Behaviour Trees Based Decision Making for Soccer Robots

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Abstract: This paper proposes a novel behaviour tree based decision making mechanism for control of soccer robots. Decision Making (DM) is a basic block that analyses the current state of world model and makes decision about new positions of robots. Using hierarchical tree structure the behaviours of robot soccer are designed. BT has high and low level behaviours and its nodes are operating using certain behaviour rules. High level behaviours are implemented using low level behaviours. The use of BT approach allows to model complicated situations easily that show advantages of this technique over finite state machines widely used in robot control. After defining behaviours and making decisions, path finding module determines the path of robot. In the paper a novel path finding algorithm that uses a Rapidly Exploring Random Tree (RRT) and path smoothing techniques has been developed to find the path of the robot in a short time. The obtained simulation and experimental results show that the constructed navigation system of soccer robots efficiently finds desirable and feasible solutions in short amount of time.

Key-Words: - Behaviour trees; robot navigation; path finding; soccer robot

1 Introduction

The main goal of mobile robot navigation is steering a robot in any direction, in particularly towards a goal, and to know its precise location in the environment at any time. Many efforts have been paid in the past to develop various algorithms for navigation and control of robots in dynamic environments. Control and navigation of robot includes a set of algorithms. These are vision module, decision making, path planning, and control algorithms. The soccer robots used in RoboCup uses SSL vision system. Decision Making (DM) is the basic intelligent module in robot navigation. This module analyses the current state of the world and makes decisions about the new positions of soccer robots and plans a motion for the robots. In the literature different approaches—finite state machines [1,2], Petri nets [3,4], behaviour based control [5-7], and topological graph map [8]—have been considered to develop DM module for soccer robots.

Finite state machine (FSM) is widely used for robot control [1,2,9]. Modelling behaviour with hierarchical finite state machines has expressiveness; it is more intuitive by utilizing more compact behaviour descriptions. For actions layer a FSM has been designed to properly select among the actions. The algorithm has been tested in simulation and provided satisfactory results in many researches. But for complex situations the use of FSM for robot games increases the number of states required to encode the behaviour of the robots, along with the number of transitions between the states. Sometimes the modelling of these situations becomes very difficult with FCM.

Petri nets are preferred to FSM due to their larger modelling power and because one can model the same state space with a smaller graph [3,4]. Composition of Petri nets leads to an exponential growth in the state space. In some cases the building of Petri nets become too large to generate all states of the system and its analysis becomes difficult.

In the paper the hierarchical BT approach that simplifies the decision making process is purposed. In mobile robots, operating in unstructured environments, a priori knowledge of the environment is usually absent or partial. Frequently, the environment where robot moves is not static, i.e., during motion the robot can face with other moving robots or obstacles, and thus execution is often associated with uncertainty.

After making decision using BT approach, the path planning is used to determine a route from the robots current coordinate location to another goal location along a set of waypoints. There have been developed a number of methodologies for robot navigation using path planning and obstacle avoidance. These approaches require certain time for finding of feasible path [10,11]. Moreover soccer robots operate in the environment having many moving obstacles and goal, and the next positions of the goal and obstacles are unknown to the robot. The use of the traditional methods for path finding of soccer robots require certain time, and the finding of this path may not complete in
reasonable time for real-time operation. For such cases, finding feasible, “near-optimal” robust path in short time becomes important. In this paper, for constructing efficient path finding system, the use of a path smoothing algorithm is considered that allows optimizing the given robot path using the local environment information.

2 Behaviour tree based decision making

BT is goal oriented. Each tree is assigned a goal, that will be achieved. The robot behaviour is a control law that satisfies a set of constraints to achieve a particular goal. Each behaviour is defined by the set of actions.

A BT enables modularity, making states nested within each other and thus forming a tree-like structure, and restricting transitions to only these nested states [6,7]. The root node branches down to the tree until the leaf nodes are achieved. The leaf nodes are the base actions that define the behaviours. A BT is made up of three types of nodes, action, decorator, composite (Fig.1). Composite and decorator nodes are used to control the flow within the tree and action nodes. Actions are used to change states such as calculating a new path or kicking the ball. Composite nodes include set of nodes such as selector, sequence nodes, and their parallel and random versions.

