Defensive Positioning Strategies For A Goalkeeper In The AI World Cup

R.G. Oude Elferink[1] , **R. Bidarra**[1] , **K. Prakash**[1]
[1]TU Delft

Abstract

The AI World Cup is a virtual competition in which teams of five players compete in a football match. The defensive strategies for the goalkeeper in this environment are yet to be researched, however. In previous editions of the competition the participating teams use a basic goalkeeper that can only dive but not position itself. This project provides research into the use of different positioning techniques to improve the performance of the goalkeeper. In the project two different positioning techniques are presented and evaluated. In the first technique, the goalkeeper moves on an imaginary arc in front of the goal and in the second technique the goalkeeper moves on a straight line in front of the goal. Moreover, teamworking techniques between a defender and the goalkeeper are used to create a better coverage of the goal. The evaluations for the positioning techniques consist of 250 shots shot by an attacker from random distances and angles. The evaluations indicate that both goalkeepers have an improvement in performance over the basic goalkeeper, used by the other teams. The goalkeeper positioning on a line has the best performance, with an increase in performance of 27% over the basic goalkeeper. These results demonstrate the value of positioning techniques for a goalkeeper in the AI World Cup.

1 Introduction

In recent years, more and more Artificial Intelligence (AI) competitions have arisen to promote and stimulate research. These competitions commonly have a wide appeal for both the general public and for researchers. People have argued that within the domain of AI competitions, team sports can serve as an excellent testbed for team AI behavior. They state that virtual sports games closely resemble real-world competitions, thus forming a border between the real and virtual world. The wide appeal of sports games helps in creating interest for the competitions. Furthermore, sports games contain certain strategical and tactical aspects that make it interesting for AI competitions. [1]

One example of such a competition is the AI World Cup [2], a football simulation competition in which teams of five players compete against each other. This competition uses the general appeal of football to create interest and stimulate research in AI team sports. Whereas other AI football competitions, such as FIRA [1] and RoboCup [2], are played in a physical environment, the AI World Cup is played in a simulated environment and thus requires no hardware for the robots. Consequently, the development is solely focused on the strategical and technical aspects of the players.

The AI World Cup environment contains two-wheeled players, each with a set of basic actions. A team in this framework consists of two attackers, two defenders, and one goalkeeper. Each player in the team can set its wheel velocities, kick speed, kick angle, and jump speed. This action set enables players to pass, shoot, dribble and intercept, therefore having all abilities to play a football match. In addition, the goalkeeper is also able to set its dive action, where it is able to dive sideways both left and right in multiple angles. One limitation for a player in the AI World Cup is that, because of the wheel movements, a player cannot move sideways, which limits the player to quickly change directions.

In a football match defensive tactics are crucial to prevent the opponent from scoring. For the defensive tactics, it is important to effectively cover the attacker carrying the ball, to prevent it from shooting at the goal. Moreover, the defenders should prevent the attackers from passing to each other, so they should try to block the passing lines. If an attacker manages to bypass the defenders, there is always one final line of defense: the goalkeeper. The goalkeeper is the only player that can dive in the AI World Cup and, therefore, its actions are important in the defense to prevent shots from being scored. This project contributes to the defense of an AI World Cup team by focusing on the goalkeeper.

A goalkeeper in the AI World Cup faces multiple challenges. The main challenges for the goalkeeper are to position itself and to decide when and where it should dive. In addition, shot prediction and teamwork with the other defenders are needed to accurately and effectively choose the goalkeeper's actions. Accordingly, this project answers the following question: what are the most effective methods for

[1]https://www.firaworldcup.org
[2]https://www.robocup.org

a goalkeeper to stop a shot at the goal?

Currently, the participating teams in the AI World Cup all use a basic goalkeeper, which does not position itself but only uses dive actions to stop a shot. To this day, no research has been conducted on the influence of positioning the goalkeeper in the AI World Cup environment. Therefore, research into this undiscovered area could provide useful insights and interesting results.

In this project, the methods for positioning a goalkeeper are investigated and the following question is answered: how can the goalkeeper's position be chosen to achieve the best possible coverage of the goal? Moreover, this project looks into the use of teamwork between the keeper and the defenders to discover if this could lead to an improvement in performance.

2 Related Work

Because of the novelty of the AI World Cup, the available research is limited. The current framework, used in this research, has only been used since the 2020 edition of the competition. Therefore, the background research is focused on other robot football competitions. These competitions, however, have a number of important differences with the AI World Cup. For each given piece of literature, the most important differences are given and the relevant additions are highlighted.

