A SIMPLE YET EFFECTIVE FAILURE RESILIENT ROBOTIC SOCCER STRATEGY

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by

SARVASIDDHI SABITHA
200702040
sabitha.sarvasiddhi@research.iiit.ac.in

CENTER FOR DATA ENGINEERING
International Institute of Information Technology
Hyderabad - 500 032, INDIA
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International Institute of Information Technology
Hyderabad, India

CERTIFICATE

It is certified that the work contained in this thesis, titled "An Elementary yet Effective Failure Resilient Robotic Soccer Strategy" by Sarvasiddhi Sabitha(200702040), has been carried out under my supervision and is not submitted elsewhere for a degree.

Date	Adviser: Prof. Kamal Karlapalem

To My Parents

Sankara Rao and Lakshmi

Acknowledgments

I would like to take this opportunity to express my deepest appreciation to my Professor Dr.Kamal karlapalem, for his continuous support and guidance throughout my Masters study and research. His patience, motivation, enthusiasm and immense knowledge inspired me a lot at every step of my research. I am fortunate to have technical discussions with him as it helped in broadening my perspectives of problem solving skills to handle challenges in this work. Without his guidance and persistent help, this dissertation would not have been possible. I'm greatly honored to finish my thesis under him.

I am grateful to G.Raghudeep, Rahul Sarika for the valuable suggestions and advices they provided in my first stage of understanding Multi-agent systems.

Needless to mention the love and support of my parents, sister and my friends.

Sarvasiddhi Sabitha

Abstract

Robots tend to fail very frequently in games like Soccer. Due to either collision with other players or objects, or extreme body actions or accident, or wear and tear of robot parts, the robot might either become unstable and even fail in the worst case. Also in soccer, fouls happen and players are sent off most commonly resulting in the variation of the number of players active in the game. The temporary or permanent unavailability of a robot player due to these situations disturbs the strategy of the team which in turn impacts the outcome of the game since the team strategy plays a key role in taking major decisions like formations of the robots, roles and actions assignment to robots to achieve the final target - win the game. So, it is essential for the game strategy of a soccer team to dynamically handle fail and fouls of the robots during the game. Whenever there are failures of the robots in the team, the remaining robots need to quickly analyze the state of the game, re-strategize and come up with a new set of actions for the team. The aim of this thesis is to propose an elementary failure resilient strategy for an 11 robots vs. 11 robots soccer team that works towards scoring the goals considering the failure of the robots. Our strategy is elementary because it is based on the idea of re-distributing the work among surviving robots to either defend or attack.

This study has two major parts:(1) Investigation of different game strategies that are already implemented in vogue, (2) from the observation of these strategies, design a game strategy for an 11vs11 Robot Soccer Team that can effectively handle the fail and fouls of the robots during the game. Four different strategies each focusing on different perspectives of the game are taken and simulated for observation and analysis. In the failure resilient strategy, decisions on player's formation, roles and actions are made dynamically considering the state of the robots (active or failed) to achieve the common objective of defending the goal line and scoring a goal. The strategy is designed in such a way that it is not affected by the dynamic change in the number of robots due to failure during the game. In this thesis, mechanisms followed to implement the four basic independent actions of the robot player necessary to play the game are also discussed.

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Chapter 1

Introduction

1.1 Multi-agent system

Autonomous agents [34] are software or hardware entities that are capable of taking individual decisions and performing various actions without human intervention in order to meet the objectives they were programmed to. Multi-agent system [32, 36] is a complex system composed of autonomous agents that co-exist in an environment. It is utilized to solve problems difficult or impossible for a single autonomous agent. Agents have the ability to interact with other agents for cooperation, coordination, negotiation, etc. A Multi-agent system consists of a set of agents and an environment where the agents observe, learn and share knowledge with other agents and act upon the environment. Multi-agent system applications cover a wide variety of domains like disaster rescue missions, aircraft maintenance and many other real world scenarios. Soccer is one such complex multi-agent system chosen by researchers which have a lot of challenging problems like multi-agent decision making, collaborative analysis in case of failure, communication and negotiation.

1.1.1 Multi-agent decision making

In a multi-agent system, cooperation and coordination [11, 37] among the agents are necessary because in a complex environment, a single agent could not get sufficient expertise, information and resources to decide on its action and solve the problem on its own. Multi-agent decision making [40] is a vast study which involves coordination, cooperation, dependability and fault tolerance of the agents. In dynamic environments like in soccer, the state of the game changes with time and the agents should frequently cooperate and co-ordinate with each other to achieve their common objective for example, scoring a goal. Sometimes, agents are assigned to different sub-goals to reach the final goal. In the course of achieving their specific sub-goals, agents might accidentally disturb each other's sub-goals. To avoid this, agents should coordinate properly before making any action to reach their goal so that they do not hinder the tasks given to the other agents. Multi-agent decision making also involves learning the weakness of the opponent agents, sharing the knowledge with other agents and deciding the set of actions to take upon the environment. Some Multi-agent systems follow a hierarchical structure where a subset of agents act as master and do the decision making for the remaining agents while some systems follow a flat hierarchy. Best example of a multi-agent system concentrating highly on multi-agent decision making is Soccer.

1.1.2 Collaborative analysis in case of failure

Multi-agent systems are decentralized and distributed in an open environment which is dynamic, complex, unpredictable and non-deterministic. In systems like these, agents do not possess complete control over the environment. Same action performed by the same agent at identical circumstances may have different effects on the environment. We cannot completely assume the actions of the agents to be accurate as there may be external disturbances from the environment hindering their actions or cause unexpected failure to them. If an agent fails, the goal or sub-goal could not be satisfied which may delay or fail to reach their main objective. When faced with these non-deterministic behavior, it is essential to analyze [5] the state of all the agents and system dynamically, before deciding the further actions of the agents for better results. RoboSoccer and Robot Rescue Missions are examples of such systems that need to consider agent's failure when designing their strategies for successful results.

1.1.3 Communication

For distributed problem solving in multi-agent systems, agents require communication [1, 22] to coordinate their actions. The main purpose of agent communication is cooperation and knowledge sharing. Communication can be point-to-point between two agents or broadcast where an agent sends information to a group of agents or mediated where there is a third party mediating the communication between agents. Agent communication needs a common language, Agent Communication Language or ACL. Any ACL can be used for our soccer playing agents to communicate with each other.

1.1.4 Negotiation

Negotiation [3, 4, 14] is a vital form of interaction in a multi-agent system that helps a group of agents to come to a mutual agreement based on a set of beliefs. In case of inter-agent dependencies, the agents should be able to convince others to act in certain ways for mutual benefit. There are two major concepts in Negotiation that have a wide range of research going on. First, negotiation protocols are a set of rules that need to be satisfied before making any interactions with the agents. Second, for a given protocol, the agent should use a strategy which has the maximum individual benefit while negotiating with other agents. Auction [2, 24] is an example of a multi-agent system where the concept of negotiation is used.

1.2 Robot Soccer

Robot soccer [11, 12, 20] is a competitive game played strategically between a team of agents [33] based on the state of the game. The strategy of a robotic team mainly involves recognition of opponents and teammates, recognition of goal posts, penalty areas on the field, coordination and cooperation among teammates, communication and negotiation. Multi-agent decision making and collaborative analysis in case of failure are the main areas focused in this thesis. *Communication [1, 22], negotiation [3, 4, 14], collision detection and avoidance [9, 13, 25, 31], instability detection [18, 19] and failure detection, fall avoidance of the robots are not covered as part of this work. Robot fall resilience is also not covered as part of this work.* In our problem specification, the agents/robots are not available due to failure or sent out (due to fouls), this unavailability is modeled as agent failures. Further, we have studied the 2D robot soccer game strategies and analyzed their failure resilience.

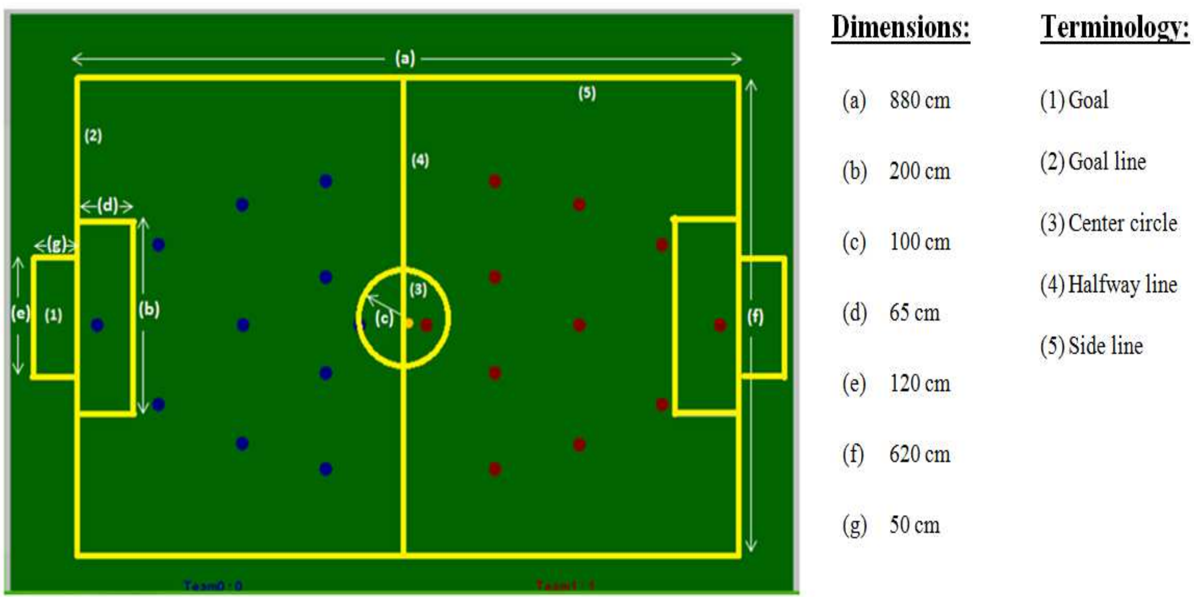

Figure 1.1 Soccer Field Simulation

1.3 Game Strategies

Many soccer game strategies [39, 28, 27, 38, 8, 23, 6] are already designed and implemented taking different perspectives of the game into consideration, prioritizing among them and taking action based on the result. However, the ability to perfectly sense the state of the game and take action as a team is always an open challenge. In this paper, we simulate and analyze four different strategies that are already designed each focusing on different perspectives of the soccer game.

- **Uniform-cover strategy** : This strategy [15] mainly concentrates on covering the game field with the players and letting only one player closest to the ball to chase after the ball. All the players except the striker place themselves in different positions uniformly across the field covering the area behind the ball.

- **Role-based strategy** : This strategy[16] maintains two modes - offense and defense. The mode of the strategy is decided dynamically based on the location of the ball in the field. If the ball is on the opponents team's court, team follows the offensive mode strategy otherwise defensive mode strategy is followed.

- **Defense-priority strategy** : In this strategy [7], the field is divided into two parts - one for offense and the other for defense. This strategy mainly focuses on the defense i.e., it concentrates more on blocking the opponents from scoring a goal rather than trying to score a goal themselves.

- **Offense-priority strategy** : In this strategy [7], the field is divided into two parts same as in Defense-priority strategy. This strategy mainly focuses on offense i.e., on scoring a goal rather than defending the opponents from scoring.

Each of these game strategies are explained in detail in Chapter 4.

1.4 Robot Failure in Soccer

In games like soccer, where contact is allowed it is usual that a player fails as a consequence of fouls, collision with other players or objects, or external body actions, such as fast movements or kicking the ball from unstable body position. Repeated fall or extreme body actions and vigorous movements can cause complete failure of robotic agent. In such situations, the agent remains passive for the rest of the game and cannot further participate in the game. In a proper soccer game of eleven players in each team, there is a high chance of failure of the agents during the game as there are a total of 22 players on the field performing different actions. So, it is vital to consider the failure of the agent when designing a game strategy for a Robot Soccer Team. In this thesis, we do not study how and why robot failed, but we study the strategies employed by other agents in the team when some agents are no longer available.

1.5 Thesis Contribution

The main contributions of the thesis are -

- Designing a robot soccer game simulation with players ranging from four to eleven in each team.

- Designing two different types of environment simulations - ideal and real. In ideal environment, ***agents do not fail during the game*** while in real environment, agent failure is possible.

- Designing a supervisor program to keep track of the game scores and other relevant information related to the game.
- Implementing four different game strategies in both ideal and real environment for failure analyses.
- Proposing a simple yet effective failure resilient soccer strategy for a Robotic team of eleven players. This strategy is implemented in our Soccer Simulator and Simbad Robot Simulator, played against the other four strategies, analyzed in both ideal and realistic mode for failure.
- Our results show that the proposed Failure Resilient Strategy performs better even with failure of the players during the game.

1.6 Thesis Outline

Thesis is organized as follows: In Chapter 2, we present the related work done on Robot soccer simulation and game strategies. In Chapter 3, we describe the Robot soccer simulator we designed, rules of the game followed, players in the field and the mechanisms players follow when taking individual actions like shoot, pass, dribble and clear during the game. In Chapter 4, we describe some of the previously designed game strategies for an eleven player team and discuss about them in our Soccer simulation. In Chapter 5, we explain the failure resilience of these ideal strategies. In Chapter 6, we describe the elementary game strategy designed considering the Fail of the agents during the game. Chapter 7 presents the Thesis conclusion and future work.

Chapter 2

Related work

There has been a significant amount of research on designing soccer game strategies for all kinds of robot teams like humanoids, four-legged robots etc.

2.1 Previous work on Robot Soccer Strategy

R.R.Heddema [7] proposed strategies - “2-2 formation”, “1-3 formation with rotational tactic” that use finite state machines(FSM) to create directed positioning for the robots. The team is composed of players who perform the role of a keeper, a defender or an attacker. In 1-3 formation with rotational tactic, the attackers help the defense resulting in a cyclic behavior for the attackers. Each role a player takes, has a finite set of states. The state a particular player takes at a particular point of time is decided based on the location of the ball - whether the ball is in defense, offense or clear area. In the 2-2 Strategy, the team has 2 players for defense and 2 players for offense and a goal keeper. When the ball is in the defense, attackers stay passive while the defenders try to defend and stop the opponents from scoring a goal. When the ball is in the offense, one of the attacking players take the supporting role while the other attacker try to score a goal.

Xiao-jun Zhoa [41] proposed a multi-agent cooperation strategy for a robot team based on the opponent information. This strategy first acquires the basic information like the location of the players and the ball in the field. From the information, it analyses the actions of the opponents and forecasts their strategy and decides the attack and defense strategy of its team. Based on the dynamic information of the environment, team strategy is adjusted to achieve the goal of destruction of the opponent strategy. This strategy consists of three parts - attack strategy, defense strategy and attack-defense strategy. Switching between strategies is done dynamically mainly based on the location of the team players, opponent players and the ball in the field.

Charles G.R.M Petit [21] proposed a strategy that mainly concentrates on the two roles - interceptor role and supporter role of the robots. A set of skills are defined in both the roles the players can perform. Interception strategy analyses the field situation and selects a player most suitable to intercept the ball. Interception can be getting a pass from the team mate or intercepting a pass between opponents or picking the ball from a clear area. After getting control over the ball, the interceptor chooses the best skill to perform to achieve its goal. The Supporting strategy aims to set the best positions to take for the non-intercepting robots based on the state of the game. Supporting player can be two types - direct supporter or indirect supporter. Direct supporter stays in a position where the chances to get a pass is high. Indirect supporter always takes a position from where it can score the goal or prevent the opponent from scoring.

Yangmin Li [16] in their paper proposed several schemes of playing robot soccer based on three-layer decision-making model. This strategy consists of two main situations - Offensive and Defensive. The control of the ball is the criteria for the switch between these two situations. In Defensive mode, the player closer to the ball tries to intercept the ball while the remaining players take defensive positions. In Offensive mode, the player who owns the ball has three options - shoot, pass and dribble. Based on the situation of the game, player chooses the best option among the three. The remaining players tries to intercept the ball or stay in attack positions if interception is not possible.

Remco Anthony Seesink [26] designed and developed a method for processing vision data into commands for motion control when playing robot soccer. The skills of the players in this strategy are decided based on the state of the world. The world data include position, orientation, velocity, angular velocity, acceleration and angular acceleration of the objects. This information is consumed by a decision system which decides the set of commands the player has to follow. The decision system can be designed to be distributed or centralized. The set of commands decided by the decision system is given to a motion control system which is responsible for deciding when a skill is finished.

Matthijis Spaan [29] proposed a strategy which has three states - Attack, Defend and Intercept. The team attacks if the ball is in their possession, defends if the ball is possessed by the opponent team and if the ball is in possession of none, try to obtain it by intercepting it. Possession of the ball is the primary criteria for deciding the roles and actions of the players.

2.2 Previous work on Dynamic Role Assignment

Dynamic role assignment is one of the major areas for research in Robot Soccer that can make a good impact on the outcome of the game. Although static role assignment can be maintained from the beginning of the match, it is not efficient in performance considering the dynamic change of the state of the world. Therefore, we need a dynamic role assignment algorithm that can map roles to the players based on the environment state. Paul A. Vallejos [30], in his paper, describes a cooperative strategy that uses dynamic role assignment which makes the team strategy more robust and flexible. Each role is defined as a state machine and state transitions are triggered based on the internal and external conditions of the robot. Attacker, Defender, Supporter and Goalie are the possible set of roles players can take in the game. Goalie role is fixed to goal keeper while the remaining roles can be transitioned based on the position on the field. In his strategy, before making any role transition, players must consider the following rules:

- Defender cannot directly transition to attacker. There should be a transition to supporter before taking attacking role.
- Defending player becomes supporter if he is no longer the last player or player closer to his team's goal line.
- Supporting player transitions to defender if he is closer to his goal line.
- Supporting player becomes attacker if he is closer to the opponents goal line.
- Attacking player can become supporting player if another attacker is closer to the ball and has already taken the position of the attacker.

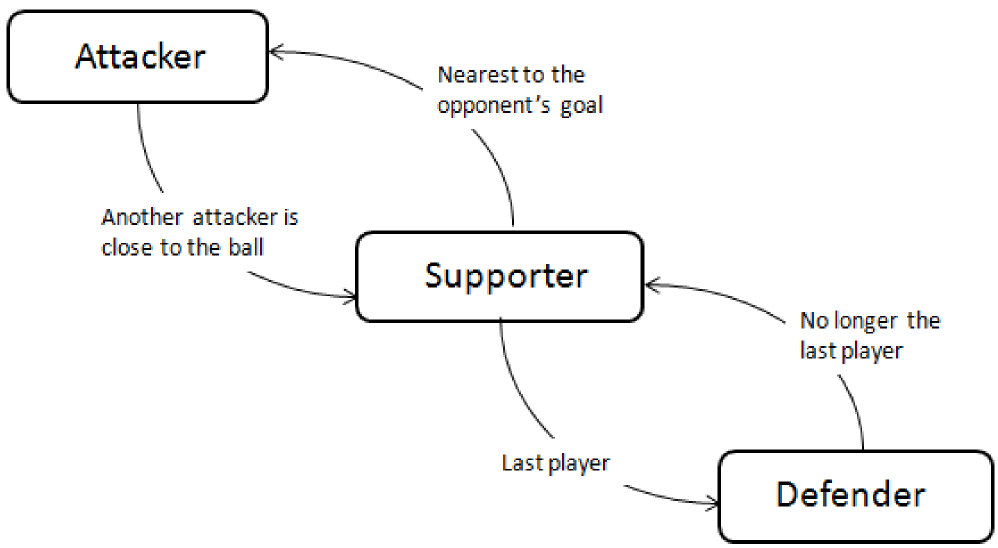

Figure 2.1 Allowed Role transitions for the field player

Patrick MacAlpine, Francisco Barrera and Peter Stone [17] came up with a role assignment algorithm that takes the state of the world as input and outputs an one-to-one mapping of the players to their roles. They proposed a dynamic programming implementation for roles assignment in order to meet the time constraints because it is important to execute the strategy quickly. The algorithm is designed considering the following three properties:

1. Minimizing long distances
2. Collision avoidance
3. Dynamic consistence

2.3 Previous work on Fall/Failure Analysis

There has also been some amount of research going on handling fall/failure of the robots during the game. Umashankar Nagarajan [19] in his paper, introduced an approach to control fall-direction of a humanoid. It also decides the best action to perform from the set of actions - No Action, Lift a Leg and Take a Step in that situation based on the scores of the fall. The score of the fall is calculated based on the direction of the fall.