Selector and sequence nodes are workhorse internal nodes (Fig. 1). A sequence represents a series of behaviours that we need to accomplish. A sequence will try to execute all its children from left to right. If all of its children succeed, sequence will also succeed. If one of its children fails, sequence will stop and return failure (Fig.1(a)). Fig. 1(a) describes a hypothetical pass sequence which will start executing its children from left to right, first checking if the receiver is at the correct assist spot waiting for a pass, then make sure a pass is safe. If both these conditions are met, only then it will execute the pass and return success up the tree.

Selector node will try to execute its first child. If its first child returns success, it will also return success. If the child fails, it will try executing its next child until one of its children returns success, or the node runs out of children at which point the node will return failure (Fig. 1.(b)). This property allows us to choose which behaviour to run next. The tree in Fig.1(b) chooses between shooting at the goal directly or executing a pass. Selector will start executing its children from left to right beginning with Shoot Goal sequence. If both Can Shoot to goal? and Shoot actions succeed, sequence will succeed, which will cause the selector to succeed. If Shoot Goal sequence fails, it will keep trying to execute its children until one succeeds, in which case selector will also succeed. If all fails selector will also fail.

Decorators take their names from the software design pattern Fig.1(c). In the context of BTs a decorator node is a node with a single child. Decorator modifies the behaviour of the branch in some way. Fig.1(c) shows the same Pass sequence with a decorator as its root. What limit decorator does is that, it will try to play pass. If a pass is made it will return success up the tree, if its children fails, it will try it n more times (1 in the case of this tree) to execute a pass. If a pass can not be made within n times then it will return fail up the tree.

The other behaviour nodes that can be used for composing tree are “non-deterministic-selector”, "non-deterministic-sequence", "parallel", "forever", "until-fail", "until-success", "limit", "inverter", "interrupter" etc.

Using above described technique, the BT of complicated behaviours can be described. In the paper the BT approach is applied to control soccer robots. Hierarchical BT that uses high and low level trees are constructed. Each behaviour is reacting to the set of input data obtained from SSL vision. Decision making (DM) block of the robot uses a hierarchy from higher level behaviours to lower level behaviours. Robots are controlled by composing lower level behaviours into more complex higher level behaviours, and then these behaviours can be dispatched to the robots.

Each low-level behaviour handles a specific low-level action: Move to behaviour provides move function for other behaviours; Pass behaviour controls two robots and plays a pass; Move to ball behaviour is used to catch the ball; Defend Goal. In this case defender-robot will place itself to the intersection of ball heading and the goal line; Shoot behaviour is optimized for kicking the ball; Assistant behaviour searches for a free space for receiving a pass; Marker behaviour selects a robot to intercept passes; Move with ball behaviour handles dribbling; Penalty-taker behaviour specializes in shoot task for penalties; Penalty keeper behaviour is optimized for keeping penalties.

As an example in Fig.2, Pass behaviour tree is described. Pass sequence begins by taking control of two robots using a parallel sequence, which acts like a sequence but executes its children in parallel aligns, passer and receiver for a pass, then the tree checks if a pass is safe. If a pass can be made passer shoots the ball. Next, the sequence waits for the ball to start moving, once that happens, we again wait
for either the ball to stop or the ball gets within a robot diameter to the receiver at which point receiver moves and captures the ball.

The low level behaviours are composed to form high level behaviours. Some of our high level behaviours include: Formations behaviour places robots on various hard coded spots on the field; Offensive Game behaviour focuses on scoring goals against the opponent, as opposed to defence plays, which focus on preventing goals being scored into our own goal; Defensive Game focuses on preventing the opponent from scoring goals, as opposed to offence plays that focus on scoring against the opponent; Game Selection behaviour is used to select the main tactic.