Research into the improvement of a goalkeeper in the RoboCup 3D simulation league has provided two approaches to improve its awareness and perception. For the first approach linear regression and Kalman filters are used and in the second approach nonlinear regression and mental models are used for increased perception and decision-making. In this competition, the action set of the goalkeeper is much broader than in the AI World Cup. Consequently, the accurate prediction of the trajectory of the ball has more value in this environment as a small change in trajectory can change the required reaction from the goalkeeper. Another interesting strategy provided by this research is the use of a 'goalkeeper arc', this imaginary arc improves the positioning of the goalkeeper and increases the coverage of the goal. [3]

Other research has aimed at providing strategies for the goalkeeper based on the position of the ball. These strategies are created for a goalkeeper in the middle-size league in RoboCup. In this league, the players are non-humanoid and the goalkeeper has no diving capabilities. The positioning of the goalkeeper is the only method that can be used to stop a shot at the goal. Four defensive positioning techniques are used in this research. In the first technique, they predict where the ball will cross the goal line and they move to the predicted location. In the second technique, they position the goalkeeper on the middle angular line to optimize the covered area of the goal. The third technique is used when the ball is in the corner of the field. The goalkeeper moves to the side of the goal to block the complete shooting angle of the attacker. In the fourth technique, the defenders are used to, together with the goalkeeper, block the largest part of the goal. The position of the ball decides which technique is used. Each part of the field is part of a certain zone. These zones are determined by the shot angle and the prospected scoring chance in that zone. [4]

The results in these papers are promising, but not all techniques can directly be applied to a keeper in the AI World Cup. In the AI World Cup a keeper cannot move sideways, but it has to turn and move forward. This usually does not leave enough time to reach the ball's position before it crosses the goal line. The positioning in the side of the goal is more vulnerable in this environment, because attackers can easily shoot the ball over the goalkeeper. The use of an exact ball trajectory prediction is also less useful, because the range of possible actions is limited and small changes in trajectory do not influence the preferred action of the goalkeeper. However, other ideas, like the goalkeeper's arc, positioning on a line and field division can be altered to be effective in the AI World Cup environment.

3 Finding The Best Strategy

In order to improve the basic goalkeeper used by the other participants in the AI World Cup, two new positioning techniques are considered. These positioning techniques aim at improving the coverage of the goal by the goalkeeper. These strategies are implemented and an evaluation is carried out to conclude whether the new strategies are an improvement over the basic goalkeeper. The goalkeeper with the best evaluation results is used in further research that focuses on the use of teamwork. Finally, this goalkeeper is evaluated to conclude if teamwork can be used to improve the performance of the goalkeeper.

3.1 Evaluation Setup

To be able to make a conclusion about the performance of the goalkeepers, an evaluation setup is created. In this evaluation, two experiments are conducted. The first experiment focuses on the performance of the different positioning techniques. Both new positioning techniques are evaluated and compared to the most basic goalkeeper. This basic goalkeeper functions as the baseline for the evaluation. Each created goalkeeper should perform at least as well as this basic goalkeeper to be deemed useful. The second experiment focuses on the performance of the teamwork, where a goalkeeper without teamworking capabilities is compared to a goalkeeper with teamworking capabilities.

In the first experiment, each goalkeeper is tested by shooting 250 balls from random distances and angles at the goal. The ball is always shot from the half of the field closest to the goalkeeper's goal. In this area, some parts are left out, as can be seen in Figure 1. The sides and the area closest to the halfway line are left out, because the program frequently crashes when a ball is shot from this area. The penalty area is left out, because an attacker cannot dribble, and therefore not shoot, in this area. For this experiment the neural network attacker with 100 subdivisions [5] is used. This attacker always shoots at the best possible scoring region.

To measure the performance of the goalkeeper in the first experiment, the number of saved shots is used as the metric. For additional insight, the position of the shots and the target of the shots are documented. Moreover, the values given by the shooting algorithm of the attacker to each scoring region

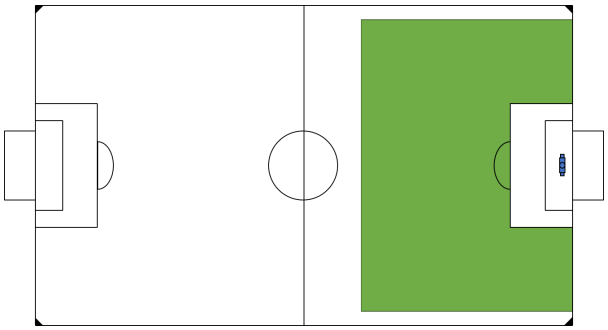

Figure 1: Possible shooting locations of the attacker shown in green.

are saved to find the effect of the new positioning techniques. This algorithm returns a value between -1 and 1 for each scoring region, where a low value indicates a low scoring chance and a high value indicates a high scoring chance for that region. [5] This means that a lower overall score of the regions corresponds to a better coverage of the goal by the goalkeeper.