Kshirabdhija Nadarajan [18] presented an approach that detects the fall of the robots during soccer, communicate the information to its teammates and incorporate it into the team's coordination strategy. This involves re-organizing the player's formations, roles and actions making the team coordination more effective. In this strategy, teammates communicate information about ball position, teammates and opponent positions, current role and state. Always, one player is sent to capture the ball. If the players do not hear any information from one of its teammates for a long period of time, that player is considered to be fallen and is communicated to the remaining players. Based on the state of the game, decisions are made assuming the fallen player absent. Various approaches on detecting the fall of the robot and minimizing the damage due to fall have already been addressed. In this thesis, we do not address the issue of minimizing the damage due to fall or failure. We also do not address fall resilience in this thesis. We propose an elementary strategy that can handle the failure of a robot during the game by coordinating with the remaining players in the team until the failed player regains its stability and participate in the game.

Chapter 3

Background

3.1 Robot Soccer Simulator

Robot Soccer Simulator typically consists of two teams say, red and blue present in the field with eleven players in each team - ten field players and one goal keeper. It has a supervisor program that controls the game and records the game scores. For this work, the game environment is developed in two modes - ideal mode and real mode. In ideal mode, there are no foul or failure of the players during the game while in real mode, all these cases are possible. Each game is under a time limit of 15 minutes. The objective of the team is to score as many goals as possible during this time interval. All the players in the game are identical i.e., they have same limits and are in same working condition at the beginning of the game. Figure 1.1 displays a snapshot of the Robot soccer field.

3.1.1 Supervisor Server

The Supervisor server typically manages the game like the referee does in a normal soccer game. Roles of the Supervisor server include :

1. Checking the fouls during the game.
2. Setting the positions of the players and the ball before every kick-off.
3. Recording the score points.
4. Controlling the game time.

3.1.2 Field Player

Field player program is where we develop the actual strategy for the team. All the field players have the same capability in terms of moving speed and maximum force with which they can kick the ball. Field player has complete knowledge of the field dimensions, position of the teammates, opponents and the ball during the game. The basic actions of the Field player include Shoot, Dribble, Pass and Clear. The mechanisms followed for each of these actions are explained in detailed in Section 1.3.

3.1.3 Goal Player

The role of the goal keeper involves defending the goal area from the opponent attacks and passing the ball to the teammate in its vicinity. Figure 3.1 shows the flowchart of the goal keeper strategy.

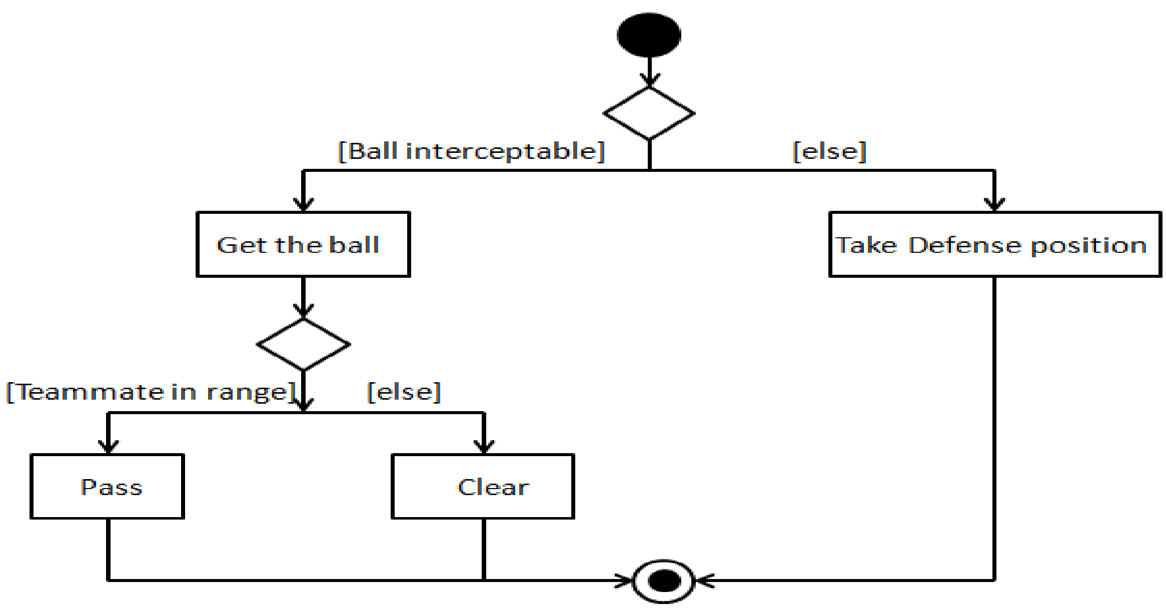

Figure 3.1 Goal Keeper Strategy flowchart

Defense Position of the Goal Keeper -

Defense position of the goal keeper is decided based on the minimum time it takes for the keeper to reach the ball that can come from any direction towards the goal line and blocking it before it reaches the goal line. To meet this condition, the best possible defense position goal keeper can take is along the line that equally bisects the lines joining from either of the goal posts to the ball as shown in the Figure 3.2.

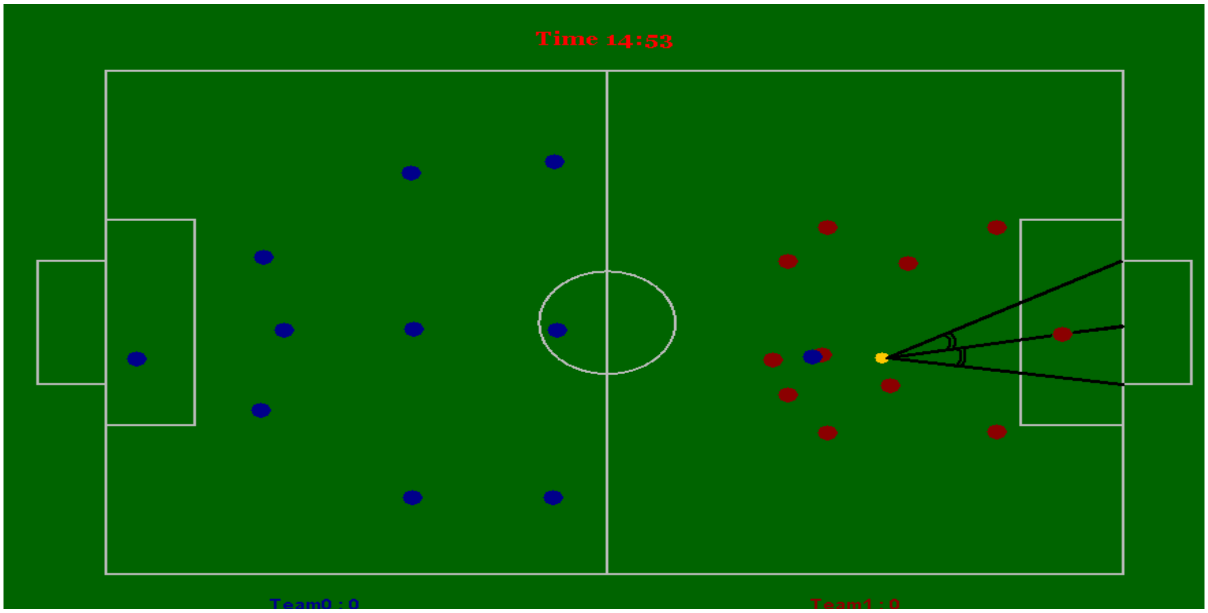

Figure 3.2 Red Goal keeper taking defense position

If the ball is relatively close to the goal keeper, the goal keeper tries to get the ball and pass it to the nearest teammate. Only the nearest teammate is chosen to pass the ball because for any other teammates, the possibility of opponents intercepting the ball is high which is not advantageous to the team. If there are no teammates nearby, the goal keeper clears the ball from the goal area.

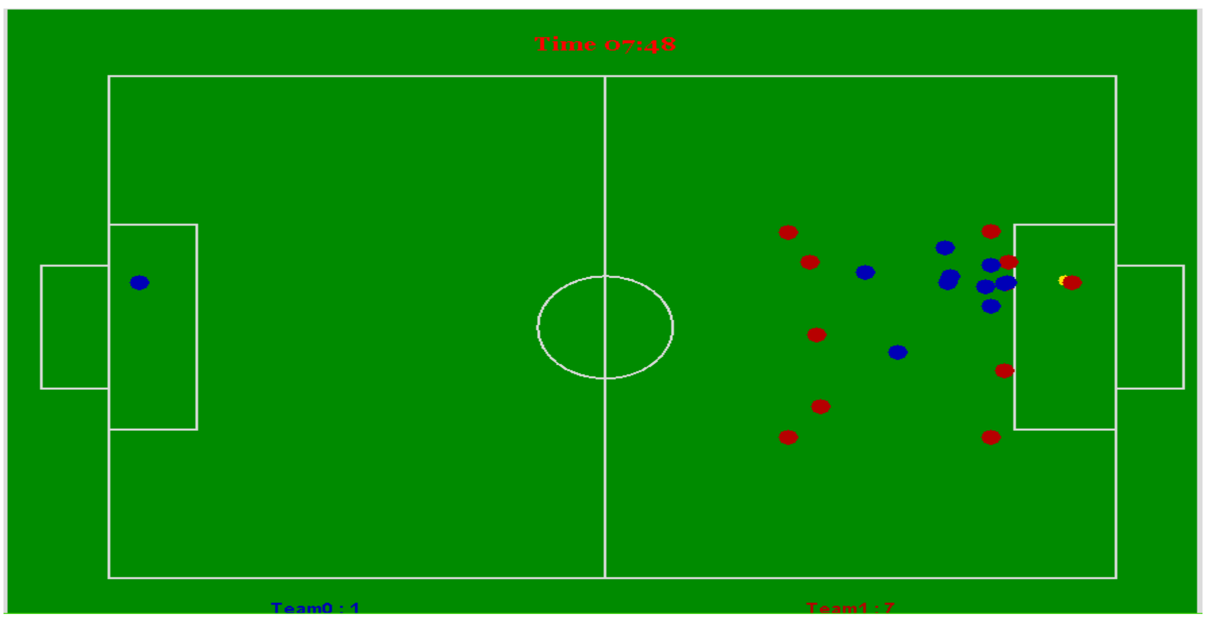

Figure 3.3 Red Goal keeper passing ball to the nearest teammate

3.2 Actions

Shoot, Pass, Dribble and Clear are the basic moves of every soccer playing robot. In this section, we explain the mechanisms followed by the robot player when performing each of these individual actions.

3.2.1 Shoot

Shoot is one of the basic skills of a soccer player necessary to score a goal. When a player has possession of the ball, he first tries to see the possibility of shooting it towards the goal before deciding on any other action. Shoot is considered possible only if the opponents goal post is in the player's shooting range and the pressure on the player is less compared to other teammates closer to the goal line. Pressure on the player is the number of opponent players in the vicinity of the player within a range of *R* units as shown in Figure 3.5. Once it is confirmed that shooting is possible, the player should then decide on the direction to shoot the ball towards the goal line. The direction should be chosen in such a way that the chance of interception from the opponent team is least.

Direction to shoot the ball -

Let $P = \{p_1, p_2, p_3, .., p_n\}$ be a set of n points marked along the opponent's goal line with a distance gap of d units between every two consecutive points along Y-axis. Let $L = \{l_1, l_2, l_3..l_n\}$ be a set of paths we are considering to shoot the ball where each path l_i is a line joining the ball's location $B(x_b, y_b)$ to the point p_i of the set P. Equation of line l_i is

$$(y - y_b) = \frac{(y_{pi} - y_b)}{(x_{pi} - x_b)}(x - x_b)$$

Let $O = \{o_1, o_2, .., o_m\}$ be the set of m opponents located between the ball and the goal line. For each path l_i whose line equation is of the form *Ax + By + C = 0*, we calculate the perpendicular distance from each of the opponents to this path using the formula below and save the minimum of all the distances.

$$\frac{|Ap + Bq + C|}{\sqrt{A^2 + B^2}}$$

Where, (p, q) is the location of the opponent.

$D = \{d_1, d_2, .., d_n\}$ is a set of distance values where $d_i = \underset{0 \leq j \leq m}{min} \{perpendicularDist(o_j, l_i)\}$ is the shortest distance from the opponents to the line l_i of the set L. From the set D, we choose the d_i with the maximum value and the corresponding line l_i to shoot the ball. If there are more than one paths with the same maximum value, we then choose the path whose distance is the shortest to the goal line among them. This way, we are choosing the path which has the least chance of interception from the opponents to shoot the ball.

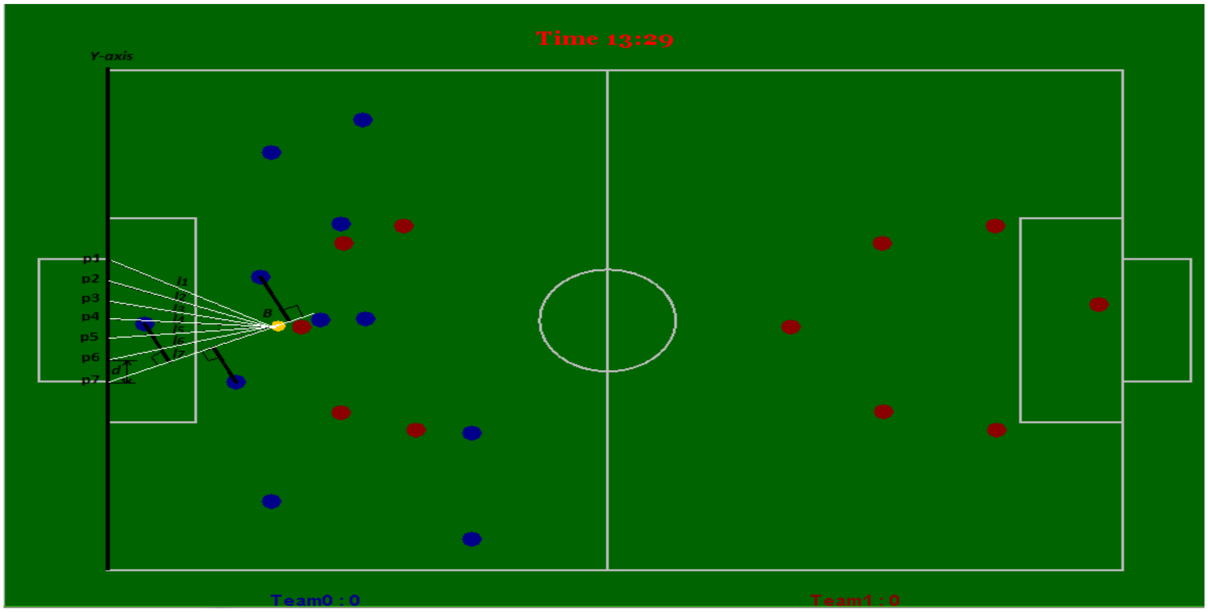

Figure 3.4 Red team player determining the direction to shoot the ball

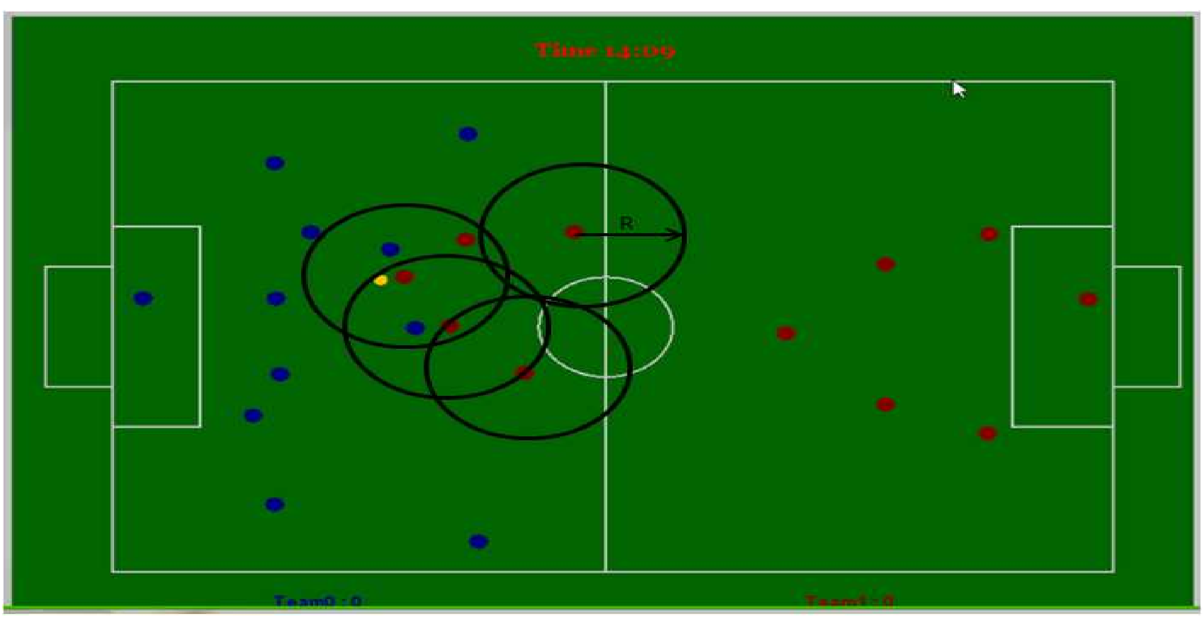

Figure 3.5 Pressure on each Red player calculated based on the number of players within a range of *R* units

3.2.2 Pass

Pass is considered possible if at least one teammate in the players vicinity has lesser pressure from opponents and is more closer to the goal line. The logic behind passing the ball is same as shoot except the points we mark this time is the teammates in the vicinity instead of the goal line. In other words, teammates in the vicinity are the targets to which the player should pass the ball. All the soccer players always keep track of the teammates and opponents located in their vicinity. When the player has possession of the ball and chooses to pass it, priority goes to the teammate in its vicinity who is closer to the goal line. If there are more than one teammates in the vicinity close to the goal line, player chooses the one who has the least chance of interception from the opponent team. Figure 3.6 and 3.7 explains how the Red striker decides to pass the ball to his teammate using this methodology.

