptron Network [11, 13]

This kind of neural network consists of only one layer of output nodes. Inputs are directly associated to output using a series of weights. If the sum of products of these weights and inputs is more than some threshold value (usually 0) then the neuron fires and assumes the activated value (usually 1). If not, then it assumes the deactivated value (usually -1).

Multilayer Perceptron Network (MLP) [11, 13]

In this, many layers of computational units are interconnected in a feed forward manner. Neurons, represented as nodes, of one layer have directed connections with the neurons of consequent layers. Backpropagation, a supervised learning technique, is used for training of MLP network.

Radial Basis Function Network (RBF) [11, 12]

RBF is the replacement of sigmoidal transfer function used in the hidden layer of MLP. It consists of three layers: an input layer, hidden layer (using non-linear RBF) and a linear output layer. Linear combination of input values, obtained using radial basis function, with NN parameters gives the output of this network.

Competitive Learning Model [14]

It is an unsupervised form of learning in which all neurons are same but with randomly generated synaptic weights. All neurons compete to acknowledge the subset of inputs and the neuron that wins is known as "winner-take-all". The corresponding output of that neuron becomes active.

Kohonen Map/ Self-Organizing Map (SOM) Network [11]

Also known as self-organising feature map (SOFM). Using unsupervised learning, it produces a discretized representation of the input training samples, called map. In other words, neurons learn to map these input space points to coordinates of output space. SOM tries to preserve the dimension and topology of input and output space during mapping.

Hopfield Network [11, 12]

It is a recurrent neural network. All connections of this network are symmetrical in nature. It is not designed to study the sequence of patterns. In fact, all inputs are stationary and its dynamics converge always.

Adaptive Resonance Theory (Art) Models [15]

ART is a theory that tells how information is processed in the brain. It is basically an unsupervised learning model in which the best neuron match of the input vector is transferred to the recognition field. It is mostly used for object identification and recognition.

3. SHORT REVIEWS ON PAPERS OF EACH TYPE

3.1 Multilayer Perceptron (MLP)

In [3], the learning capability of neural network algorithm is used for developing autonomous navigation system to navigate a mobile robot out of a maze. Backpropagation algorithm [16] uses a number of training samples to train the network. Sonar sensors provide input data to the neural network for navigating in a dynamic and unstructured environment.

In [2], two-layered neural network is used for collision-free path planning in a structured environment having stationary obstacles. One neural network, which is a modified PCA network, determines "free space" using ultrasound sensor. The other network is a multilayer perceptron that finds a safe direction in which the robot should move next in order to reach the destination location. Since real-time data is collected using sensors, therefore, this method can be used to avoid dynamic obstacles as well.

Hurdle avoidance and goal reaching controllers are used in [4] for developing an intelligent autonomous vehicle. Both of them are feed forward networks implemented in real time using tangent sigmoid activation function and AT89C52 microcontrollers. Offline training is done using back propagation algorithm and testing is carried out in a unacquainted environment. Approximated activation function may produce some errors which can be surpassed by using either more AT89C52 with true tangent sigmoid function or by using a neural network that doesn't need any activation function.

In [17], three controllers are used, out of which two are responsible for target localisation (mapping temperature fields to angular sector of the target) and obstacle avoidance (maps sensor values to stored obstacle configurations) behaviours of the intelligent vehicle and third acts as a supervisor for making final decisions depending upon the output obtained from the first two controllers. Standard backpropagation algorithm, a supervised learning technique, is used for training. The system thus obtained is less complex with faster response time.

Two layered neural network is employed in [18] for navigation of mobile robots along with avoiding obstacles. One is a PCA network with Hebbian rule used to find free space using ultrasonic sensor and the other is MLP network used to find the safe direction in which the robot should move. Back propagation is used for training and the idea is implemented on Intel Pentium processor -350 MHz in real time.

3.2 Radial Basis Function (RBF)

In [19], path planning of an autonomous robot is achieved using two NN based techniques (MLP and RBF) and the results are then compared. Khepera II is the circular shaped mobile robot, consisting of 8 uniformly distributed ultrasonic sensors to acquire real time environmental information, which is used to study the two algorithms. Simulation is carried out in MATLAB using both the algorithms. RBF appears to have greater efficiency, generates shortest path and has larger speed of convergence as compared to MLP.