In the second experiment, the teamwork of the goalkeeper is tested. The difference with the first experiment is that in this experiment there is a defender that also tries to block the shot, whereas in the first experiment only the goalkeeper is used. First 100 balls are shot at a goalkeeper that does not work together with the defender. Then another 100 balls are shot at a goalkeeper that does work together with the defender. All balls are shot from a random position within the area specified in Figure 1. For this experiment, an attacker is used, that only shoots in the top left and top right corner of the goal, which are the areas that are hardest to reach for the goalkeeper. This attacker is used to find out if the goalkeeper can save these shots when it works together with the defender. In this experiment the amount of saved shots are used as a metric to measure the performance of the goalkeeper.

4 Goalkeeper Strategy

The most basic goalkeeper used by the other participants falls short in a number of situations. Especially when the ball is shot from sharp angles, the basic goalkeeper has trouble stopping the ball because of the sub-optimal positioning. To counter this weakness, the goalkeeper should alter its position to have a better coverage of the goal.

4.1 Positioning Techniques

This research considers two positioning techniques, one where the goalkeeper walks on an arc in front of the goal and one where the keeper walks on a straight line.

Goalkeeper's Arc As mentioned before, the goalkeeper's arc is an imaginary arc in the goalkeeper's penalty area. The goalkeeper moves on this arc and, ideally, always positions itself where the line from the predicted location of the ball to the middle of the goal crosses this arc. This is shown in Figure 2. The future location of the ball is estimated with a linear prediction based on the difference between the current and previous frame. In this case, the goalkeeper predicts where the ball will be in five frames.

Advantage: the area of the goal covered by the goalkeeper increases. More effective coverage of sharp angles.

Disadvantage: the goalkeeper cannot move sideways, so moving from one position on the arc to another is a challenge. The distance from the goal might introduce a weakness for lob shots, which are shots that are shot high over the goalkeeper.

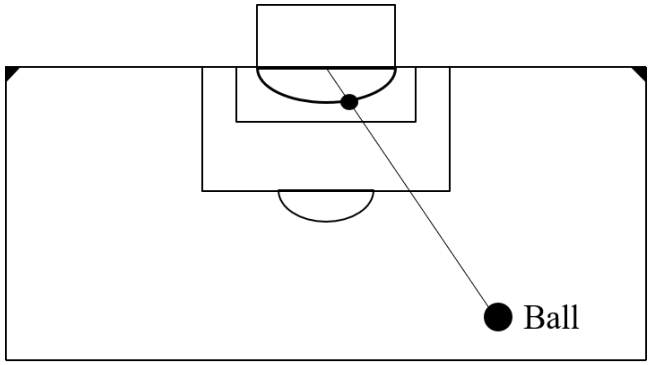

Figure 2: Positioning on goalkeeper's arc. The dot indicates the location where the goalkeeper should position itself on the arc in this scenario.

Line Positioning The second positioning technique that is considered is the positioning on a straight line in front of the goal. In contrast to the goalkeeper's arc, this positioning technique has a smaller vulnerability for lob shots, because the keeper is positioned closer to the goal. The goalkeeper is positioned on the crossing between the straight line and a line from the predicted location of the ball to the middle of the goal. The distance from the goal to the line is chosen such that the sides of the goal can still be covered when a ball is shot from a sharp angle.

Advantage: lob shots are a smaller threat, since the goalkeeper is always close to the goal. Smoother movement between points is possible, because all points are aligned.

Disadvantage: Less coverage of the goal for normal shots compared to arc positioning, because the goalkeeper is positioned further away from the ball.

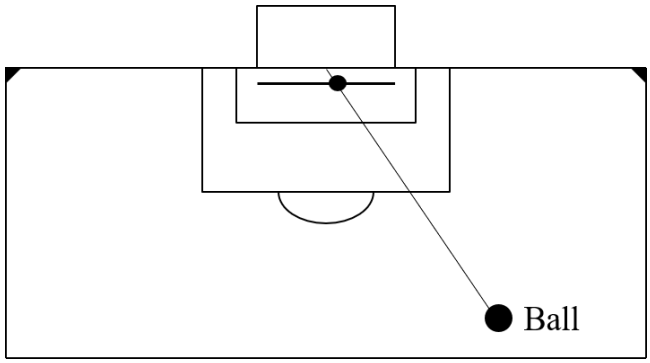

Figure 3: Positioning on straight line. The dot indicates the position where the goalkeeper should position itself on the line in this scenario.

4.2 Movement On The Line

Players in the AI World Cup environment are limited in their movement, since they cannot move sideways. If the goalkeeper wants to move left or right, it has to turn first before it can move forward. A challenge for the goalkeeper, therefore, is to change positions while staying alert for incoming shots. The goalkeeper can only dive sideways, so it should always face the ball when starting a dive. When moving to another position, the goalkeeper does not face the ball, so it should have a strategy to reduce this time in which it is vulnerable to shots.