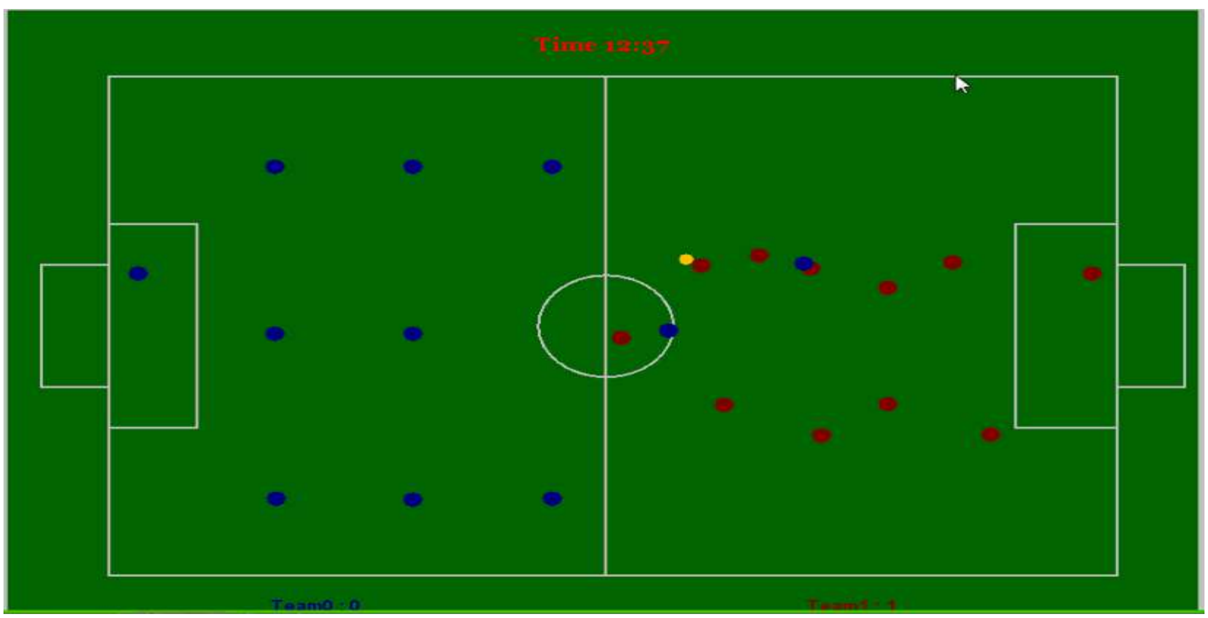

Figure 3.6 Red team player passing ball to the nearest teammate-1

In Figure 3.6, the Red team player who has the ball chooses to pass it since shooting is not possible from that position. He passes the ball to the teammate in vicinity who is closer to the goal as shown in Figure 3.7.

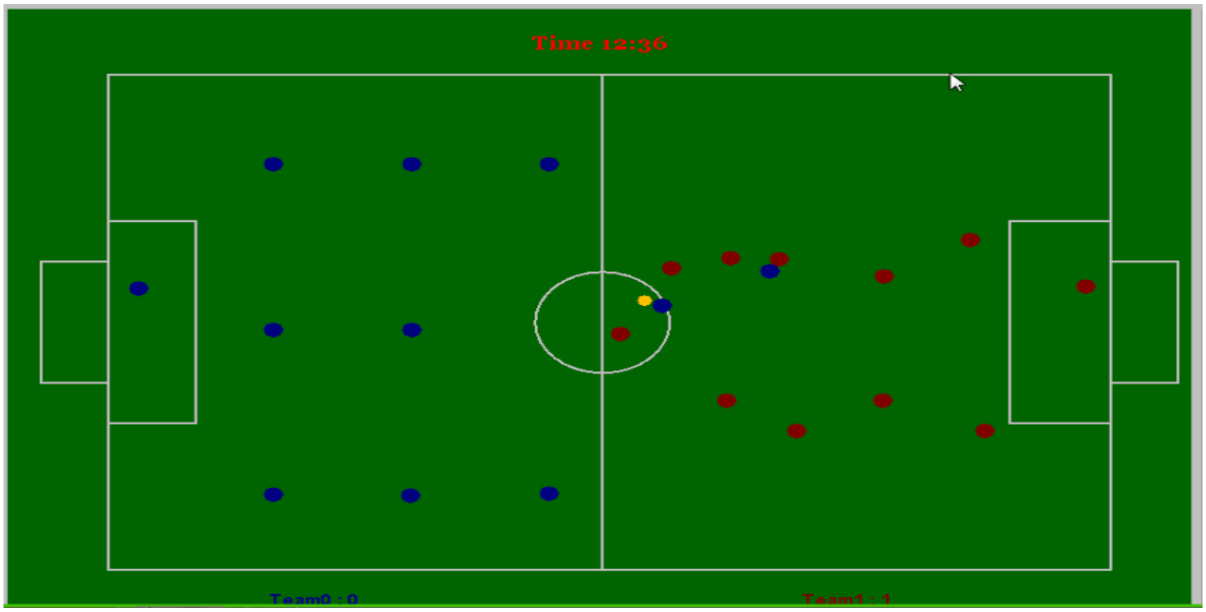

Figure 3.7 Red team player passing ball to the nearest teammate-2

3.2.3 Dribble

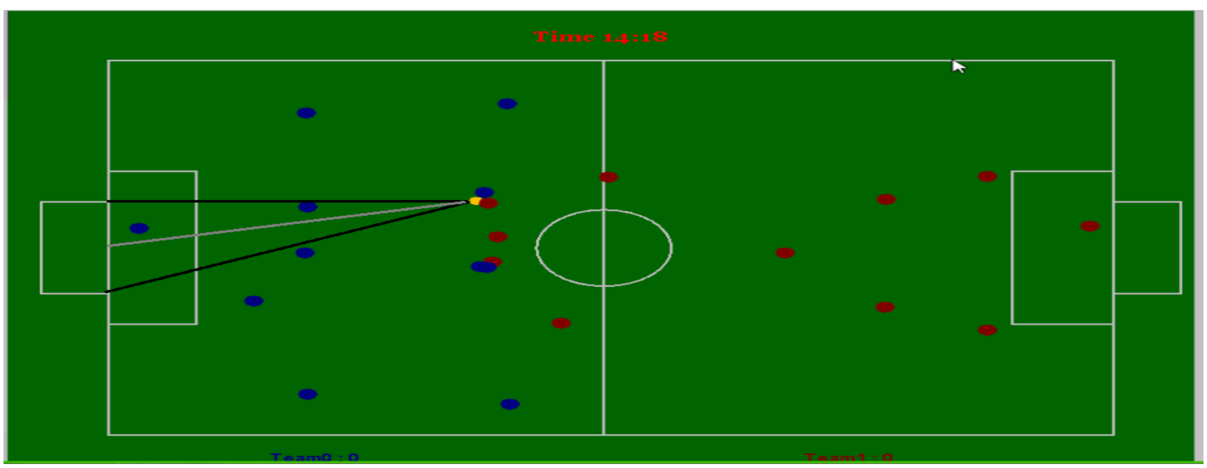

Figure 3.8 Red team player dribbling the ball-1

Soccer player chooses to dribble the ball when shooting is not possible and there are no players in his vicinity to pass the ball. Dribble is considered possible if the player who has possession of the ball has minimum pressure from the opponents. The logic followed in dribbling is also same as shooting except in this case, the player slowly dribbles the ball towards the direction chosen based on opponent teams interception and distance to the goal line instead of directly shooting the ball to the goal line in one strike.

In the Figure 3.8, The Red team player who has the possession of ball is closer to the goal line than any of the teammates in his vicinity. In this case, shooting the ball or passing it to his teammates would decrease the chances to score a goal and the team might even lose the possession of the ball. So, the player chooses to dribble the ball in the direction with less interception from the opponents and shorter route to the goal line as shown in Figure 3.9.

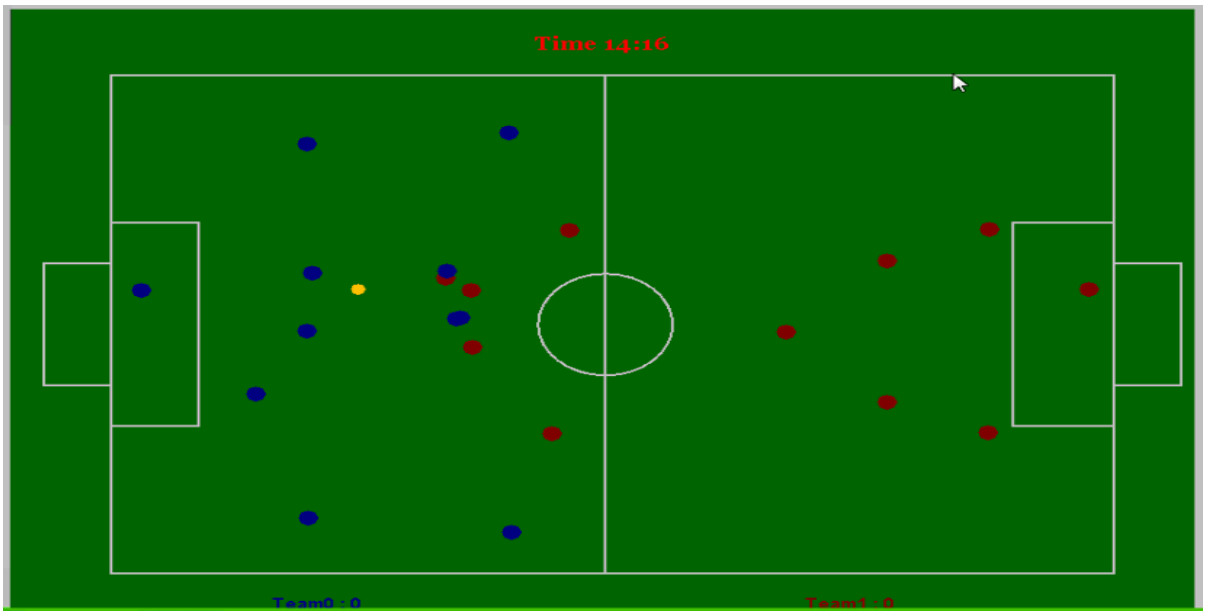

Figure 3.9 Red team player dribbling the ball-2

3.2.4 Clear

Clear the ball is the last best action player chooses to take as part of attack, defense and goal keeping role in a soccer game. During attack or defense, when the player could not shoot, pass or dribble the ball and the opponent team has numerical advantage, clearing the ball would decrease the pressure on the team giving the players chance to re-group and plan. The direction to clear the ball should be the one with no interception from the opponents otherwise unsuccessful clear would give the team a huge disadvantage. To achieve a successful clear, we mark points along the side boundaries of the field as shown in the Figure 3.10, choose the one which has the minimum opponent interception and clear the ball in that direction. Figure 3.10 is an example of such situation for the Red Team where the ball is closer to the team's goal line. The Red team player who has the possession of the ball is not in a position to shoot the ball or pass it to the nearest teammate as he is completely surrounded by the opponents. Even dribbling the ball is not a good choice here since there is a high chance of losing the ball with so many opponents nearby. The best action Red player can perform here is clear the ball away from the goal line.

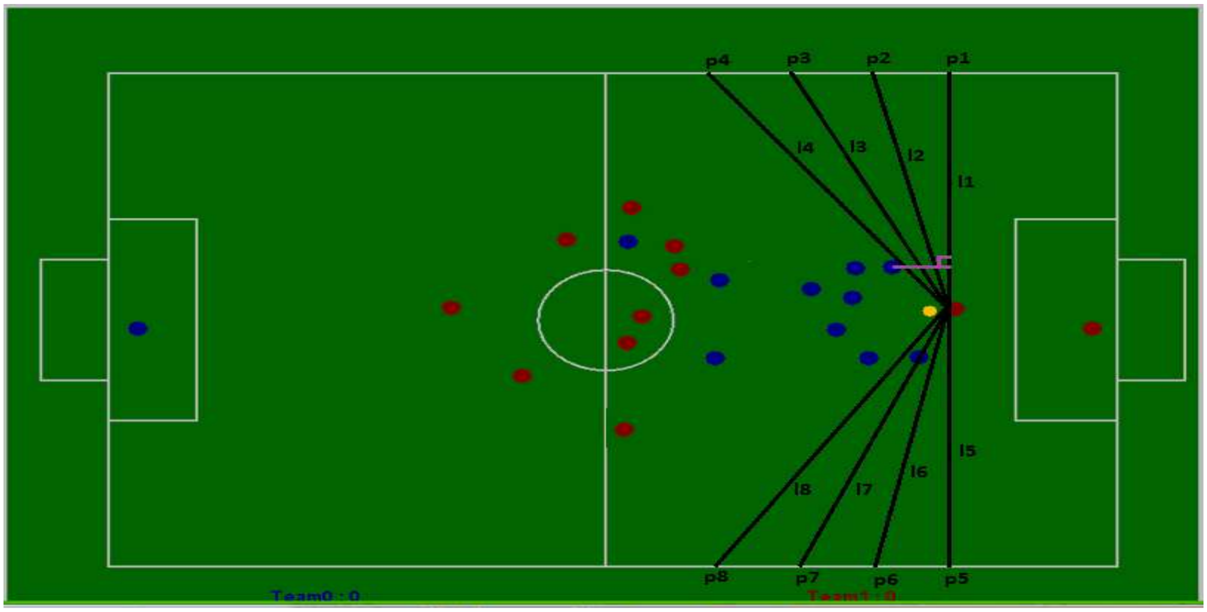

Figure 3.10 Red team determining the direction to clear the ball

Chapter 4

Ideal Strategies

Four different game strategies each focusing on different aspects of the game are taken for the opponent team's strategy to play soccer against our team strategy. In this chapter, we explain each of these game strategies applied on a soccer team of 11 players.

4.1 Uniform cover strategy

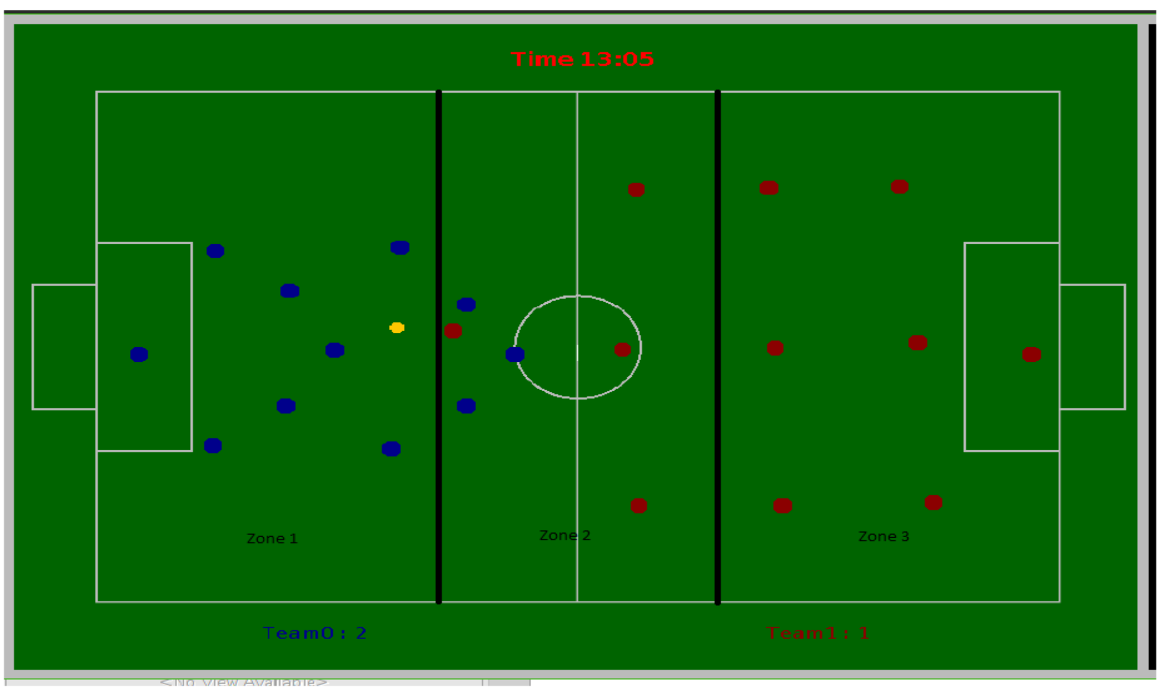

Figure 4.1 Field divided into 3 zones from Red team's perspective

Uniform cover strategy mainly focuses on covering the soccer field with all the field players except for the player closer to the ball who takes the role of striker. All the field players except the striker place themselves in different positions uniformly across the field covering the area behind the ball. The field is divided into three zones as shown in the Figure 4.1. Based on the location of the ball in these three zones, formation of the players is decided.

4.1.1 ZONE 1

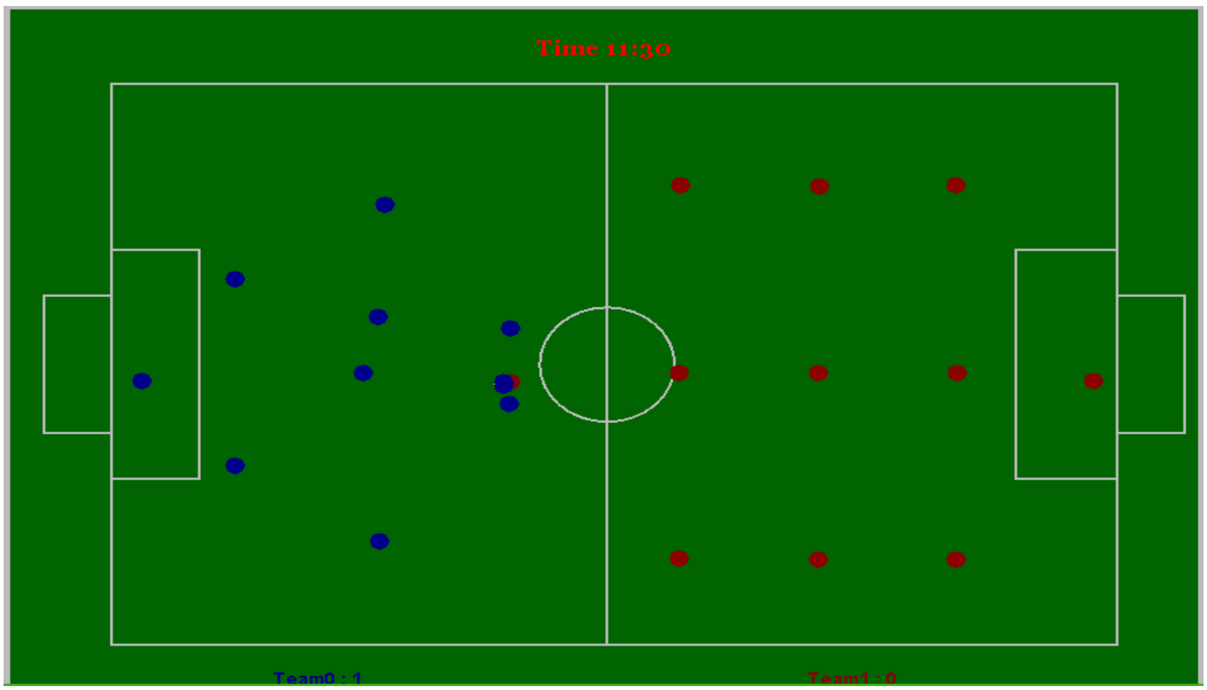

Figure 4.2 Ball in ZONE 1 from Red team's perspective

When the ball is in zone 1, all the players except the striker spread themselves across the field uniformly like the red team formation shown in Figure 4.2.