3 Design of Efficient Path Finding Procedure

The next important problem is designing of the path finding algorithm in mobile robot navigation. One of the commonly used fast algorithms for path finding is a Rapidly-exploring random tree (RRT) algorithm [12,13]. The RRT algorithm is designed for efficiently searching nonconvex, high-dimensional search spaces. RRTs incrementally reduce the expected distance of a randomly-chosen point to the tree. The RRT algorithm is extremely simple and cheap to calculate but it is not optimal. A path will be computed quickly but it is not guaranteed to be the cheapest, and will results a
different path for every search. Fig. 3 depicts the result of the RRT algorithm. As shown RRT algorithm finds many paths, then selects the path that can achieve the goal. RRT contains many zig zags and unnecessary edges. In order to deal with this problem, we use a path smoothing algorithm. Given two nodes that are reachable A and B. Assume that A is start point of the path. This algorithm removes any nodes between A and B since we can go from A to B directly without going through all the nodes in between (Fig.4). Here a dashed line depicts the original path, solid line demonstrates the optimal smoothed path. In the process of smoothing, the path is optimized. The use of path smoothing procedure with RRT-Plan allows to optimize the path of the robot.

```plaintext
function smooth-path (isWalkable, path, curr-node, path-rest)
if(isEmpty(rest) == false)
    path_rest = drop-while-walkable(fn(isWalkable, curr-node,%),path_rest)
    x = first(path-rest)
    xs = rest(path-rest)
    smooth-path(isWalkable, addNode(path-rest, curr-node), x, xs))
else
    return addNode(path_rest,curr-node)

function drop-while-walkable (pred, path, curr-node)
if(isEmpty(path) == false && pred(first(path)) == true)
    drop-while-walkable(pred, rest(path),first(path))
else
    return addNode(curr-node, s)
```

Table 1 demonstrates the simulation results of RRT-plan, using path smoothing algorithm for Fig.6 for different values of pGoal and epsilon. As shown from the tables, the use of path smoothing allows optimizing the tree and decreasing the path. The simulation results of A* and APF algorithms for Fig. 6 for different values of grid sizes are given in Table 2. Comparing these results with the ones given in Table 1 we can show that the run time of RRT and path smoothing algorithm are considerably lower than the run time of A* algorithm. Because of the optimization, the length of path used by RRT and path smoothing algorithms are close to those of the A* algorithm. From this it follows that the use of RRT and path smoothing algorithms allow efficient control of the robot in dynamic environments cluttered with obstacles.

The simulation studies were done using RRT-Plan and path smoothing algorithms. Simulation of the RRT-Plan algorithm has been done for different values of parameters- Epsilon (the amount that the tree is expanded at each iteration) and pGoal (probability goal). The resulting trajectory found by RRT-Plan is not guaranteed to be optimal, which causes the planned trajectory to be longer than the optimal path found by A* and APF [14]. To overcome this deficiency, the path found by RRT-Plan is optimised by a “quick path smoothing” algorithm. Fig.6 (a,b) depicts the results of simulation of RRT-Plan and quick path-smoothing algorithms, when epsilon=50, pGoal=0.3 (a), epsilon=5, pGoal=0.1 (b) and epsilon=5, pGoal=0.3 (c). In figures dashed lines indicate results for the RRT-plan algorithm only, and solid lines indicate the RRT-plan and path-smoothing algorithm results. In Fig.6 (a) two different cases are given for the RRT-plan and path-smoothing algorithms, when epsilon=50, pGoal=0.3. In (b) epsilon=5, pGoal=0.1 and in (c) epsilon=5, pGoal=0.3.
In order to track the world in real time, the data is collected using high speed overhead cameras. SSL-Vision system is used to obtain the coordinates of soccer robots and balls, and in addition simulates the environment using high speed overhead cameras. SSL-Vision system is a vision system of soccer robots of RoboCup Small Size League. Computer tracks the coordinates of each holonomic robot, and in addition simulates the movements of the robot by receiving control signals. In real life the same coordinates are sent by the SSL-Vision system to the robot soccer through wireless. A PID controller is used to control rotational speed of the robot soccer which keeps it pointing to an angle. Motor drivers are driven by a microcontroller. Microcontroller is connected to the computer via wireless link. By changing the speed of the individual omni-wheels we can control direction, rotation and speed of the robot. The formula used to calculate the speeds of each wheel, for a robot with four wheels, is given below,