Field Division A possible strategy is to reduce the number of times the goalkeeper has to move. Instead of constantly moving on the line to keep the optimal position, the keeper could also have a field division where it only has to move if the ball changes zone. For this strategy a division based on angles is considered, which can be seen in Figure 4. In this division, the field is divided in nine 20-degree angles. The goalkeeper positions itself on the intersection between the arc/line and the line that splits the zone. So for the zone from 0 to 20 degrees the keeper positions itself on the intersection of the arc/line with the 10 degree line.

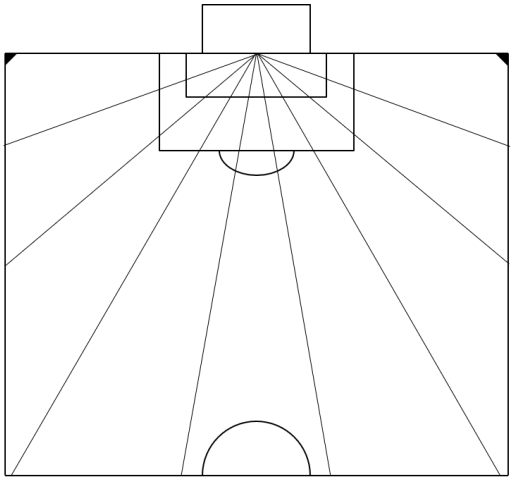

Figure 4: Field division based on angles.

Facing The Ball Instead of always moving when the ball changes position, the goalkeeper can also take into account the perceived risk of the attacker dribbling with the ball. In this case, it means that the goalkeeper only moves when the attacker with the ball is not facing the the penalty area. If the attacker does face the penalty area, the keeper will face the ball to be prepared for a shot. Because a player can more easily move forward than backward, the keeper should always move in the direction of the ball. Therefore, if the ball moves from the top of the field to the bottom of the field, the goalkeeper should be facing the bottom of the field while moving and vice versa. This technique can be seen in Figure 5.

4.3 Defending Lob Shots

The different positioning techniques all have one similarity, which is an increased weakness for lob shots, shots that are

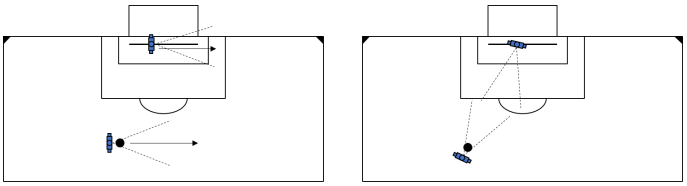

Figure 5: Stance of the goalkeeper when the attacker is not facing the goal and is moving to the right (left). Stance of the goalkeeper when the attacker is facing the penalty area (right).

shot over the goalkeeper with enough height such that the goalkeeper cannot reach it. Whenever the keeper moves to cover one side of the goal, the distance to the other side increases, making it more vulnerable for a lob shot.

To counter this vulnerability, the goalkeeper needs to be able to timely recognize a lob shot and act accordingly. First, the goalkeeper has to recognize when a ball is shot. It does this by calculating the distance traveled by the ball between frames. If this value is larger than the maximum distance a player can travel between frames, it indicates a shot. This indicator together with the direction of the ball is the indicator used to recognize a shot. However, this shot recognition is only effective in the evaluation setup used in this research and not in an actual AI World Cup match. In the evaluation setup it is known that the attacker will either dribble or shoot, which makes the described recognition method effective. In an actual match this method cannot be used, because any movement of the ball towards the goal, a pass, for example, will be recognized as a shot.

To recognize a lob shot, the goalkeeper checks the difference in z-coordinates of the ball in the first two frames after it has been shot. If this is a large value, it shows that the ball is quickly increasing in height, thus indicating a lob shot. A threshold is set for this value, where the keeper can assume that the shot is a lob shot if the difference in z-coordinates is larger than the threshold. In this research, this threshold is chosen by shooting lob shots from multiple locations and picking the smallest difference in z-coordinates from the shots. There is, however, no indication that this is the optimal threshold in any way. Therefore, further research is needed to find the optimal value for this threshold or to find another method for recognizing a lob shot.

When the ball is shot, the clock is ticking and the keeper does not have much time to react to the shot. Therefore, moving to another more optimal position is not an option. The goalkeeper can, however, rotate its body to a rotation, such that it can more easily dive to intercept the ball. Normally the goalkeeper is rotated in such a way that the side of the goalkeeper is aimed at a point slightly next to the nearest goalpost. When a lob shot is shot to the other side of the goal, the keeper turns its side to the point at the other goal post. This point is chosen such that the goalkeeper does not hit the goal post when it makes a dive. This behaviour is illustrated in Figure 6.