4.1.2 ZONE 2

When the ball is in zone 2, all the players except the striker position themselves like the red team formation shown in the Figure 4.3 so that they uniformly cover the field between the team's goal line and the ball.

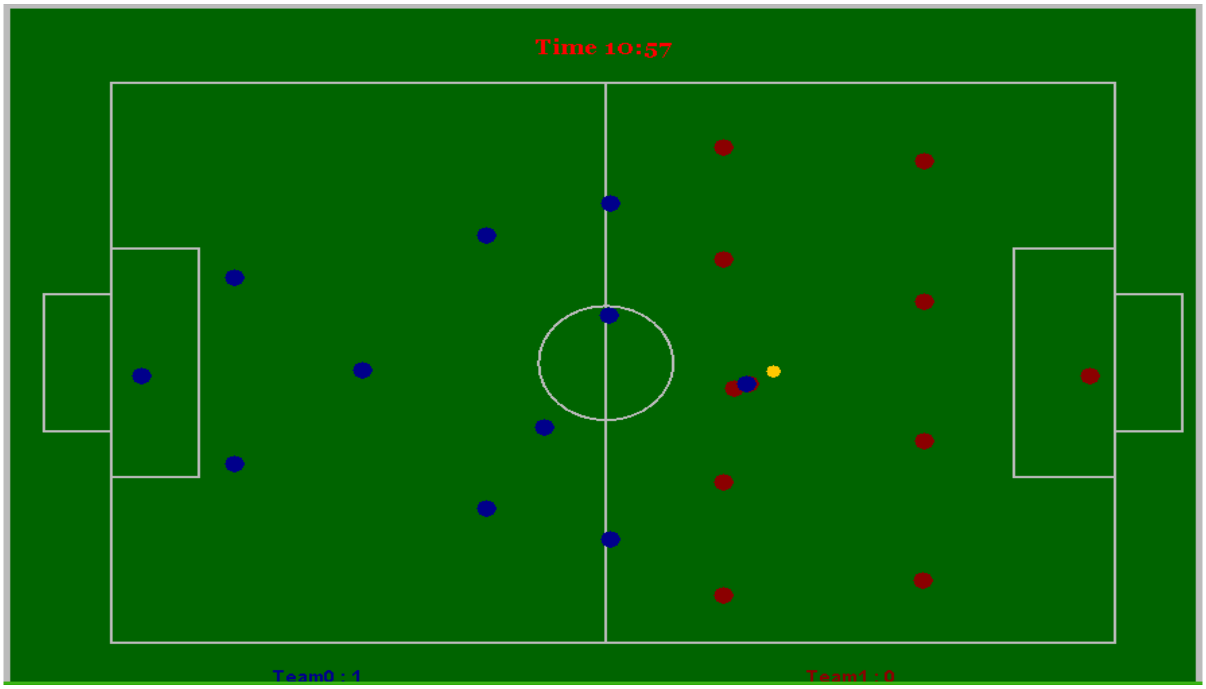

Figure 4.3 Ball in ZONE 2 from Red team's perspective

4.1.3 ZONE 3

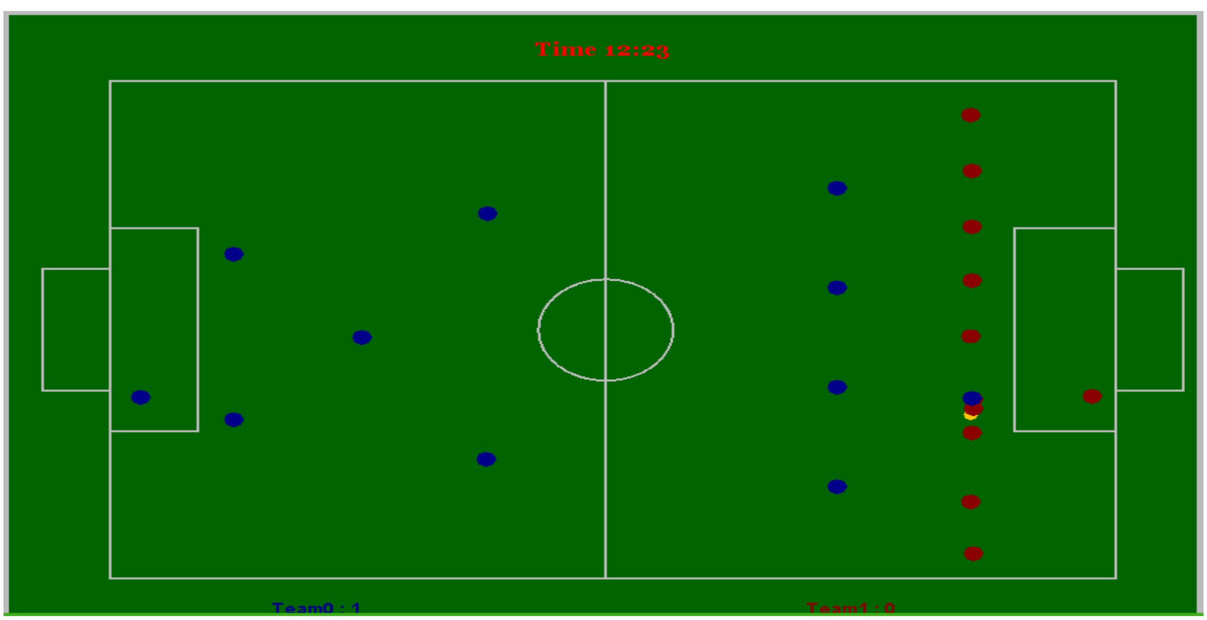

Figure 4.4 Ball in ZONE 3 from Red team's perspective

When the ball is in zone 3, the player closer to the ball tries to intercept the ball. All the remaining players position themselves in between the goal line and the ball making a formation covering the area uniformly as shown in the Figure 4.4.

4.2 Role-based strategy

This strategy involves two modes - offense and defense. The switch between modes is decided dynamically based on the location of the ball in the field. If the ball is on the opponents team's court, offensive mode strategy is followed otherwise defensive mode strategy is followed. In both the modes, Striker role is given to the player who has the possession of the ball or is the nearest player to the ball.

4.2.1 Offensive mode

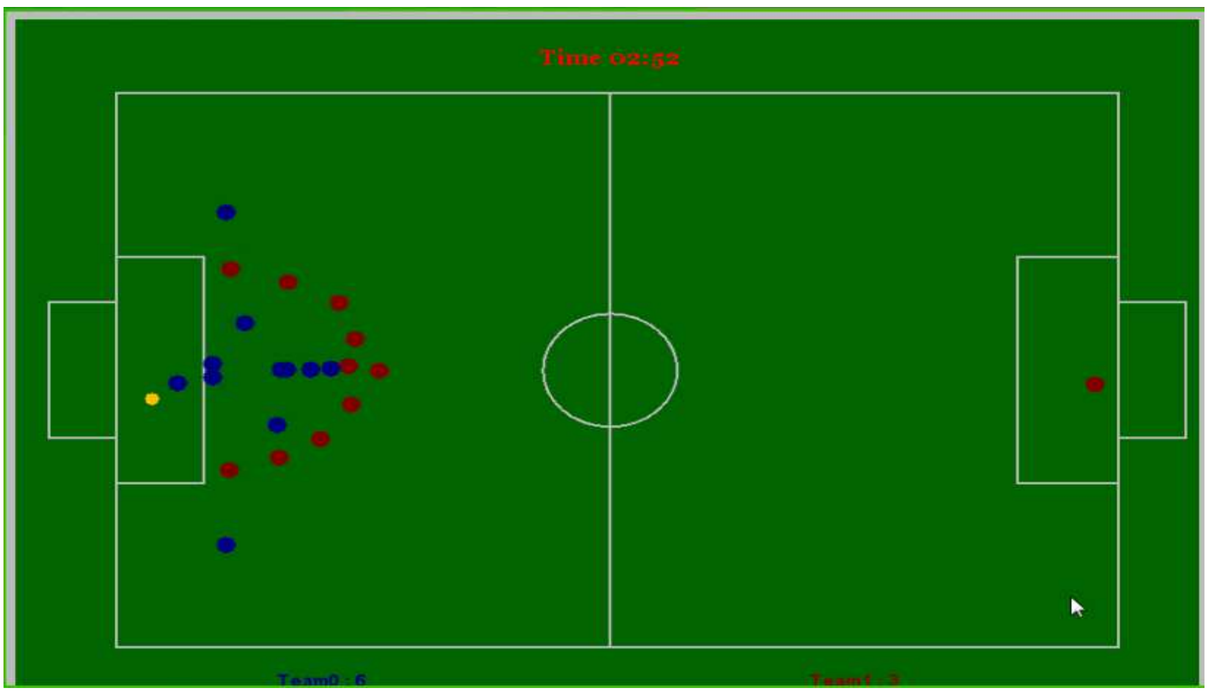

Figure 4.5 Red team players taking attacking positions

The team plays in offensive mode when the ball is in the opponent's court. If one of the team players already has the possession of ball, he tries to shoot, pass, dribble or clear the ball depending upon the situation. If the team does not have possession of the ball, the player closer to the ball tries to intercept and get the ball while the remaining players take attacking positions around the opponents goal area forming a semi-circle as shown in the Figure 4.5. The attacking positions are determined using the following formula:

$$x = x_0 + r * cos(\theta)$$
$$y = y_0 + r * sin(\theta)$$

Where, (x_0, y_0) is the center of the circle, *r* is the radius of the circle and θ is the angle made by line joining *(x,y)* and (x_0, y_0) to the positive X-axis. The difference between the θ made by two consecutive attacking players is *180/8* degrees.

4.2.2 Defensive mode

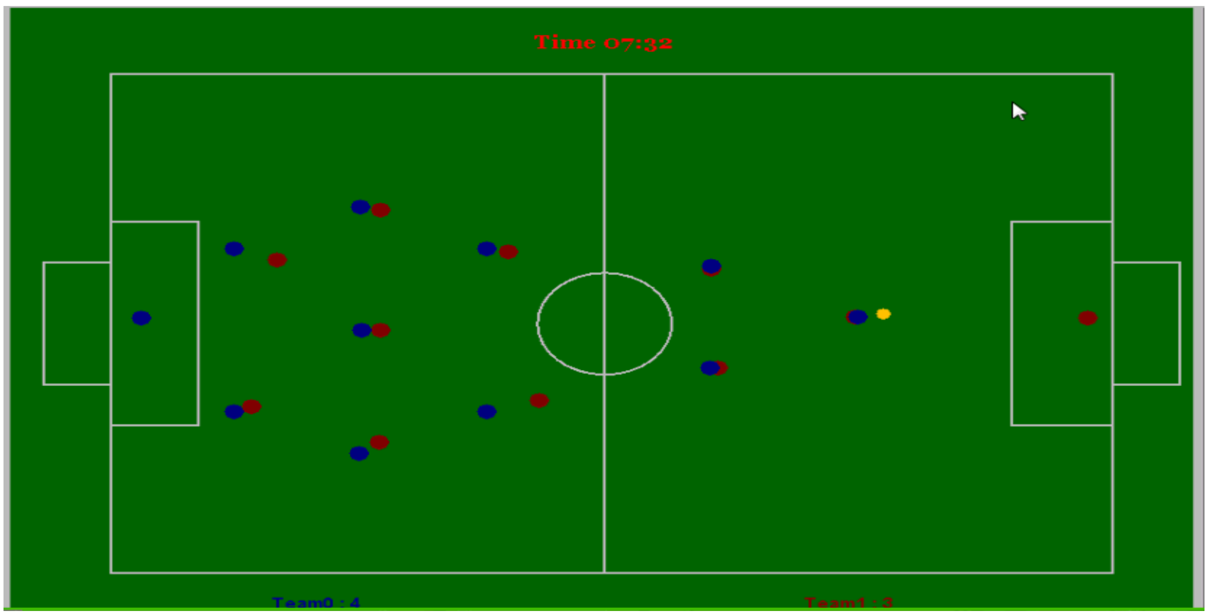

Figure 4.6 Red team players marking their opponents

Team plays in defensive mode when the ball is in the team's own side of the court. In this mode, if one of the players already has the ball, he tries to shoot, pass, dribble or clear the ball depending on the situation. If the team do not have the possession of the ball, the player closer to the ball tries to get the ball while the remaining players take defense roles. Excluding the striker and the goal keeper, each of the remaining 9 field players mark one of the opponents closer to them and try to intercept the ball before it reaches them. In the Figure 4.6, red team players play in defense mode as the ball is in teams own court. Striker tries to capture the ball while the other players mark the opponents.

4.3 Offense-priority Strategy

In this strategy, the field is divided into two parts - one for the offense and one for the defense. This strategy mainly focuses on offense i.e., on scoring goal rather than defending the opponents from scoring. Excluding the goal keeper, there are 10 field players active during the game. Of these 10, the player closer to the ball will be assigned the role of the striker. Of the remaining 9 players, 4 players are assigned to support the striker while the rest play the role of defense. The role of striker is not fixed to one player and dynamically changes throughout the game. It switches between the striker and the supporting players based on the situations which will be explained in-detailed in the sections below.

4.3.1 Striker

Always out of the 5 offensive players(1-striker and 4 supporting players), player who is closest to the ball will be given the role of striker. The main goal of the striker is to always go towards the ball, capture it and strike it towards the opponent's goal line.

4.3.2 Supporting player

There are total four supporters for the striker. The role of the supporter involves intercepting the ball if it goes past the striker, capture it and pass it to the striker. If the supporter who has the possession of the ball is closer to the goal line than the striker, they switch roles and the supporter takes the striker role while the remaining four supporters support him.

4.3.3 Defense player

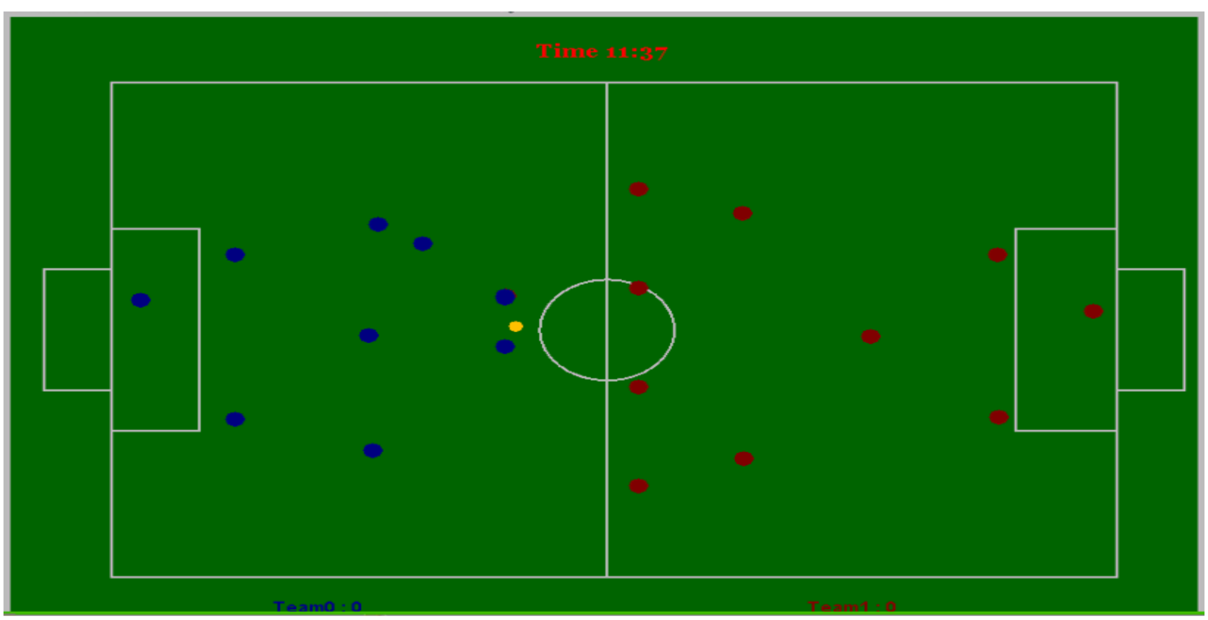

Figure 4.7 Red team defense players 2-1-2 formation

There are 5 defense players in this strategy. Each of the defense player is assigned to look after a particular space in the field as shown in the Figure 4.7. The team's court is divided into three partitions for defense. The defense players positions themselves in 2-1-2 formation and guard the space allocated to them. When ball is not in their space, they stay in their position and guard the area assigned to them. If the ball reaches any of the guarded space, the defense players assigned to it try to intercept the ball and pass it to the nearest defense player closer to the goal line or the nearest supporting player or the striker. Once they pass the ball and clear it from their space, they return to their guarding positions.

4.4 Defense-priority Strategy

In this strategy, the field is divided into two parts - one for the offensive and one for the defensive similar to the Offense-priority strategy. This strategy focuses mainly on the defense i.e., it concentrates more on blocking the opponents from scoring the goal rather than trying to score the goal themselves. Excluding the goal keeper, there are 10 field players present in the team during the game. Of these 10, one player is assigned the role of striker. Of the remaining 9 players, two are assigned to support the striker while the rest play the role of defense. The role of the striker is not fixed to one player and is similar to the striker's role in Offense-priority strategy.

4.4.1 Supporting player

There are total two supporters for the striker. The role of the supporter is to support the striker by capturing the ball if it goes past the striker and pass it to the striker. If the supporter who has the possession of the ball is closer to the goal line than the striker, they switch roles and the supporter becomes the new striker while the remaining supporters support him.

4.4.2 Defense player

There are 7 defense players in this strategy. Each of the defense player is assigned to look after a particular space in the field as shown in the Figure 4.8. The team's court is divided into three partitions for defense. The defense players positions themselves in 2-3-2 formation and guard the space allocated to them. When ball is not in their space, they stay in their position and guard the area assigned to them. If ball comes to any of the guarded space, the defense players assigned to it try to intercept the ball and pass it to the nearest defense player closer to the goal line or the nearest supporting player or the striker. Once they pass the ball and clear it from their space, they return to their guarding positions.