In [20], RBF neural network is used for autonomous trajectory tracking in a static and unknown environment. Collision free motion is achieved using proportional controller.

In [21] as well RBF is used for path planning but it involves a non-linear trajectory for autonomous navigation in an unknown environment.

Local model networks are used for solving the navigational problem in [22]. The network consists of a set of sub-models such that each one is feed-forward network trained using back-propagation algorithm. Motion commands for the robot are generated by weighing the output of the sub-models with the RBF neural network. The performance of the robot using this algorithm is found to outperform both MLP and RBF, in terms of time utilised by the robot in reaching the goal.

The research carried out in [23] utilises RBF network to produce safe path for the autonomous vehicle to traverse large distances in a real and unstructured environment. Training data points are selected using global path and drivability grid map. The path thus generated can timely react to real time changes. RBF has the advantage of rapid learning speed and thus can easily meet the requirements for autonomous driving.

3.3 Competitive Learning Model

Competitive learning based neural network model is used in [1], in which each neuron has just neighbourhood associations only. Kinematics mathematical model is used for planning of path and obstacle avoidance is achieved using training of the input samples by the NN controller. MATLAB is used for simulation and an efficient path is obtained using this.

Competitive learning model is used [24] as well for guidance of an autonomous robot along an unknown path. Lyapunov stability theory [25] is used to check the convergence and stability of shunting equation and the system is found to be stable. But when this system is compared to Yang-Meng model [26], the robot is found to take sub-optimal path at places where Yang-Meng model fails. This can be fixed by choosing the parameter values wisely so as to obtain the shortest possible path.

3.4 Kohonen Map/Self-Organizing Map (SOM)

Low et al. [27] have used extended kohonen map technique (EKP) for motion control of mobile robot. A self-organising neuro integrated controller is used for goal reaching and obstacle avoidance.

In [28], a two dimensional kohonen map and reinforcement learning technique is used for mobile robot navigation in an unknown environment. Real time location of obstacle and target position is obtained using sensors and is stored in the map.

In [29], Kohonen neural network has been used for navigation of underwater vehicles.

The global self-localization problem in mobile robots can be addressed by using kohonen and region feature based neural network, as said in [30]. The robotic controllers learn to determine the current position of robot in a manner similar to optical character recognition using sensory data obtained from observing the environment. This technique is effective owing to time.

For navigation based on robotic vision, self-organizing incremental NN has been used in [31]. The algorithm used requires simple computation and executes in less computational time.

3.5 Hopfield Network

Glasius et al [32] proposed Hopfield type neural network algorithm for real time path generation of a mobile robot while avoiding obstacles in a randomly changing environment. There is no learning process involved in this and the robot doesn't get trapped in a local minima. Also, the solution obtained is globally optimal. But the system cannot deal very efficiently in the fast changing environment.

In [33], harmonic function properties are applied on neural network for real time and collision free path planning of robot, navigating in a randomly varying environment, without using any learning procedure. This paper utilises the concept of neural dynamics in which an improved Hopfield network is used for target activity propagation, similar to physical heat conduction, so that the robot can respond to changes in real time while moving in a dynamic and unacquainted environment.

4. CONCLUSION

Robotic path planning problem can be resolved in a way similar to humans. The problem can be broken down into three levels: understanding the environment using sensory data, global path planning and local path planning. The learning algorithms that have been addressed in this paper are: MLP, RBF, Hopfield type, Kohonen map and competitive model. Various trade-offs exist between different algorithms. Any algorithm can be used to solve path planning problem on a particular data set as long as training parameters are chosen wisely. However, selecting a training algorithm for an unknown data requires a set of experiments to be performed.

One type of artificial neural network that we have not discussed in this paper is ART based neural networks algorithm. It is basically an unsupervised learning model in which the best neuron match of the input vector is transferred to the recognition field. It is mostly used for object identification and recognition.

Also, there can be other types of classification of neural network, such as, on the basis of learning method used : supervised, unsupervised, reinforcement; based on transfer function used: linear, non-linear; based on number of layers: single, multilayer.

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