4.4 Defensive Teamwork

Due to the limited diving range of the goalkeeper, the goalkeeper is not able to cover the complete goal by itself. To be

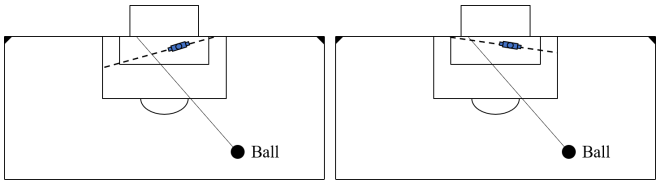

Figure 6: Positioning of the goalkeeper before a shot (left) and the positioning of the goalkeeper after it recognizes a lob shot (right).

able to cover each area of the goal, the goalkeeper needs the help of the defenders. In this teamwork, one of the defenders covers the far angle of the goal and the goalkeeper covers the angle closest to the ball. This distribution of the sides is chosen, because the goalkeeper already positions itself on the side of the goal closest to the ball, assuming it uses the positioning techniques described in this chapter. So the keeper has to travel a shorter distance to cover the side closest to the ball than to cover the other side.

This positioning is set up in multiple steps, as can be seen in Figure 7. First, the defender defending the ball carrier [6] looks at the position of the goalkeeper to decide which corner it should cover. If the goalkeeper stands in the right corner, as in Figure 7a, the defender moves to a position to cover the left corner. To cover this corner, the defender moves to a point slightly next to the line between the current location of the ball and the location of the goalpost of the corner it should cover. When it has reached this point, the defender moves towards the ball until the distance to the ball is smaller than a selected value. This behaviour can be seen in Figure 7b/c. In this research 1 meter is used for this value, since the attacker could not shoot over the defender from this distance. This value still has to be optimized, however. The goalkeeper constantly checks if both distance 1 and 2, shown in Figure 7, are smaller than a certain threshold. Currently, the values 1 meter and 3 meters are taken for distance 1 and 2, respectively. However, these values are currently chosen by trial-and-error and still have to be optimized in further research. If both values are below the given threshold, the goalkeeper moves to a predefined position in the left or right corner of the goal, depending on which corner it is covering. This predefined position is chosen in such a way that the keeper can just reach the top corner of the goal with a dive. If both the defender and the goalkeeper reach the desired position before the ball is shot, then each shot should be able to be blocked.

4.5 Goalkeeper Versions

The previously described techniques are used to create three different goalkeepers. The first one uses the positioning based on the goalkeeper's arc, together with a combination of the described movement techniques in subsection 4.2, in which the goalkeeper only moves to a new zone when the attacker is not facing the goal. In the remaining part of this research this goalkeeper is referred to as the 'arc goalkeeper'.

The second goalkeeper, the 'line goalkeeper', uses the line positioning technique mentioned in section 4.1. Because the movement on a straight line is smoother than on an arc, this goalkeeper does not need a field division and only uses the

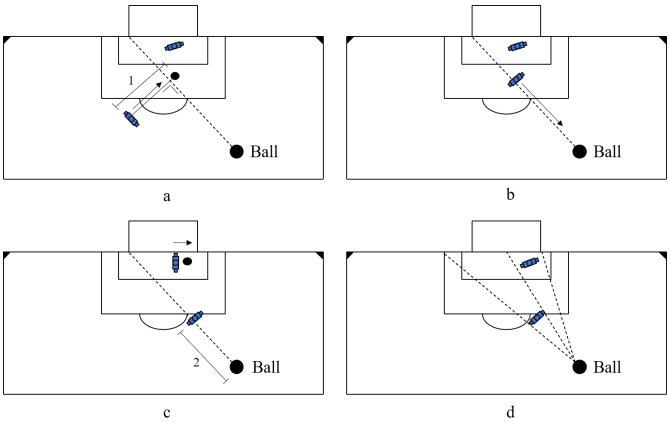

Figure 7: Teamwork behaviour used to cover the goal. The defender moves to a position next to the line from ball to goalpost (a). The defender moves towards the ball (b). The goalkeeper moves to predefined position if defender is close enough to the ball (c). The complete angle of the goal is covered (d). (Note: the players are not to scale.)

perceived risk of the attacker, as mentioned in the last paragraph of subsection 4.2.

The third goalkeeper uses the same techniques as the previous described line goalkeeper. In addition to this goalkeeper, the third goalkeeper also has teamwork capabilities that enable it to work with the defender, like described in subsection 4.4. This goalkeeper is used to test the effectiveness of the defensive teamwork.

5 Goalkeeper Performance

To run the experiments described in subsection 3.1, a PC or Laptop with dual-core CPU with a clock speed of at least 2 GHz and 2 GB RAM is needed. It should also have an NVIDIA or AMD graphic adapter capable of using OpenGL version 3.3 or higher with at least 512 MB RAM. The AI Soccer Platform supports Windows 8.1, Windows 10 or any Linux distribution 16.04 LTS or above. Moreover, a python environment, the Webots Robot simulator and the AI Soccer Simulator are needed to use the AI Soccer Platform. Details regarding the installation and execution can be found in the official AI World Cup manual [3].