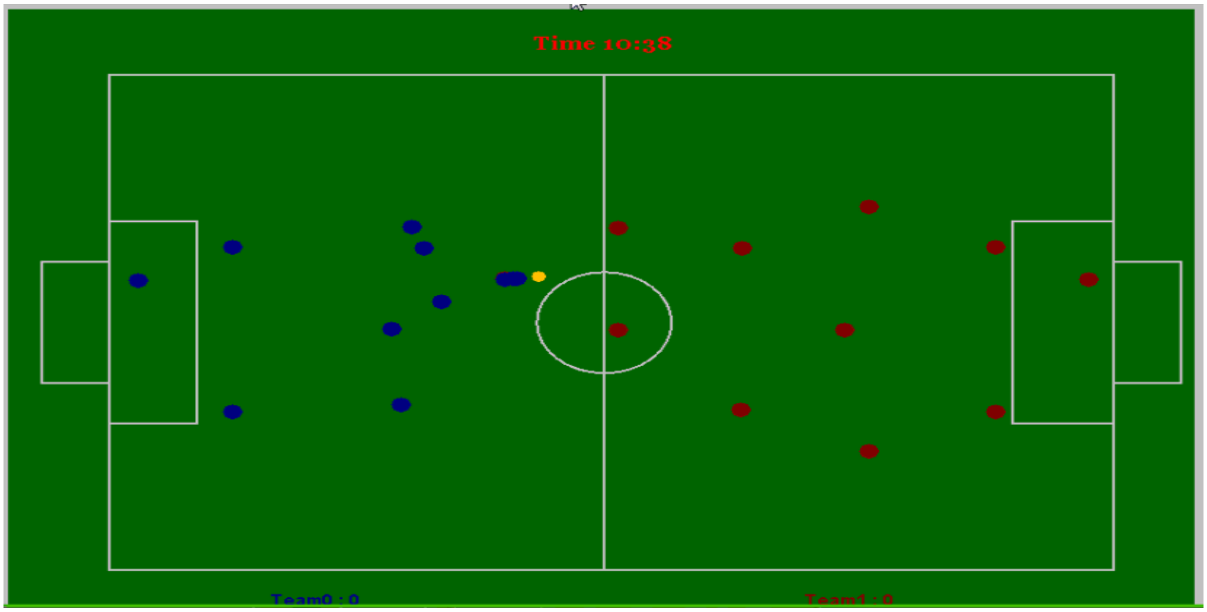

Figure 4.8 Red team defense players 2-3-2 Formation

4.5 Summary

Following table summarizes the areas each of the strategies explained in this chapter are focused on.

Focus	Uniform-cover	Role-based	Defense-priority	Offense-priority
Zones	√	×	×	×
Offense	×	√	×	√
Defense	×	√	√	×
Ball-possession	×	√	×	×
Pressure	×	×	×	×

In this paper, we are proposing a new strategy that focuses on all these areas, prioritize among them before making any decisions for the team. Further details about this strategy will be explained in Chapter 5.

Chapter 5

Failure Resilience of Ideal Strategies

In the previous chapter, we have discussed about the four game strategies - Uniform-cover strategy, Role-based strategy, Offense-priority strategy and Defense-priority strategy. In this chapter, we analyze the advantages and disadvantages of each of these four strategies and their behavior in case of failure or fouls of players during the game. We consider some frequently encountered situations in a soccer game when there is a failure or foul and discuss how it is handled in each of these four strategies.

5.1 Uniform cover strategy

5.1.1 Advantages

This strategy mainly concentrates on uniformly distributing its players across the area behind the ball. By maintaining this distribution, the distance from any one of the players to any point in the area behind the ball is minimum. Uniform coverage and availability across the field are the main advantages of this strategy. Also, the roles of each of the players and the locations to guard are clearly identified and distributed among the players which makes the possibility of collisions among the players very less.

5.1.2 Disadvantages

This strategy focused mainly on uniform coverage of the field behind the ball. Also, it covers all the areas behind the ball with equal priority and guards them which may not be the best way to deploy the players. For example, if we consider the corners, it is not always essential to guard them as the possibility of ball reaching the corner is very low. Instead, the players assigned to guard such areas can be given other offensive roles or defend the high priority areas like the area in front of the goal line. Another drawback of this strategy is its weak offense since the strategy mainly concentrated on defense by guarding the field with all the players in the team and allowed only one player to play the offensive role. If this single offensive player is blocked by the opponents, there is no other way to score a goal which is highly disadvantageous to the team.

5.1.3 Failure analysis of Uniform cover strategy

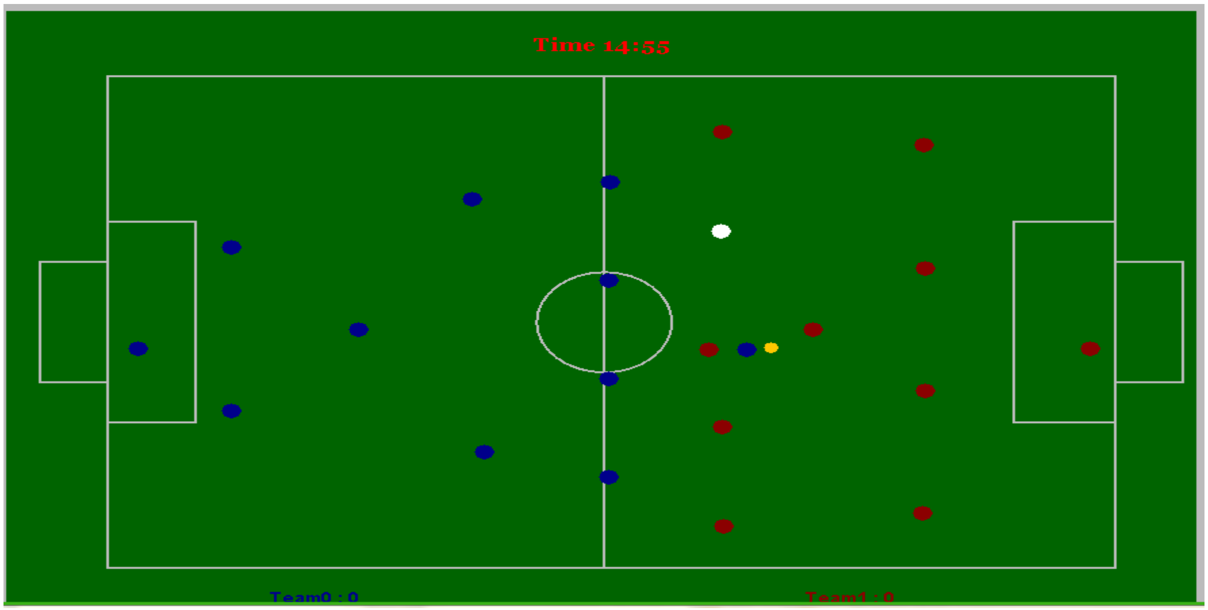

Figure 5.1 Failure of the red team defense player leading to vacancy in that partition

To analyze the failure, consider the following three scenarios which cover most of the failure situations of this strategy -

- **Failure of the Striker:** In this strategy, only one player plays the role of offense. Only this player is responsible for chasing the ball, intercept it and strike a goal. If this player has fails during the game, there will be no offensive-side to the team's play. All the remaining players play their respective roles as partition guards but there will be no player to attack and score a goal which is the main purpose of a soccer game.

- **Failure of the player guarding one of the critical partitions in the field:** If one of the players guarding the critical partitions like the area in-front of the team goal line has a failure, that partition will be left vacant as shown in Figure 5.1 which can give a significant advantage to the opponent team.

- **Failure of the player guarding the least priority partitions on the field:** If the player that failed is the one guarding a least priority area, like one of the corners of the team's goal side, the impact of this is low compared to a failure in one of the partitions in-front of the goal line. This is because it is very rare for the ball to reach these partitions. Of all the players in the team, failure of players guarding partitions like these will result in least impact to the game.

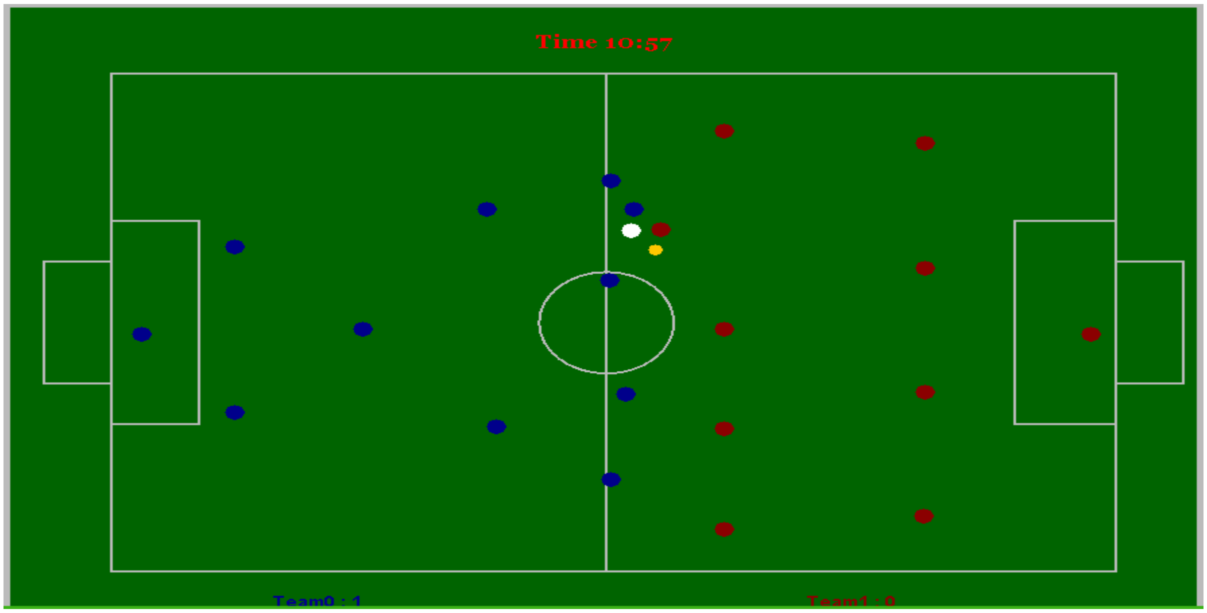

Figure 5.2 Failure of the Red team striker

5.2 Role-based strategy

Role based strategy has two modes - offense and defense mode. In the offensive mode, the striker tries to score a goal and the remaining players take attacking positions while in defense mode, the striker tries to intercept and shoot the ball and the remaining team players mark the opponents and defend them. Main drawback of this strategy is at a point of time only one mode of strategy is strong i.e., either team plays with strong offense or strong defense. In games like soccer, strategy of the team should always support both offense and defense and maintain a balance between them so that the players will always be ready to attack and defend the opponents at any point of time without sudden surprises.

5.2.1 Failure analysis on Role-based strategy

This strategy is prone to more number of collisions between the players compared to other strategies since all the players focus on one mode - either offense or defense. Consider marking the opponents in defense mode for example. The players have to make contact with the opponents and stop them from gaining ball possession which might lead to fall or failure. Since the players act independently without co-ordination among them, they could also hinder each others tasks unknowingly.

5.3 Failure analysis on Offense-priority strategy and Defense-priority strategy

Offense-priority strategy mainly focuses on offense i.e., on scoring goal rather than defending the opponents from scoring. The main drawback of this strategy is its weak defense. Considering the failure case scenarios, if the player failed was playing defense, it would make the defense even weaker and impacts the outcome of the game. Similarly, Defense-priority strategy focuses more on defense strategy more than offense. Failure of the offense players would give negative impact to the game compared to the failure of the defense players.

Chapter 6

Failure Resilient Strategy

Researchers came up with many strategies for robot soccer team focusing on different perspectives of the game, prioritizing among them and deciding the course of action for the team based on the results. Some of the main perspectives are:

- **Field**: Many strategies divided the game field into different types of partitions; giving some partitions priority and covering the partitions with players for guarding using different formations based on the state of the game for example, ball possession, ball location etc..

- **Offense**: This corresponds to mainly attacking i.e., scoring the goal.

- **Defense**: Blocking the opponents from scoring the goal.

- **Ball location**: Location of the ball in the field.

- **Ball Possession**: Ball in the possession of the team or opponents or free.

Our Failure Resilient strategy is designed taking all the perspectives listed above into consideration, prioritizing among them and deciding the course of action for the team. In all the figures presented in this chapter, Red team is following Failure Resilient Strategy while the Blue team is following Uniform Cover strategy.

The soccer field is divided into three equal zones vertically as shown in the Figure 6.1. Based on the location of the ball, these are categorized as *danger*, *neutral* and *safe* zones. The zone which has the teams goal area is called the *"Danger zone"*. If the ball is in this zone, chances for the opponent team to score a goal is high. The zone in the middle is the called the *"Neutral zone"* as both the teams have equal chances of scoring a goal when the ball is in this zone. Lastly, the zone near to the opponent teams goal area is called the *"Safe zone"* since the team has the high chance of scoring a goal when the ball is in this zone. Based on the location of ball in these zones, the roles of the players is decided.

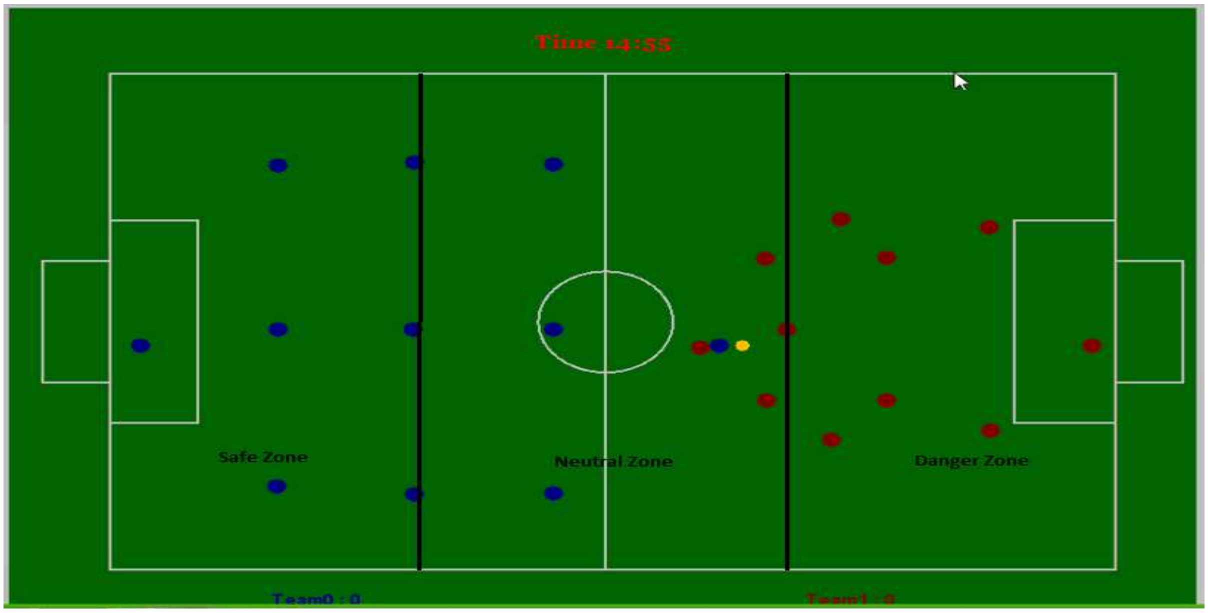

Figure 6.1 Soccer Field partitions from the perspective of the Red Team

6.1 Ball in Danger Zone

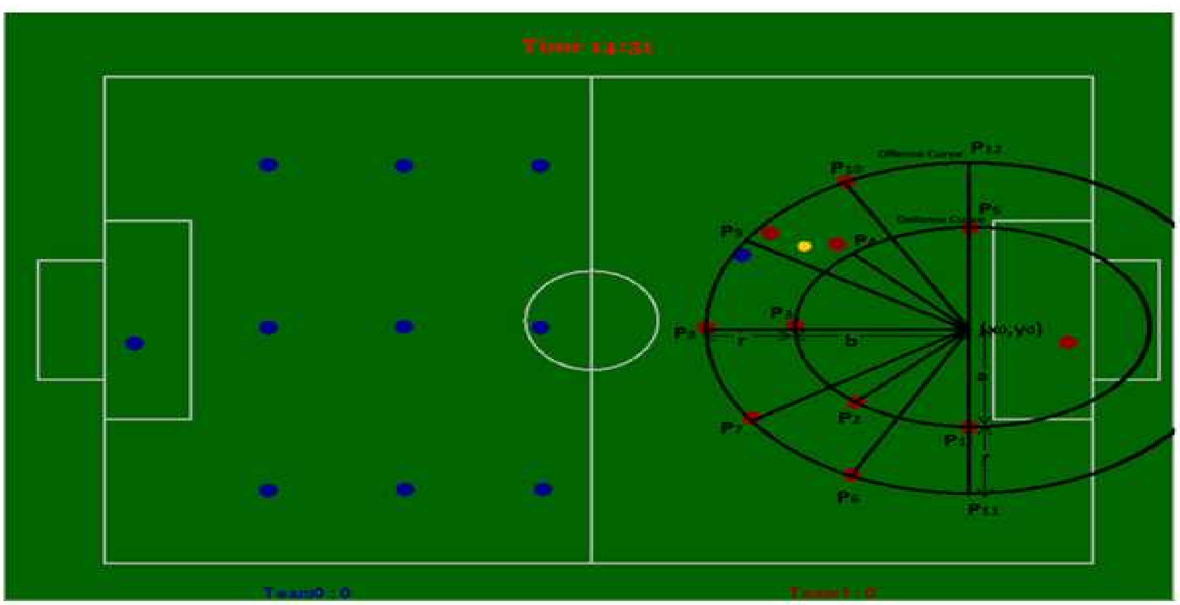

Figure 6.2 Red team defense players taking curve formation when the ball is in Danger zone

If the ball is in danger zone, the team focuses more on defense. Main goal of the team in this case is to prevent the opponent team from scoring a goal. Out of ten field players in the team,

1. Five players take defense role.

2. Five players take offense role.

The defense players place themselves in the form of a semi-ellipse covering the goal area as shown in the Figure 6.2.

Determining the positions of the defense players over the semi-ellipse circumference:

Let *n* be the number of defense players and (x_0,y_0) be the center of the ellipse which is at a perpendicular distance of *d* units from the center of the goal line. Any point(x,y) on the ellipse at an angle θ from the positive X-axis can be determined using the following formula:

$$(x, y) = \begin{cases} (x_0 - \frac{ab}{\sqrt{b^2+a^2(tan(\theta))^2}}, y_0 - \frac{abtan(\theta)}{\sqrt{b^2+a^2(tan(\theta))^2}}), & \text{if } 90^o < \theta < 270^o \\ (x_0, y_0 + a), & \text{if } \theta = 90^o \\ (x_0, y_0 - a), & \text{if } \theta = 270^o \\ (x_0 + \frac{ab}{\sqrt{b^2+a^2(tan(\theta))^2}}, y_0 + \frac{abtan(\theta)}{\sqrt{b^2+a^2(tan(\theta))^2}}), & \text{if } 0 \leq \theta < 90^o \text{ or } 270 < \theta \leq 360^o \end{cases}$$

Equation 1.

Where, *a* is the radius of the minor axis which is half the length of the goal line, *b* is the radius of the major axis which varies depending on the location of the ball. If (x_i, y_i) is the location of the ball, then *b*=$(x_0 \pm x_i)$. Each defense player takes position along the circumference of the semi-ellipse at equal intervals of angle as shown in Figure 6.2. The difference between the angles made by two consecutive players along the semi-ellipse with the positive X-axis is *180/(n-1)* degrees. This way, players will be able to equally distribute along the semi-ellipse and defend the ball. To illustrate this more, let us consider idle case scenario where all the defense players are active. A semi-ellipse curve of five players(*n=5*) should be made to cover the goal post area when the ball is in Danger zone. The difference between the angle made by the line joining a point on circumference of the ellipse and (x_0, y_0) to the positive X-axis should be $180/(5 - 1) = 45^o$. Let θ be the angle made by the line joining a point on circumference of the ellipse and (x_0, y_0) to the positive X-axis. Each player places themselves at $0^o, 45^o, 90^o, 135^o$ and 270^o using Equation 1.