\[
\begin{bmatrix}
  v_1 \\
  v_2 \\
  v_3 \\
  v_4
\end{bmatrix} = \begin{bmatrix}
-\sin \theta_1 & \cos \theta_1 & 1 \\
-\sin \theta_2 & \cos \theta_2 & 1 \\
-\sin \theta_3 & \cos \theta_3 & 1 \\
-\sin \theta_4 & \cos \theta_4 & 1
\end{bmatrix} \times \begin{bmatrix}
  v_x \\
  v_y \\
  R\omega
\end{bmatrix}
\]

Here \(v_x, v_y, v_3, v_4\) are motor speeds. \(v_x\) and \(v_y\) are the speed of robot in horizontal and vertical direction, \(R\omega\) is the rotation speed. After calculation the wheel speeds, the computer sends these values to the robot soccer via wireless. The speed of robot is determined by the DM block using this data and converts it into a data structure which is used by DM module. DM block using this data, makes strategic planning of soccer robots.

\[\text{Table 1. RRT-Plan and quick path smoothing algorithm results}\]

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<th>(\xi_{\text{Goal}})</th>
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\[\text{Table 2. Simulation results of A* and APF algorithm}\]

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<td>APF</td>
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</table>

4. Real time implementation

The structure of the robot soccer navigation system designed in this paper is given in Fig. 7. The mobile soccer robots and their navigation system are designed, manufactured and assembled in our research laboratory [15]. To design soccer robots we used holonomic robots that have holonomic wheels with 2 degrees of freedom. Before applying the robot navigation software on soccer robots, we've tested the algorithms using a simulation software package called grSim [16]. grSim acts as the vision system of the robot which sends coordinates of all robots and balls, and in addition simulates the movements of the robot by receiving control signals. In real life the same coordinates are sent by the SSL-Vision system.

SSL-Vision is a vision system of soccer robots of RoboCup Small Size League. Computer tracks the coordinates of each holonomic robots and sends them to the computer/s. In order to track the world in real time, the data is sent every 1/60th of a sec. Tracker module captures this data stream off the network and converts it into a data structure which is used by DM module. DM block using this data, makes strategic planning of soccer robots. Behaviour tree based control with RRT-Plan and path smoothing algorithms are applied for decision making and path finding of the holonomic robots. After selecting certain behaviours, path finding block find the new coordinates of each holonomic robots. These coordinates describes a path, which is then sent to the Velocitiy block where a velocity vector is calculated and updated to guide the robot along the path. Between each velocity update a set of four motor speeds, one for each wheel, is calculated and sent to the soccer robots. Motor drivers are driven by a microcontroller. Microcontroller is connected to the computer via wireless link. By changing the speed of the individual omni-wheels we can control direction, rotation and speed of the robot. The formula used to calculate the speeds of each wheel, for a robot with four wheels, is given below,
5 Conclusion

The hierarchical BT based algorithm is developed for efficient navigation of soccer robots. BTs easily define complex states. The modularity of the behaviour tree based control design allowed for incremental development and ease of maintainability and extendibility of control system. The algorithm has been extensively tested in simulation and through experimental tests and provided satisfactory results. Also improved path finding algorithm is presented to provide navigation path in required shortest time. Through simulation it was shown that the proposed algorithm efficiently finds feasible and near optimal solutions in short time and shortens the path length considerably. The described BT based control and path finding algorithm are applied for control of the holonomic soccer robots which are designed and assembled in our research laboratory. The experimental results demonstrate the efficiency of the proposed algorithms in navigation of soccer robots.

References