Table 1: The save rates and mean zone values for each of the three goalkeepers measured over 250 shots from random positions on the field. The standard deviation of the zone values is shown in parentheses.

	Save Rate	Mean Zone Value
Basic GK	38.4%	-0.07702 (0.424494)
Arc GK	42%	-0.3572 (0.34951)
Line GK	48.6%	-0.21676 (0.39726)

Table 1 shows the results obtained by the first experiment. This table shows that both the arc goalkeeper and the line

[3] https://github.com/aisoccer/aisoccer-3d/releases/

goalkeeper perform better than the basic goalkeeper, with a save rate of 42 and 48.6 percent, respectively. These results indicate that the presented positioning techniques lead to an improvement in the performance of the goalkeeper.

What is surprising is that, although the arc goalkeeper has a lower mean zone value than the line goalkeeper, indicating a better coverage of the goal, its save rate is lower. A possible explanation can be found in Figure 9 and Figure 10. These figures show the positions of the shots, together with the height and success of the shots. These figures reveal that the low shots have a lower scoring rate than the high shots. This observation is supported by the data, which shows that for the arc goalkeeper the scoring rate for a low shot is 42.2%, whereas the scoring rate for a high shot is 63.4%. For the line goalkeeper, this difference is even larger with a scoring rate of only 32% for the low shots and a scoring rate of 63.7% for the high shots. Moreover, the results show that for the arc goalkeeper 64 out of 250 shots were shot low and for the line goalkeeper 98 out of 250 shots were shot low. Therefore, the difference in save rate between the arc and the line goalkeeper could be attributed to the difference in the number of shots that were shot low by the attacker.

The findings also indicate that both the arc goalkeeper and the line goalkeeper have a better coverage of the goal than the basic goalkeeper. This result is illustrated by the lower average value given to each scoring region by the attacker. These results support the conclusion that the given positioning techniques lead to a better coverage of the goal.

Figure 8, Figure 9 and Figure 10 show the positions of the shots and they show both the success and the height of each shot. From Figure 8 it can be observed that, as expected, the basic goalkeeper has a vulnerability for shots shot from a wide angle. The figure shows that most of the saved shots were shot from positions on the field that have a small angle to the goal, and that almost all shots from the sides could not be saved by the goalkeeper.

In contrast to the basic goalkeeper, the arc and the line goalkeeper do change their location based on the location of the ball. The result of this behaviour can be seen in Figure 9 and Figure 10. These figures show that both the arc and the line goalkeeper save a larger part of the shots shot from a wide angle than the basic goalkeeper. Surprisingly, both the arc and the line goalkeeper seem to perform worse than the basic goalkeeper in the area right in front of the goal.

Table 2: The save rates of two line goalkeepers with a defender blocking one angle. The save rate is measured over 100 shots shot from random positions on the field.

	Save Rate
Line GK	57%
Line GK with teamwork	72%

The results for the second experiment can be found in Table 2. In this experiment an attacker only shoots in the top left and top right corner of the goal. One defender is used in the evaluation to block one side of the goal. The difference between the two evaluated goalkeepers is that one goalkeeper does not change its position based on the defender's position, while the other goalkeeper does work together with the defender to achieve the best coverage of the goal. The table shows that the use of teamwork between the defender and the goalkeeper leads to an increase of 15 percentage points in the

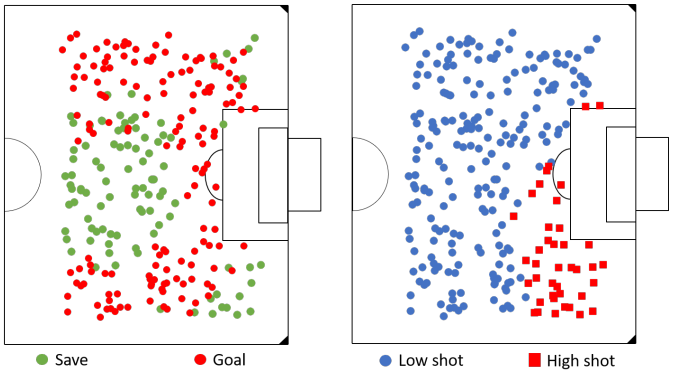

Figure 8: The outcome of the shots (left) and the height of the shots (right) mapped to the positions of the shots, evaluated with the basic goalkeeper.