Position 1:

This position is nothing but a point at a distance *a* to the center of ellipse along positive Y-axis. $\theta = 90 + 0 * 45 = 90 + 0 = 90^o$

$$(x_1, y_1) = (x_0, y_0 + a)$$

Position 2:
$\theta = 90 + 1 * 45 = 90 + 45 = 135^o$

$$x_2 = x_0 - \frac{ab}{\sqrt{b^2 + a^2(tan(135^o))^2}}$$
$$y_2 = y_0 - \frac{abtan(135^o)}{\sqrt{b^2 + a^2(tan(135^o))^2}}$$

Position 3:
$\theta = 90 + 2 * 45 = 90 + 90 = 180^o$

$$x_3 = x_0 - \frac{ab}{\sqrt{b^2 + a^2(tan(180^o))^2}}$$
$$y_3 = y_0 - \frac{abtan(180^o)}{\sqrt{b^2 + a^2(tan(180^o))^2}}$$

Position 4:
$\theta = 90 + 3 * 45 = 90 + 135 = 225^o$

$$x_4 = x_0 - \frac{ab}{\sqrt{b^2 + a^2(tan(225^o))^2}}$$
$$y_4 = y_0 - \frac{abtan(225^o)}{\sqrt{b^2 + a^2(tan(225^o))^2}}$$

Position 5:
$\theta = 90 + 4 * 45 = 90 + 180 = 270^o$
This position is a point at a distance *a* to the center of ellipse along negative Y-axis.

$$(x_5, y_5) = (x_0, y_0 - a)$$

Based on the location of the ball in the danger zone, the major axis radius varies resulting in the defense curve compressing and expanding with it. By doing this, if the ball comes closer to the teams goal post, defense players curve compress and cover the goal area leaving less gap for the opponents to score a goal. In danger zone, the offense players stay passive in the same semi-ellipse like formation at a distance from the defense players curve ready to get the ball from the defense players anytime. The offense players also take positions over the semi-ellipse whose center is the same as defense semi-ellipse, with radius of major and minor axis $(a + r)$ and $(b + r)$ respectively excluding positions P_{11} and P_12 as shown in Figure 6.2. Following flow charts explain the defense and offense roles of a player.

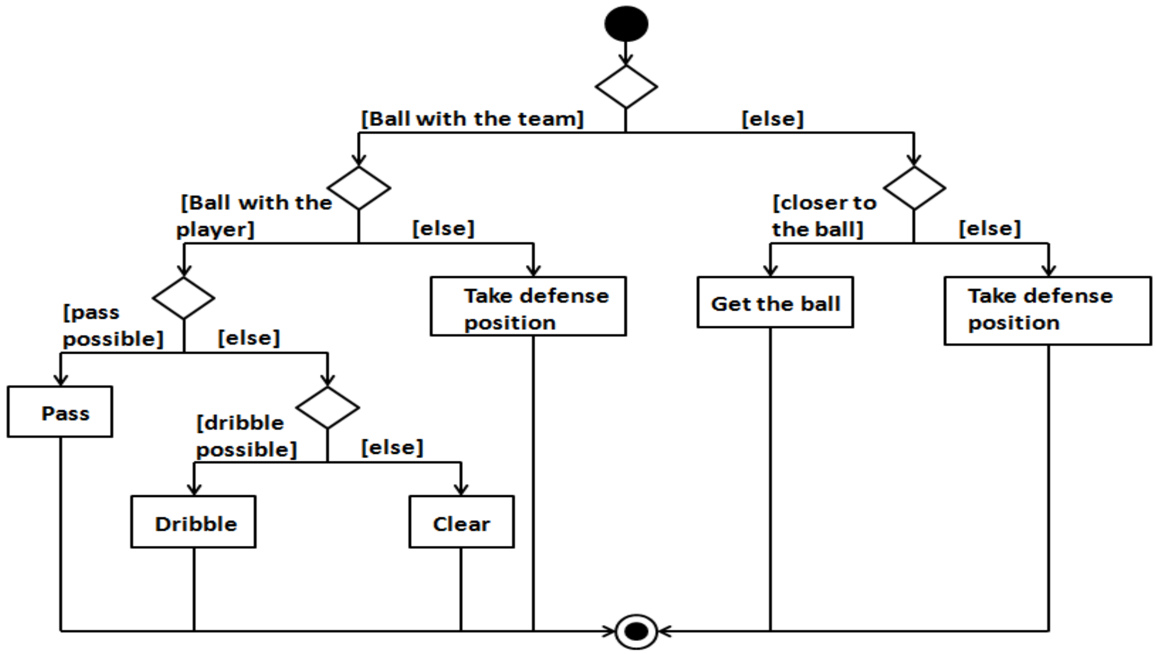

Figure 6.3 Defense player Strategy flowchart

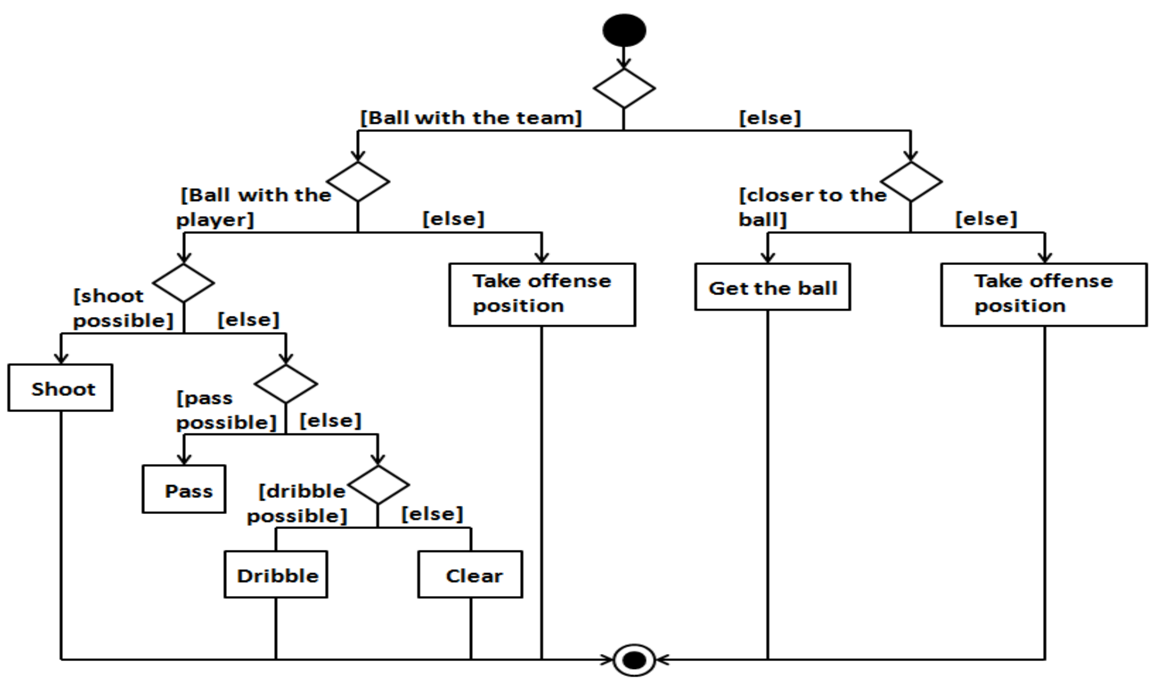

Figure 6.4 Offense player Strategy flowchart

6.2 Ball in Neutral Zone

If the ball is in Neutral Zone, team strategy focuses equally on defense and offense. Out of the ten field players,

1. Five players take defensive roles.
2. Five players take offensive roles.

Defense players stay in semi-ellipse formation like in danger zone with constant major axis radius which is equal to the distance from the center of the semi-ellipse to the line separating danger zone and neutral zone. Offense players form a semi-ellipse formation with the major and minor axis radius same as defense curve. The center of the offense semi-ellipse formation is at a distance of *b* from the ball location along the X-axis as shown in Figure 6.5.

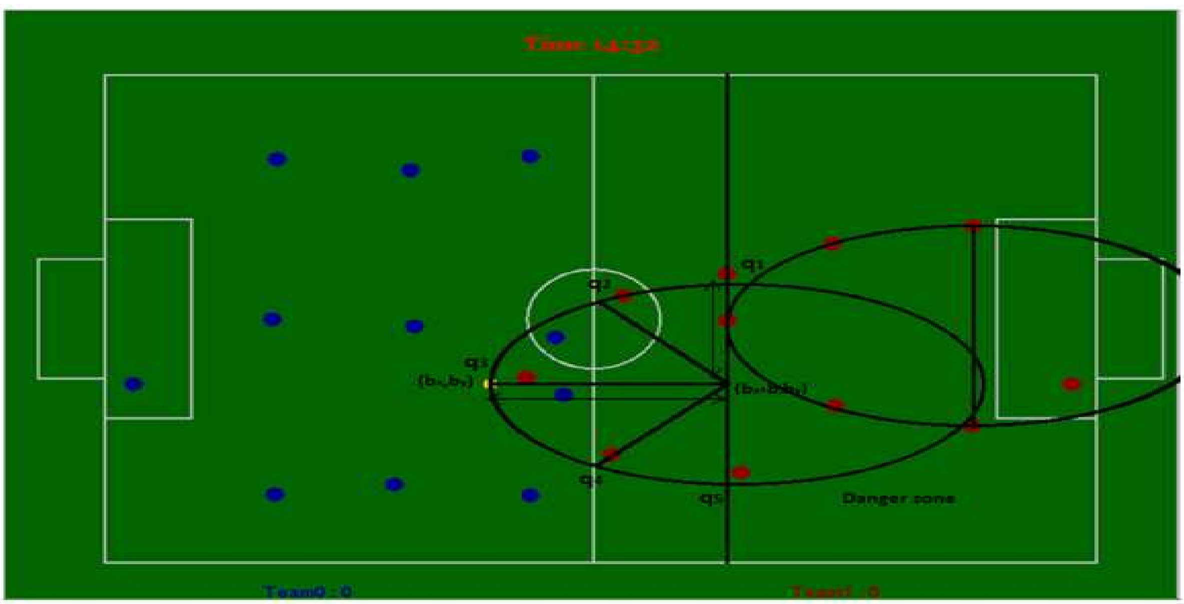

Figure 6.5 Offense and Defense players curve formation when the ball is in Neutral zone

6.3 Ball in Safe Zone

If the ball is in Safe zone, the team strategy leans more towards offense. Out of 10 field players,

1. Five players take defense role.
2. Five players play offense role.

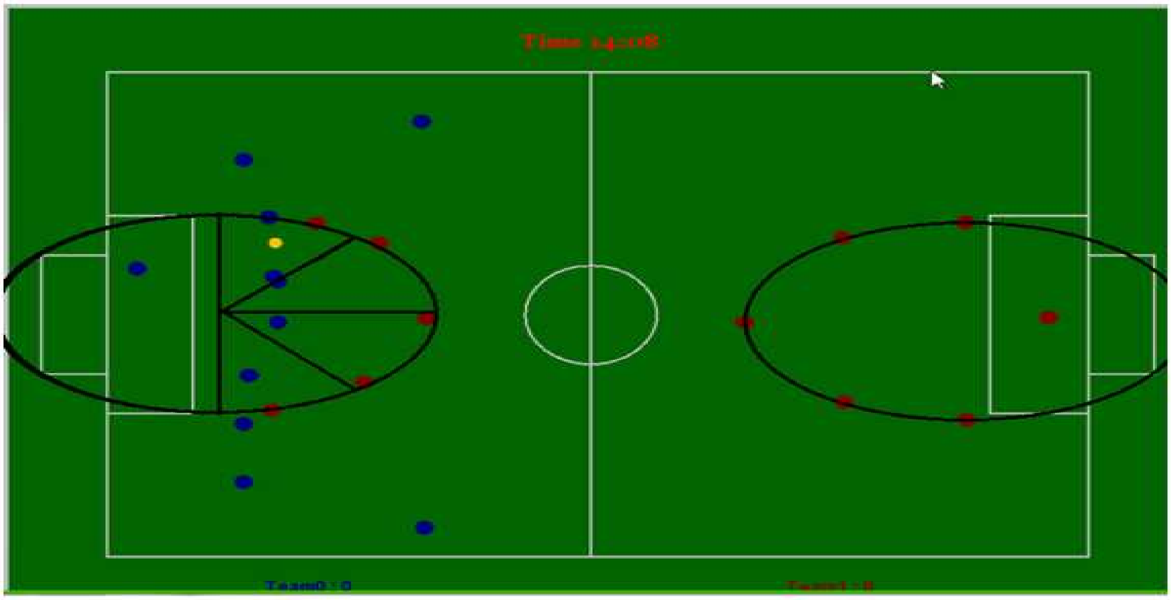

Figure 6.6 Defense and Offense player curve formation when ball is in Safe zone

Defense players stay passive in curve formation guarding the goal post like in neutral zone. Offense players form a semi-ellipse formation around the opponents goal post like the defense players formed along the teams goal post. Figure 6.6 shows the positions of the Red offense players around the opponents goal post when the ball is in safe zone.

6.4 Failure analysis of the Proposed strategy

If any of the defense or offense players fail or make foul, the information is broadcasted to all the members of the team. Taking this information, location of the ball and state of the game into consideration, team then decides the new set of actions and formations players has to take to reach their goal.

6.4.1 In Danger zone

When the ball is in danger zone, the team should maintain a strong defense covering the goal line and block the passes opponents make towards the goal. To achieve this, a complete defense semi-ellipse curve with 5 players as shown in Figure 6.7 is necessary. In an idle case, this kind of formation can be maintained perfectly. But in realistic mode where fail and fouls are possible, the team should give priority to defending and assign a considerate number of players for defense. Assigning more than 5 players to defense curve might make the curve more defensive but could lead to more number of collisions among players as the gap between players is very less.

$$Number\,of\,Defense\,players(N_d) = \begin{cases} \frac{N}{2}, & \text{if } N \text{ is even and } n \geq \frac{N}{2} \\ \frac{N}{2}+1, & \text{if } N \text{ is odd and } n \geq (\frac{N}{2}+1) \\ n, & \text{otherwise} \end{cases}$$

$$Number\,of\,Offense\,players(N_o) = \begin{cases} n - N_d, & \text{if } n \geq N_d \\ 0, & \text{otherwise} \end{cases}$$

Where, *N* is the total number of players in the team and *n* is the total number of active players in the team.

6.4.2 In Neutral zone

When the ball is in neutral zone, the team should maintain both offense and defense with equal preference. Out of the total active players in the team excluding the goal keeper, half of them are assigned to offense and the remaining half to defense.

$$Number\,of\,Offense\,players(N_o) = \begin{cases} \frac{n}{2}, & \text{if } n \text{ is even} \\ \frac{n}{2}+1, & \text{if } n \text{ is odd} \end{cases}$$

$$Number\,of\,Defense\,players(N_d) = \frac{n}{2}$$

Where, *N* is the total number of field players in the team and *n* is the total number of active players in the team.

6.4.3 In Safe zone

When the ball is in Safe Zone, team should focus more on scoring a goal. The assignment of offense roles in this zone is same as the defense roles in Danger zone. Assigning more than *N/2* players to offense might make the curve more offensive but could result in more collisions among players which might lead to failure of the players. Also, that would make the defense weak giving opponents an opening if by chance ball reaches danger zone.

$$Number\,of\,Offense\,players(N_o) = \begin{cases} \frac{N}{2}, & \text{if } N \text{ is even and } n \geq \frac{N}{2} \\ \frac{N}{2}+1, & \text{if } N \text{ is odd and } n \geq (\frac{N}{2}+1) \\ n, & \text{otherwise} \end{cases}$$

$$Number\,of\,Defense\,players(N_d) = \begin{cases} n - N_o, & \text{if } n \geq N_o \\ 0, & \text{otherwise} \end{cases}$$

Where, N is the total number of field players in the team and n is the number of active field players in the team. The players re-form their formations based on their reassignments accordingly. This way, the defense curve formation can still be maintained which covers the goal post and no vacancy is left for the opponent to score a goal easily. In the same way, the offense curve formation is maintained to actively offend and score the goal.

Chapter 7

Results

In this chapter, we present the results of the games played by the proposed strategy against Uniform-cover strategy, Role-based strategy, Defense priority strategy and Offense priority strategy in our Robot Soccer simulator. We also present the results of the games played by our FR strategy against Role-based strategy and Uniform cover strategy in Simbad Robot Simulator [35].

7.1 On our Robot Soccer Simulator

A total of 400 games were played by FR team, 50 games against each of the four strategies in both ideal and realistic mode. As mentioned in previous chapters, in realistic mode, failures of the robots can happen and in ideal mode there are no failure of the robots. In the 200 games played in realistic mode by FR strategy against other strategies, minimum number of failures happened to both the teams were two, average was five and maximum was eight.