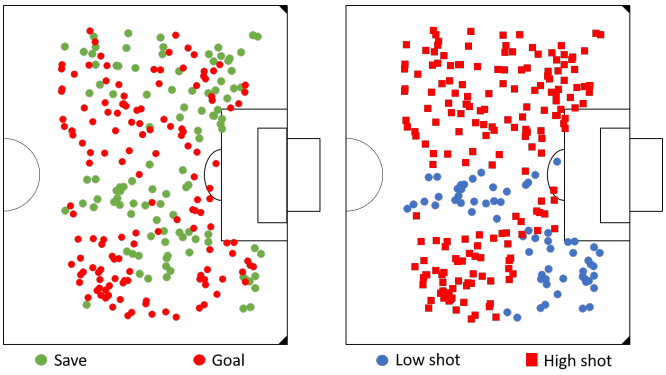

Figure 9: The outcome of the shots (left) and the height of the shots (right) mapped to the positions of the shots, evaluated with the arc goalkeeper.

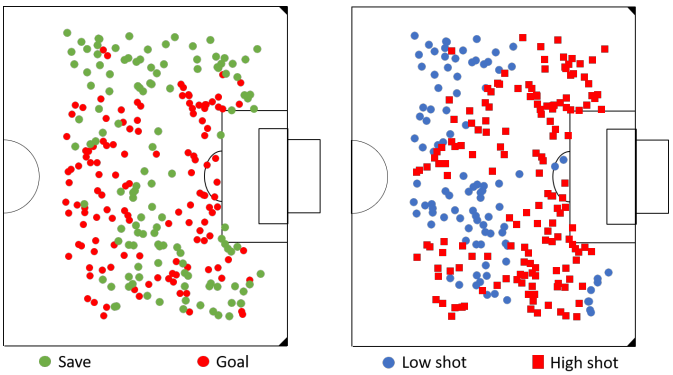

Figure 10: The outcome of the shots (left) and the height of the shots (right) mapped to the positions of the shots, evaluated with the line goalkeeper.

amount of saved shots. So it can be concluded that the teamwork between the goalkeeper and the defender lead to a better performance of the defense.

6 Responsible Research

The evaluation results presented in this research clearly show an improvement in performance for the given positioning techniques over the basic goalkeeper. To adhere to the principals of responsible research, it is important that a critical look is given at the credibility and reproducibility of these results.

Due to the randomness used for choosing the position of a shot, it could be argued that the improvement in performance is due to the attacker picking a less optimal shooting position more often, therefore resulting in less goals. However, this influence is minimized in this research by using a large number of shots in the evaluation. Figure 8-10 also show a uniform distribution of the shots, which indicates that the randomness does not significantly influence the results. If the evaluations were to be reproduced, slight differences in the outcomes could emerge, because slightly different positions could be selected by the attacker. Nevertheless, the number of shots and the uniform distribution of the shots ensure that the influence of the randomness in the evaluation is minimized. This supports the credibility of the research and provides confidence in the measured performance of the positioning techniques.

To support the credibility and reproducibility of the research and to adhere to the principles of Open Science, the data and code used in the research should be openly available. The data collected in this research can be shared if requested by any interested parties. However, the code used for the evaluation is not be published openly, since this code and the created framework might be used in the creation of a team that will eventually participate in the AI World Cup. Therefore, making the source code openly available can give other teams a strategic advantage over this team. However, all details regarding the implementation of the goalkeeper are given, which should enable any skilled reader to reproduce the results presented in this research.

7 Discussion

The aim of the present research was to examine the best methods for a goalkeeper to stop a shot at the goal in the AI World Cup environment. In this project, several techniques were considered to improve the performance of the widely-used basic goalkeeper, and the evaluation of these techniques provided some interesting insights.

One important finding was that both the arc and the line goalkeeper have a better performance than the basic goalkeeper. For both goalkeepers, the number of saved shots is higher and the mean zone value is lower. These results provide confidence that the considered positioning techniques could be effectively used to improve upon the basic goalkeeper used by most teams in the AI World Cup. However, this research did not investigate the performance of the goalkeepers in an actual match. In an actual match the ball movements are less predictable and the ball changes direction more frequently. For a goalkeeper, this means that it has to change its position more often. The behaviour of the goalkeeper in these scenarios should be evaluated before the keeper is adopted as an improvement over the basic goalkeeper. This evaluation should aim at testing the goalkeepers in more realistic scenarios, where the scenarios resemble an actual match more closely. Only after this evaluation is done and the results are positive, the goalkeeper should be adopted as a replacement for the basic goalkeeper.

Moreover, the results found that the difference in performance between the arc and the line goalkeeper could be attributed to the types of shots that were shot at the goal. While this might have an influence on the presented outcomes, other research [5] has shown that the line goalkeeper does actually perform better than the arc goalkeeper. This shows that the difference in save rates of the goalkeeper is not only caused by the types of shots, but that it is also due to the line goalkeeper having a better strategy to save shots.

The research also aimed at distinguishing the weaknesses and strengths of the goalkeepers for different types of shots. For the type of shot, the position and height of the shot were taken into account. An interesting finding was that the basic goalkeeper saves most shots shot from the middle of the field, while it has a vulnerability for shots shot from the sides of the field. This result is a logical outcome of the evaluation, because this goalkeeper always stays in the center of the goal, which means that its position is quite optimal for a shot from the center. However, when the ball is shot from a position on the field that is closer to the side of the field, this center position becomes less optimal, thus resulting in a lower save rate for these shots. The results showed that the arc and line goalkeeper save more shots shot from the side, which shows that the positioning leads to an improved performance for shots shot from wider angles.

What is surprising from these results is that the basic goalkeeper had a better performance for shots shot from the middle than the arc and line goalkeepers. A possible explanation can be that there are more high shots for these two keepers in this area and, as previously stated, a high shot is harder to save. However, Figure 8 and Figure 10 show that some of the low shots from this area could be saved by the basic goalkeeper but not by the line goalkeeper. This suggests that the positioning of the line keeper is not optimal when the ball is in the middle of the field.

The results of the teamwork indicated that the teamwork technique presented in this paper improves the performance of the defense in the given evaluation setup. One could expect that the teamwork would lead to a save percentage of 100%, since the two players together can cover the whole goal. However, the save percentage found was only 72%. This could be caused by the goalkeeper and defender not always reaching the desired position, shown in Figure 7d, in time for a shot. The goalkeeper only moves when the defender is close enough to the ball to block it. If the defender does not reach this position in time, the goalkeeper does not move to another position. Moreover, if the defender does not reach the desired position in time, the side of the goal that it should cover is exposed and therefore vulnerable for a shot. Further research should focus on the effectiveness of this teamwork in an actual match.

One final interesting observation from the results is that the maps for the chosen shot type in Figure 8 and Figure 9 are asymmetric. There are multiple possible explanations for this pattern. One possible explanation is that the goalkeeper performs slightly worse for certain types of shots from one side than for the same shots from the other side. It could be that the neural network attacker picked up on this during training and, therefore, shoots differently from one side. Another explanation can be that the sample size of 500 used for the training of the attacker is too small. This does not allow the attacker to properly learn the best shots from each position, which explains why the pattern seen in the figures is asymmetric.

8 Conclusions and Future Work

The main goal of the current study was to determine the best method for a goalkeeper to save a shot at the goal. In order to guide the research, one main sub-question was created. This question was: how can the goalkeeper's position be chosen to achieve the best possible coverage of the goal? This project has identified two positioning methods that lead to an increase in the coverage of the goal over the benchmark keeper, which is used by all other teams in the AI World Cup. From the two considered methods, it can be concluded that the second goalkeeper, which positions itself on an arc in front of the goal, has the best coverage of the goal. Another way in which the goalkeeper's position can be chosen to achieve the best coverage is by working together with a defender. With this positioning, the goalkeeper and the defender can cover the whole goal by both defending one side of the goal. From the results it can be concluded that this teamwork-based positioning improves the performance of the goalkeeper.

Considering the main goal of this research, a conclusion can also be made about the best methods for a goalkeeper to save a shot at the goal. The research has shown that the goalkeeper, which positions itself on a straight line in front of the goal, has the best performance of the evaluated methods. The positioning method used by this line goalkeeper is, therefore, more effective to save a shot than the methods used by the widely used benchmark goalkeeper. An interesting, but not unexpected, conclusion is that the line goalkeeper's increase in performance is caused by a higher save rate for shots shot from the side of the field. Overall, the results show that the best method to save a shot at the goal is by working together with the defender to cover the entire goal.

This project has shown that positioning methods can be used to improve the benchmark goalkeeper. However, the current line goalkeeper still has some room for improvement. One aspect of the goalkeeper that needs more attention is the setup of the teamwork. Currently, the threshold values used to check if the defender is close enough to the ball are chosen empirically. Further research should focus on the optimization of these values and it should also look into the effectiveness of teamwork in an actual match. Further research should also aim at indicating the effectiveness of the positioning techniques in an actual match.

One of the results showed that the line goalkeeper has a worse performance for shots shot from the middle than the benchmark goalkeeper. More research into the causes for this result could help in the further improvement of the goalkeeper.

A way in which the positioning of the goalkeeper could be improved even further, is by adding an algorithm, presented in other research [5], to the goalkeeper, that sees where the most vulnerable areas are in the goal. By using this algorithm, the goalkeeper can adjust its position to create the best possible coverage of the goal.

Currently, the teams participating in the AI World Cup do not use any positioning techniques for the goalkeeper. However, this research has shown that the use of positioning methods lead to a significant improvement in the performance of the goalkeeper. This project has, therefore, demonstrated that the benchmark goalkeeper will soon be outdated, and that the use of positioning techniques is the way forward for a goalkeeper in the AI World Cup.

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