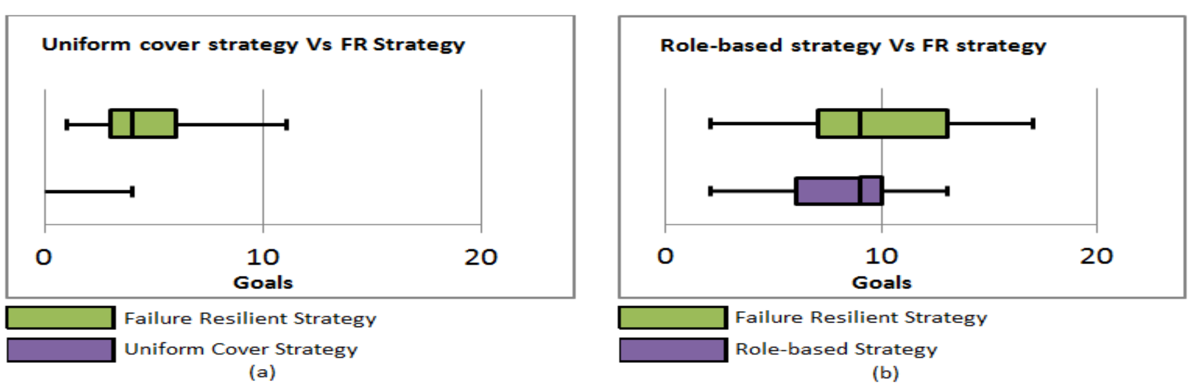

Figure 7.1 (a),(b) - Box plots of goals scored by FR strategy against Uniform cover strategy and Role-based strategy in ideal mode

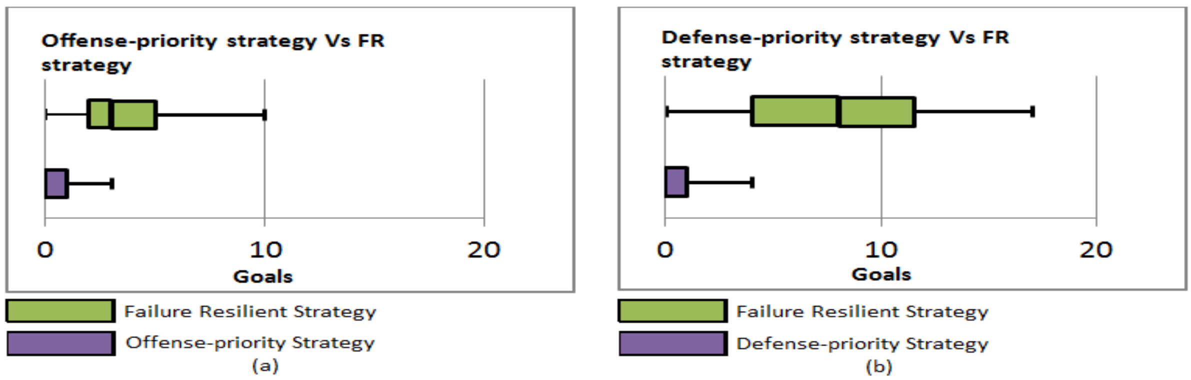

Figure 7.2 (a),(b) - Box plots of goals scored by FR strategy against Offense-priority strategy and Defense-priority strategy in ideal mode

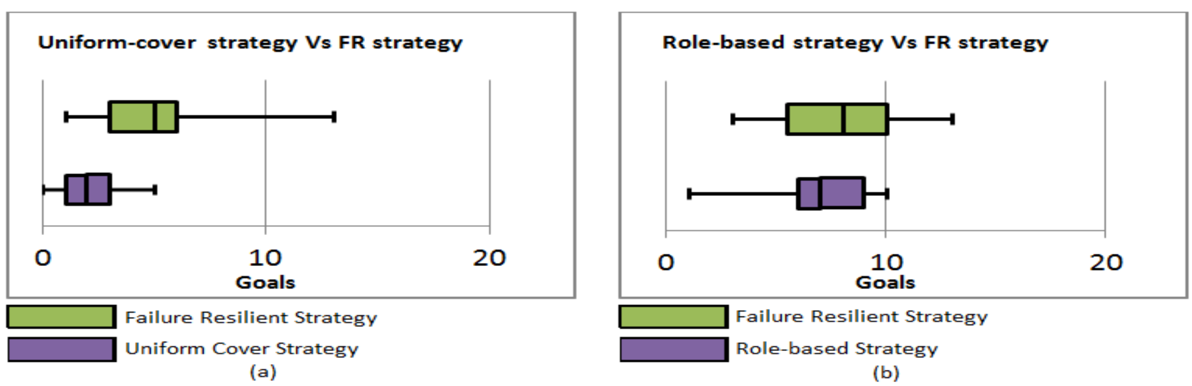

Figure 7.3 (a),(b) - Box plots of goals scored by FR strategy against Uniform cover strategy and Role-based strategy in realistic mode

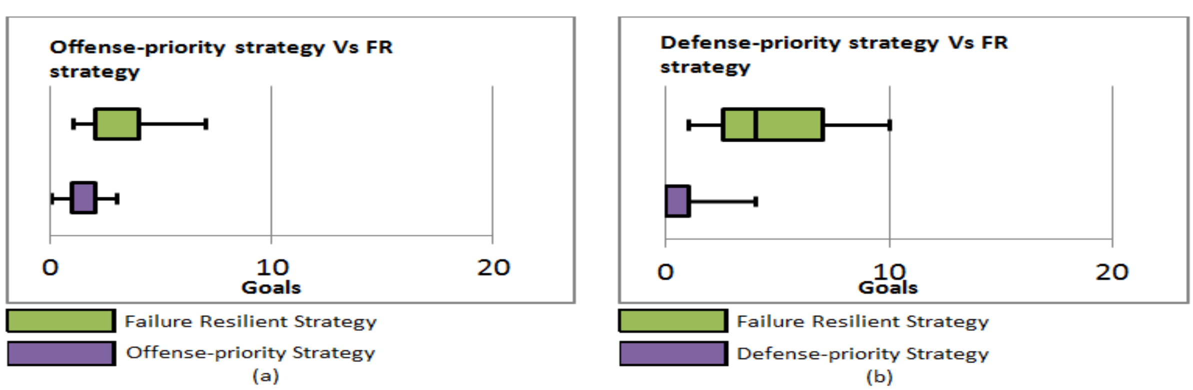

Figure 7.4 (a),(b) - Box plots of goals scored by FR strategy against Uniform cover strategy and Role-based strategy in realistic mode

We used box plots to graphically depict and compare the goals scored by Failure Resilient strategy against the four opponent strategies. Figure 7.1-7.4 shows the boxplots with the number of goals scored by each team on the X-axis against the game strategies on Y-axis. Upon observing the plots, in both ideal mode and realistic mode, Failure Resilient strategy has recorded more number of ways to score a successful goal compared to the other opponent strategies. In the ideal mode where the agents do not fail during the game, Failure Resilient Strategy showed better performance compared to the other four opponent strategies. These results are recorded from the games played on the Simulator which we've developed from the scratch. In the next section, we will explain the working of the Failure Resilient strategy against other opponent strategies in-detailed considering the failure of the offense and defense players in the FR team. We've also implemented the strategies in Simbad Robot Simulator [10], an open source cross-platform software simulator to prove that our strategy works on other robot simulators as well.

7.2 On Simbad Robot Simulator

A total of 160 games were played by FR strategy in this simulator, 80 games against Uniform cover strategy and 80 games against Role-based strategy. Both the opponent strategies are existing 2D Robot Soccer simulation strategies. In all the 160 games, opponent team always plays in ideal mode with no failures of the players in its team.

Out of the 80 games played against each opponent strategy,

1. 20 games are played with one failure in the FR team.
2. 20 games are played with two failures in the FR team.
3. 20 games are played with three failures in the FR team.
4. 20 games are played with four failures in the FR team.

We have considered this kind of environment to analyze the impact of failure of agents on FR strategy and the extent to which it can cope-up with the dynamic change in the number of players in the team and compete against the opponent team. In Tables 7.2, 7.4, 7.6 and 7.8, the Min, Q1, Med, Q3 and Max parameters are referring to the Minimum, Lower Quartile, Median, Upper Quartile and Maximum of goals scored by the teams respectively.

7.2.1 Failure Resilient Strategy vs Role-based Strategy

In this section, we present the results of the games scored by FR strategy and Role-based strategy followed by the analysis of the FR strategy behavior considering different failure situations in the FR team during the game.

7.2.1.1 One failure in the FR team

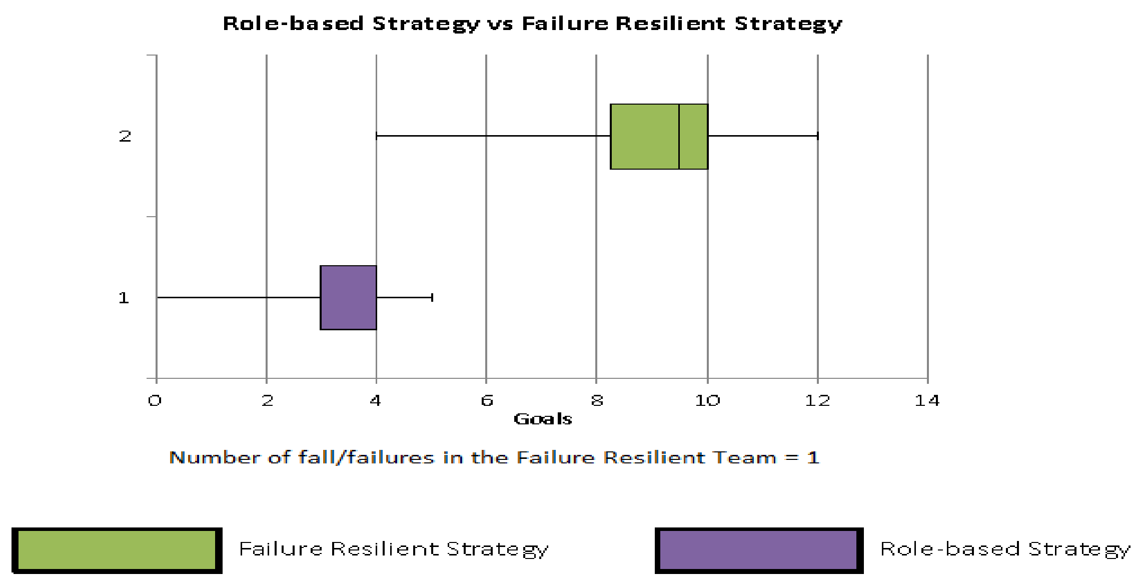

Figure 7.5 Role-based Strategy vs FR Strategy. Number of failures in the FR Team = 1

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	1	0	11	0	1
2	1	0	12	0	1
3	1	0	13	0	1
4	1	0	14	0	1
5	1	0	15	0	1
6	1	0	16	0	1
7	1	0	17	0	1
8	1	0	18	0	1
9	1	0	19	0	1
10	1	0	20	0	1

Table 7.1 Number of failed offense agents and defense agents in FR team for the games scores represented as box plot in Figure 7.5

	Role-based Strategy	Failure Resilient Strategy
Number of players in the team	11	11
Number of failures in each game	0	1
Minimum	0	4
Lower Quartile	3	8.25
Median	3	9.5
Upper Quartile	4	10
Maximum	5	12

Table 7.2 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.5

To analyze the behavior of the FR strategy when there is a failure of one player in the FR team, let us consider different scenarios of offense or defense player failure when the ball is in danger, neutral and safe zones. At the beginning of the game, out of ten field players, five players are assigned the offense role and the remaining five players are assigned defense role in FR team. When the ball is in danger zone, failure of the offense player in the FR team poses very less or no impact to the team's strategy since the priority in this situation is defense. The five defense players continue to defend the opponents from scoring a goal without any deviation and the remaining four offense players re-organize their offense formation and wait for a chance to attack. Similarly, when the ball is safe zone and there is a defense player failure, the offense players continue to play while the four defense players re-organize their formation and stay on guard. When the ball is in neutral zone and there is a offense/defense player failure, five players are assigned to offense role and four players to defense role. We chose to assign more players for offense in this case because when the ball is in neutral zone, instead of defending the ball to not enter the danger zone, it is always better to attack first and push it to the safe zone. Four players are anyway assigned to defend in-case the ball reaches the danger zone. When the ball is in danger zone and there is a defense player failure, one of the offense players in the team is re-assigned to defense role. During this switch and filling the gap in the defense formation, opponent team might sometimes gain a chance to score a goal. When the ball is in safe zone and there is a offense player failure, one of the defense player is re-assigned to play offense and support the remaining offense players in scoring a goal.

7.2.1.2 Two failures in the FR team

Figure 7.6 shows that FR team scored more number of goals compared to the Role-based strategy even with failure of two players in the FR team and no failure in the Role-based strategy and Table 7.3

shows the failures of offense and defense players in each game. The FR team showed better results even with failure of two players at different situation in the game.

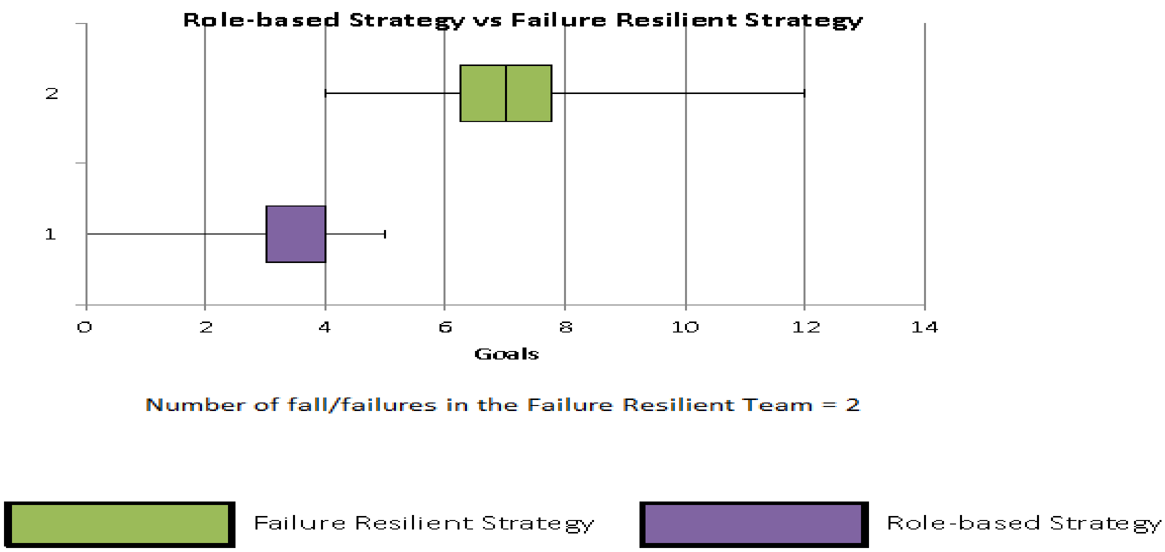

Figure 7.6 Role-based Strategy vs FR Strategy. Number of failures in the FR Team = 2

For the game analysis, let us consider a case where both the offense players are failed when the ball is in danger zone. Out of ten players, five players will continue to play the defense role and provide the maximum defense strength which is of high priority in this situation while the remaining three players re-organize themselves in offense formation. When the ball is in safe zone and there are two defense players failure, the five offense players continue their role and provide maximum offense strength to the team while the remaining three defense players re-organize themselves in defense formation. In both the cases, the impact of the two failures on the team is less. Now, consider a case where the ball is in danger zone and two defense players are failed. In this case, FR strategy will re-assign two offense players to defense roles in order to form a complete defense formation to defend the opponent team. The remaining offense players re-organize themselves in the offense formation. Similarly, when the ball is in safe zone and two offense players are failed, two defense players are re-assigned to the role of offense to provide maximum support in attacking. The remaining defense players re-organize themselves and stay in defense formation. In both these cases, between the switch of roles and re-organization of team formations, the opponent team sometimes get more chances to score a goal or intercept the FR team from scoring a goal since the opponent's Role-based strategy is strong in offense when the ball is in our danger zone and strong in defense when the ball is in our safe zone. When the ball is in neutral zone, both offense and defense modes of FR strategy are given equal priority and the eight players are equally distributed for offense and defense roles. When the ball is in safe mode and there is one offense player and one defense player failure, one of the players in defense is re-assigned to the offensive role. Lastly, when the ball is in danger zone and there is one offense player and one defense player failure, one of the offense player is re-assigned for defense to provide strong defensive support.

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	2	0	11	1	1
2	2	0	12	1	1
3	2	0	13	1	1
4	2	0	14	1	1
5	2	0	15	0	2
6	2	0	16	0	2
7	1	1	17	0	2
8	1	1	18	0	2
9	1	1	19	0	2
10	1	1	20	0	2

Table 7.3 Number of failed offense agents and defense agents in FR team for the games scores represented as box plot in Figure 7.6

	Role-based Strategy	Failure Resilient Strategy
Number of players in the team	11	11
Number of failures in each game	0	2
Min	0	4
Q1	3	6.25
Med	3	7
Q3	4	7.75
Max	5	12

Table 7.4 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.6

7.2.1.3 Three failures in the FR team

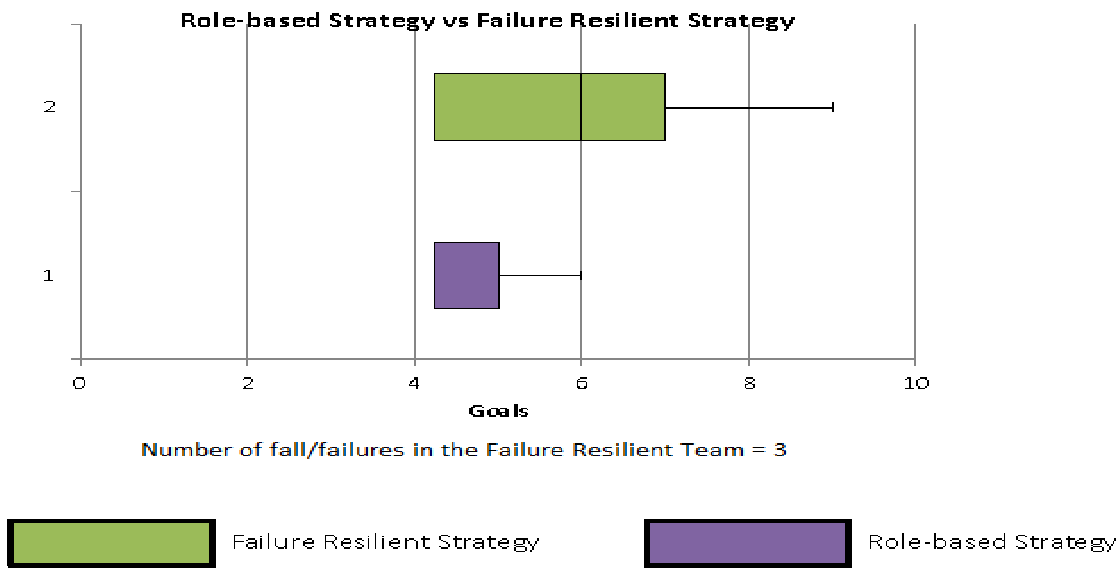

Figure 7.7 Role-based Strategy vs FR Strategy. Number of failures in the FR Team = 3

The three failed players in the FR team can be either only offense players or only three defense players or one offense and two defense players or two offense and one defense players. In all these cases, the location of the ball in each of the three zones impacts the team's strategy in different ways. When the ball is in danger zone and there are three offense players failure or when the ball is in safe zone and there are three defense players failure, the remaining players continue to play without any role re-assignment since the team is still providing complete offense or defense as required in both the cases. When the ball is in neutral zone, four players are assigned for offense and three players are assigned for defense. All these cases discusses so far do not pose much impact to the FR team's performance. Now, consider the case where the ball is in safe zone and there is a failure of one offense and two defense players. In this case, one of the players among the remaining three defense players is re-assigned to offense to support the remaining offense players. When the ball is in danger zone and there is one defense player failure and two offense players failure, one of the remaining offense players role is re-assigned to defense to provide maximum defense support in danger zone. There is one player switch in both these cases which gives some impact to the team strategy. When the ball is in danger zone and there is a failure of two defense players and one offense player, two offense players are re-assigned to defense role to provide maximum defense which is of high priority in this case. Similarly, when the ball is in safe zone and there is a failure of two offense players and one defense players, two defense players are re-assigned to offense role to provide maximum support in offense. Three defense players failure when the ball is in danger zone or three offense players failure when the ball is in safe zone creates more impact to the FR strategy since this involves re-assigned of three players and during the switch it leaves more opportunities for the opponent team to score the goal or intercept the FR team from scoring a goal.

Game ID	**no. of offense agents failed**	**no. of defense agents failed**	**Game ID**	**no. of offense agents failed**	**no. of defense agents failed**
1	3	0	11	2	1
2	3	0	12	2	1
3	3	0	13	1	2
4	3	0	14	1	2
5	3	0	15	1	2
6	3	0	16	1	2
7	2	1	17	1	2
8	2	1	18	1	2
9	2	1	19	0	3
10	2	1	20	0	3

Table 7.5 Number of failed offense agents and defense agents in FR team for the games presented as box plot in Figure 7.7

	Role-based Strategy	**Failure Resilient Strategy**
Number of players in the team	11	11
Number of failures in each game	0	3
Min	4	4
Q1	4.25	4.25
Med	5	6
Q3	5	7
Max	6	9

Table 7.6 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.7

7.2.1.4 Four failures in the FR team

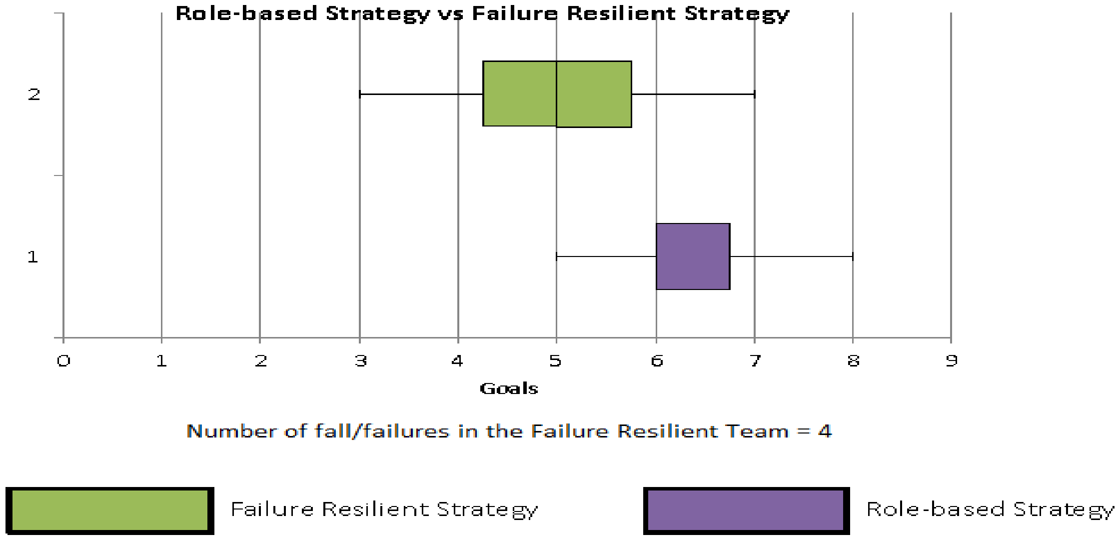

Figure 7.8 Role-based Strategy vs FR Strategy. Number of failures in the FR Team = 4

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	4	0	11	2	2
2	4	0	12	2	2
3	3	1	13	2	2
4	3	1	14	2	2
5	3	1	15	1	3
6	3	1	16	1	3
7	2	2	17	1	3
8	2	2	18	1	3
9	2	2	19	0	4
10	2	2	20	0	4

Table 7.7 Number of failed offense agents and defense agents in FR team for the games presented as box plot in Figure 7.8

	Role-based Strategy	Failure Resilient Strategy
Number of players in the team	11	11
Number of failures in each game	0	4
Min	5	3
Q1	6	4.25
Med	6	5
Q3	6.75	5.75
Max	8	7

Table 7.8 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.8

In case of four failures in the FR strategy against Role-based strategy, our strategy scored less because both the offense and defense formation became weak since there are only six active players in the team against ten active opponent players playing strong offense or defense. Even with four failures in the FR team, the team still managed to score some goals against the Role-based strategy. Figure 7.8 shows the box plot of the goals scored by FR strategy and Role-based strategy and Table 7.7 shows the failures of the offense and defense players in the FR team in each game. Overall, FR strategy performed better than Role-based strategy even with three failures in its team. It also managed to score a considerate number of goals when there are four failures in the FR team.

7.2.2 Failure Resilient Strategy vs Uniform Cover Strategy

In this section, we present the results of the games scored by FR strategy and Uniform cover strategy followed by the analysis of the FR strategy behavior considering different failure situations during the game.

7.2.2.1 One failure in the FR team

The working of the FR team when there is one failure is explained in detailed in section 7.2.1.1. Uniform cover strategy focuses more on defending the opponents by uniformly covering the field area behind the ball. This strategy provides very weak offense by assigning only one player to chase the ball and strike a goal. So, Even with one player less in the FR team, the team could still provide strong offense and defense against the Uniform cover strategy by creating proper offense and defense formations prioritizing only the critical areas around both the goal posts. Figure 7.9 shows the box plot of the goals scored by FR strategy and Uniform cover strategy with one failure in the FR team. Table 7.9 shows the number of failures of the offense and defense players in FR team in each game.

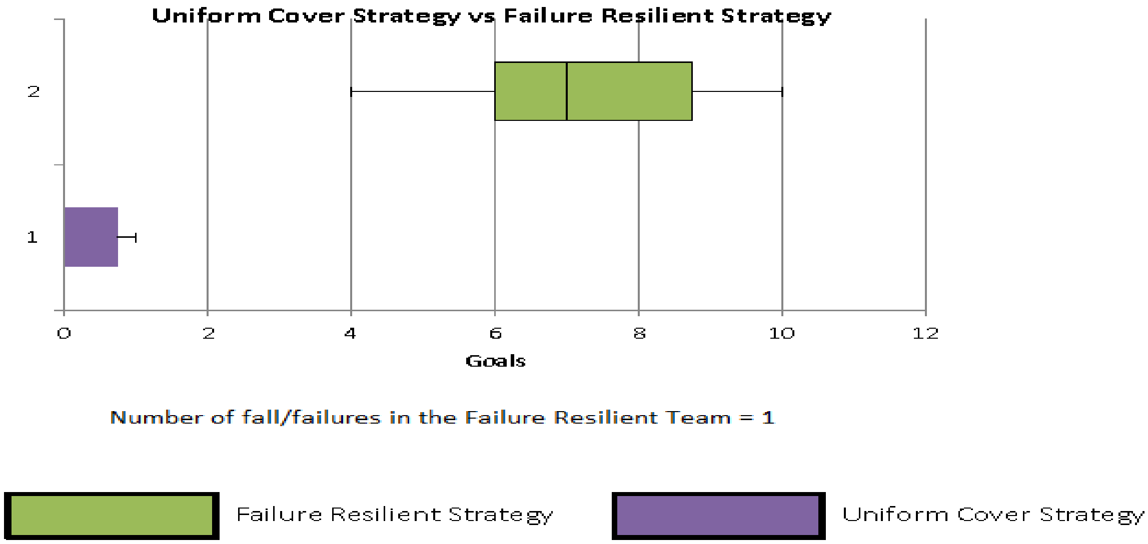

Figure 7.9 Uniform Cover Strategy vs Failure Resilient Strategy. Number of failures in the Failure Resilient Team = 1

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	1	0	11	0	1
2	1	0	12	0	1
3	1	0	13	0	1
4	1	0	14	0	1
5	1	0	15	0	1
6	1	0	16	0	1
7	1	0	17	0	1
8	1	0	18	0	1
9	1	0	19	0	1
10	1	0	20	0	1

Table 7.9 Number of failed offense agents and defense agents in FR team for the games presented as box plot in Figure 7.9

	Uniform cover Strategy	Failure Resilient Strategy
Number of players in the team	11	11
Number of failures in each game	0	1
Min	0	4
Q1	0	6
Med	0	7
Q3	0.75	8.75
Max	1	10

Table 7.10 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.9

7.2.2.2 Two failures in the FR team

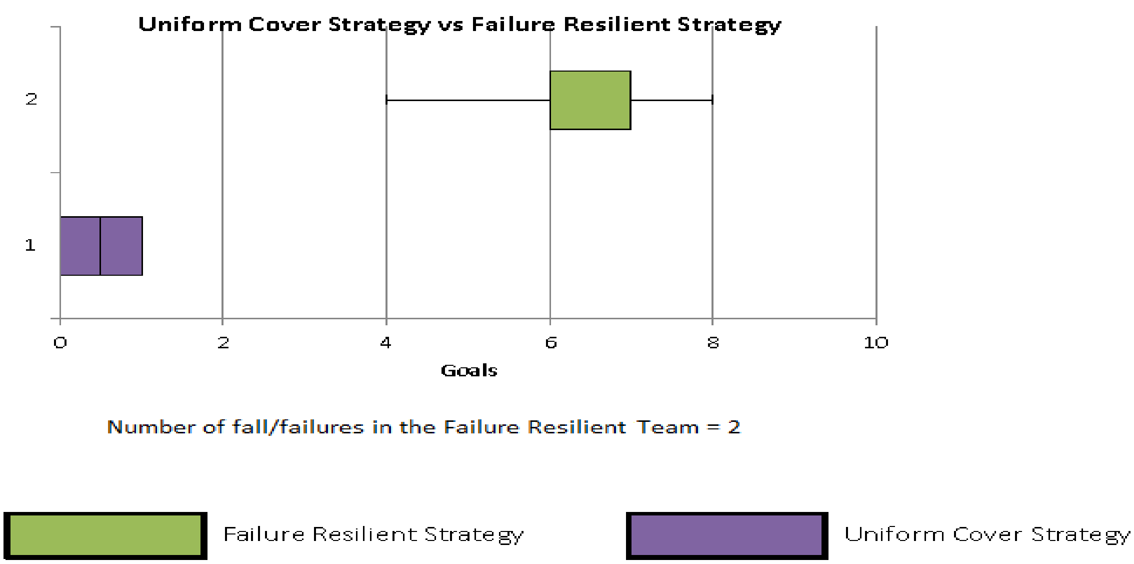

Figure 7.10 Uniform Cover Strategy vs Failure Resilient Strategy. Number of failures in the Failure Resilient Team = 2

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	2	0	11	1	1
2	2	0	12	1	1
3	2	0	13	1	1
4	2	0	14	1	1
5	2	0	15	0	2
6	2	0	16	0	2
7	2	0	17	0	2
8	2	0	18	0	2
9	1	1	19	0	2
10	1	1	20	0	2

Table 7.11 Number of failed offense agents and defense agents in FR team for the games presented as box plot in Figure 7.10

	Uniform cover Strategy	Failure Resilient Strategy
Number of players in the team	11	11
Number of failures in each game	0	2
Min	0	4
Q1	0	6
Med	0.5	7
Q3	1	7
Max	1	8

Table 7.12 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.10

Section 7.2.1.2 explains the working of FR strategy when there are two failures in the team. When there are two failures in the FR team, in the worst case scenario, the team would have either three defense players or three offense players active during the game. When the ball is in danger zone, even with a minimum of three defense players the FR team can still manage to defend the opponents because except for the striker all the opponent team players are dispersed across the field for defense. FR team with three defense players in close defense formation can easily defend one opponent striker and get the possession of the ball. Also, The FR team would anyway re-assign defense role to two offense players to provide complete defense support for the team. When the ball is in safe zone and there are only three offense players active, the FR team can still score a goal with high possibility because the attack formation of the FR team is around the opponent team's goal post area and the opponents positions are spread across the area uniformly giving less focus to the main goal post area. FR team also re-assigns two defense players for offense to support complete offense in this case. In both the cases, FR team can still manage to defend and score a goal against Uniform cover strategy. Figure 7.10 shows the number of goals scored by FR strategy and Uniform cover strategy and Table 7.11 shows the number of failures of the offense and defense players in FR team in each game.

7.2.2.3 Three failures in the FR team

Figure 7.11 Uniform Cover Strategy vs Failure Resilient Strategy. Number of failures in the Failure Resilient Team = 3

The working of the FR team when there are three failures in the team is explained in detailed in section 7.2.1.3. Against Uniform cover strategy, FR team with three failures can still perform better because at a particular point of time and a particular ball location in the field, the opponent team provides only two players at maximum - the striker and a player guarding that partition to chase the ball or defend the FR team. On the other hand, the FR team based on the location of the ball tries to provide the complete defense and offense support for the team. Also, the offense and defense players in FR team only cover the critical areas in the field and closely work together with co-ordination both when trying to score a goal or defend the opponent. Figure 7.11 shows the goals scored by FR strategy and Uniform cover strategy with three failures in the FR team and Table 7.13 shows the number of offense and defense players failure in FR team in each game.

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	3	0	11	1	2
2	3	0	12	1	2
3	3	0	13	1	2
4	3	0	14	1	2
5	2	1	15	1	2
6	2	1	16	1	2
7	2	1	17	0	3
8	2	1	18	0	3
9	2	1	19	0	3
10	2	1	20	0	3

Table 7.13 Number of failed offense agents and defense agents in FR team for the games presented as box plot in Figure 7.11

	Uniform cover Strategy	**Failure Resilient Strategy**
Number of players in the team	11	11
Number of failures in each game	0	3
Min	0	3
Q1	0	4
Med	0	5
Q3	1	5.75
Max	2	7

Table 7.14 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.11

7.2.2.4 Four failures in the FR team

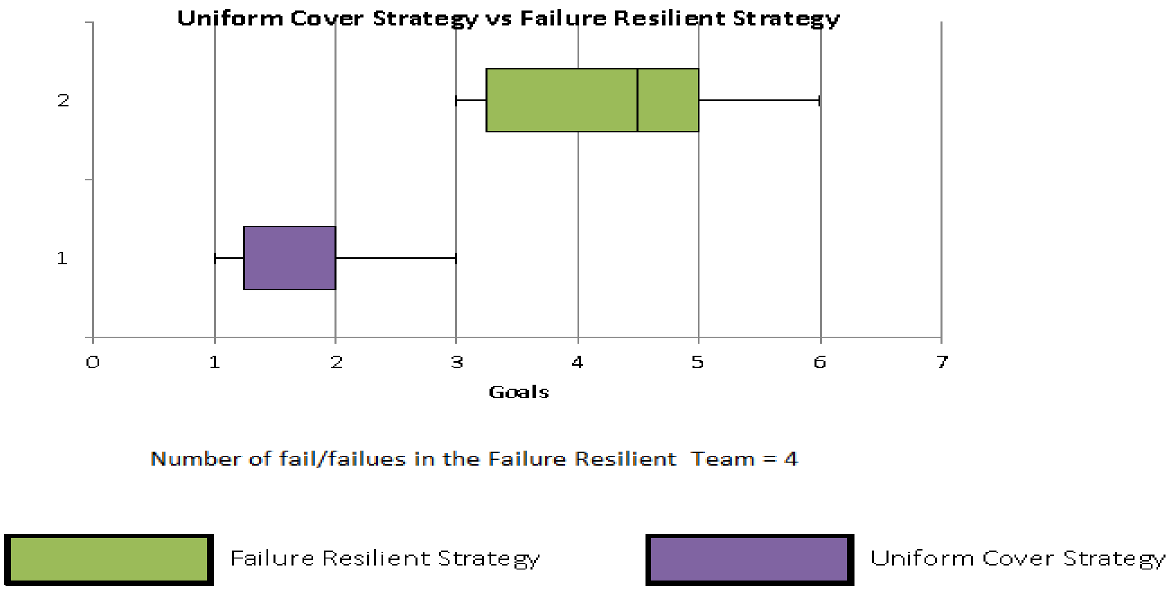

Figure 7.12 Uniform Cover Strategy vs FR Strategy. Number of failures in the FR Team = 4

Game ID	no. of offense agents failed	no. of defense agents failed	Game ID	no. of offense agents failed	no. of defense agents failed
1	4	0	11	1	3
2	4	0	12	1	3
3	3	1	13	1	3
4	3	1	14	1	3
5	3	1	15	1	3
6	3	1	16	1	3
7	2	2	17	0	4
8	2	2	18	0	4
9	2	2	19	0	4
10	2	2	20	0	4

Table 7.15 Number of failed offense agents and defense agents in FR team for the games presented as box plot in Figure 7.12

	Uniform cover Strategy	Failure Resilient Strategy
Number of players in the team	11	11
Number of failures in each game	0	4
Min	1	3
Q1	1.25	3.25
Med	2	4.5
Q3	2	5
Max	3	6

Table 7.16 Min, Q1, Med, Q3 and Max values of the goals scored by FR strategy and Role-based strategy represented as box plot in Figure 7.12

The working of FR strategy in case of four failures in the team is explained in-detailed in section 7.2.1.4. With four failures, the FR team will have only one defense or offense player in the worst case scenario. Defending on the location of the ball in each of the three zones, the players are re-assigned to offense and defense roles and the strategy always tries to provide the maximum required offense or defense support for the team. During the role switch between offense and defense, there are few chances for the opponent team to capture the ball and score a goal. Figure 7.12 shows the goals scored by FR strategy and Uniform cover strategy and Table 7.15 shows the number of failures of the offense and defense players in FR team in each game.

From the results and analysis, we can conclude that our proposed strategy performs better even with some failures rates against an opponent team of eleven active players following other popular strategies. Dynamic decision making on roles and formations based on the state of the players, prioritizing different partitions based on the ball location, deciding actions based on ball possession and creating formations that can be easily maintained with the change in the number of players are the main points that made the FR strategy more successful.

Chapter 8

Conclusions and Future Work

8.1 Conclusion

In Robot Soccer, agents are not available temporarily or permanently due to failure or sent out (due to fouls). In our problem specification, this unavailability is modeled as agent failures. An elementary failure resilient strategy is presented for a 2D Robot Soccer team of eleven players. The game field is partitioned into three zones - Danger, Neutral and Safe. The roles of the players during the game are categorized as Goalie, Striker, Defense player and Offense player. The roles of the players is dynamically decided by the location of the ball in each of these zones. The offense and defense modes of the team strategy are treated with equal priority and are balanced between the opportunities to score a goal and the risks in losing a goal. Shoot, Pass, Dribble, Clear, Move and Intercept are taken as the basic actions a player can perform independently during the game. The decisions on the actions a player should perform is dynamically made based on the state of the players, location of the ball, pressure on the players and location of the players in the field.

In a team of eleven players, with the exception of goal keeper, ideally five players are given offensive roles and five players are defensive roles to maintain equal defense and offense ratio. The role of a particular player may change but the total count of the number of offense and the number defense players is always maintained equally throughout the game. In case of failure of the players during the game, this cannot be the case always since the total number of active players vary. Whenever there is a failure of a player, the remaining players in the team immediately re-strategize and come up with a new set of roles and actions for the team. The assignment of offense and defense roles depends on the location of the ball in the field. If the ball is present in danger zone, more players are assigned to defense role to avoid the risk of losing a goal and if the ball is present in safe zone, more players are assigned to offense role to increase the chance to score a goal. The offense and defense formations of the players is dynamically decided based on the available number of active offense and defense players respectively. This strategy has the flexibility to manage a maximum of any number of players to a minimum of two players in a team. In this paper, we also showed that our strategy is able to adapt and score goals against popular other game strategies with failures of the players during the game. In this thesis, we do not study how and why robot failed, but we study the strategies employed by other agents in the team when some agents are no longer available.

8.2 Future Work

In this thesis, we've researched and tried to address two major challenging problems - Multi-agent decision making and Collaborative analysis in case of failure of the multi agent system Robot Soccer. There are many other challenges that can be considered and implemented along with this strategy to improvise the soccer game results. One among them is the prediction of the failure of the players in the team. If the team can already predict the possibility of failure of a players during the game much before their actual failure, it would help in pre-planning the next steps of the team without any sudden surprises. This would also avoid unnecessary collision with the failed robots which could lead to more failures in the team. Fall and failure avoidance is another major challenge in Robot Soccer that can make an impact to the outcome of the game. If the player can predict that performing some action in a particular situation will definitely lead to fall or failure in the worst case, it would help in avoiding the fall by not performing that action at all. Collision detection and avoidance is one more challenge that would help in improving the performance of the team. Collision among players or collision with the objects in the environment might slow down the task the player has to perform during the game. It can even lead to fall or failure of the players during the game. Prediction of such scenarios and avoiding unnecessary collisions will minimize the impact to the team strategy. As we already mentioned in Chapter 1, same action performed by the same agent at identical circumstances may have different effects on the environment. So, it is always useful to keep monitoring the health statistics, location, surroundings and the stability status of the robot during the game. Prediction of opponent team movements is one another interesting challenge that can help the team in counter attacking the movements of the opponent team which is very advantageous to the team.

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