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STATE AND PROSPECTS OF DEVELOPMENT OF TEAM INTERACTION OF ROBOTS ON THE EXAMPLE OF COMPETITIONS OF THE WORLD TOURNAMENT "ROBOCUP"

Summary: Today, effective group work management is one of the main problems of mechatronics. As the development of generalized algorithms and principles of management is at an early level, the scientific community has formed several model tasks, one of which reads as follows: "By the middle of the XXI century the winner of the last world championship". As part of the wording, the world's first RoboCup competition was launched in 1996 to promote research in the field of robot design and artificial intelligence.

The main task of the article is to analyze and highlight the current state of algorithms for command control of robots on the example of the RoboCup world tournament. The article describes the general schemes of team interaction in the divisions of the tournament, the hardware characteristics of the agents, the history, chronological development and the current state of the rules of the divisions. Based on the analysis, a comparative table of basic technical parameters of RoboCup leagues and approaches used for team management is formed. The conclusion concerning the most actual directions of researches of methods of group interaction is made.

Key words: RoboCup; RoboCup Soccer; multi-agent systems; robots' soccer; team interaction; robotics; Artificial Intelligence; Simulation League.

Actuality of the topic

Researchers from around the world have begun to work on the main task of the RoboCup initiative. Annual competitions have been held for 24 years to assess how far the community is on the way to achieving this goal. Over the years, the robot tournament has produced more and more varieties of competitions. All leagues differ in a large number of parameters: elements of tactics of interaction on the field, type of robots, types of competitions and technologies used, etc. Since research in the field of group interaction is actively engaged only in the Simulation League unit, in this area remain open questions about the application of global tactics (the moment of transition from attack to defense), pre-calculation of player positions, distribution of roles in the team. Over the years, RoboCup has accumulated experience in this area, so there is a need for a comparative analysis of all existing leagues, including their tactical schemes.

For the 10th anniversary of the league Visser and Burkhardt for the first time considered the achievements of the RoboCup [1]. A review article by Alexander Ferrey and Gerald Steinbauer on the 20th anniversary of the competition has also been published [2]. According to their report, after 20 years of RoboCup, the achievements and structure of the competition, which has evolved from two leagues to five, are considered. Most review articles of the tournament make a general description of the achievements of the units almost without covering the issues of group dynamics on the field, so there is a need to look at RoboCup from this point of view.

Presentation of the main material

At this time, the following areas of competition and the corresponding categories of robots have been formed [3]:

1. RoboCup Soccer:
   a) Standard Platform League(SPL);
   b) Small Size League (SSL);
   c) Middle Size League (MSL);
   d) Simulation League (SL):
      − 2D Soccer Simulation;
      − 3D Soccer Simulation.
2. Humanoid League(HL):
   a) KidSize;
   b) TeenSize;
   c) AdultSize.
3. RoboCup Rescue;
4. RoboCup@Home;
5. RoboCup industrial.

Each league focuses on solving a local problem with a specific type of work, which in combination with other types of competitions, solves the global problem. However, the unit solves separately from its own task, four common problems [4]:

- **Machine vision.** All elements of the playing field must be determined by the robot correctly, with the correct distance to the object and be low – cost for computing resources;
- **Modeling.** To track the personal position on the field, the position of the opponent, the position of the ball and its speed, we need algorithms that calculate accurate and stable estimates of the situation on the field;
- **Displacement.** Fast and reliable movement according to the situation: robots must kick the ball accurately and correctly;
- **Proceeding.** The right choice of the proceeding in relation to the situation around. We need to take into account the current and predict the future state of the environment. As the number of players in team increases, the urgent task is to determine the roles of the players. Their interaction during the game.

Every year the rules of the game in RoboCup are changed in order to get closer to the real conditions in which the game takes place. Each year, these changes address one or two of the above issues. Recently, there have been changes such as the introduction of white targets,

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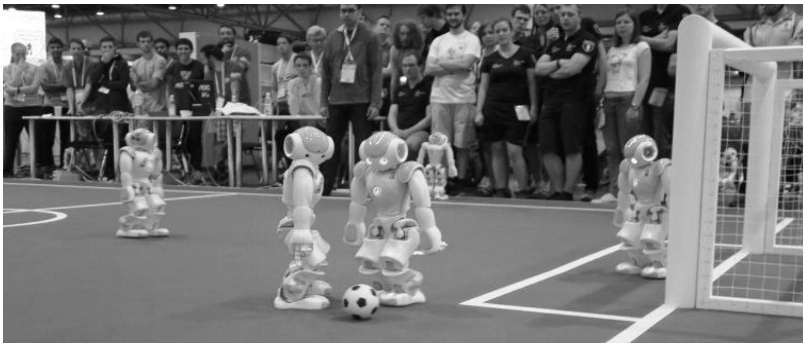
the change of color of the ball from orange to white or black, the beginning of the game is signaled by a classic whistle (perception and simulation), artificial grass (movement). Also for the development of artificial intelligence and group dynamics, in all leagues, without exception, the number of robots in the team is growing.

Standard Platform League (SPL) is formed from the league of four-legged Sony-robots when the company stopped production of AIBO robots. Since 2008, the four-legged AIBO standard has been replaced by the humanoid platform NAO. In many aspects, this league resembles the KidSize Humanoid League (HL). While a part of HL is focused on developing humanoid hardware, the Standard Platform League (SPL) builds on the same hardware for all teams and focuses on developing software and control algorithms for the humanoid robot. Up to five NAO robots (plus one coaching robot per team) compete on a 9x6 m field [5].



Picture 1. – Standard league [6]

Until 2013, a team of robots played under the control of a single software, pre-synchronized in the initial data before the game. This software was of the same type and was developed by one team. Starting in 2013, a new additional experimental type of competition was introduced - "Drop-in player challenge". In this type of competition, each team programs its own robot to coordinate with unknown team allies. Teams are asked not to synchronize robots in advance so that agents can participate in a special teamwork during the game and analyze how they can be useful to their team's players. The main goal of each agent is to win a football match and get the status of "the best player on the team".

As of today, robofootball does not have such a technical and physical development of players to implement such full-fledged tactics as, for example, in human football. The above-mentioned main problems, such as machine vision, modeling, movement and proceeding, are at a fairly early stage of development. The lack of tactics in the standard league is due to the fact that the team consists of 5 players. This fact limits the implementation of a wide range of tactics, compared to teams with a standard number of players. Out of 5 robots, only 4 are actively involved, as the fifth participant is a goalkeeper who does not go beyond the allowable goal area. Among the best teams, the principle is common, when robots are not assigned certain roles on the field, but they perform basic coordination during the game. Instead, elements of group interaction are still present.

Therefore, the following tactics are used for 5 players [7]:

- The first tactic is to protect its own goal from an enemy strike. The team has one goalkeeper, who is always in the goal area, and two defenders, who are located only in their own half of the field and react to how the ball moves on the field. One attacking robot (forward) plays in the enemy's half of the field and scores goals. There is also an assistant forward, who must, in the event of a rebound by the enemy goalkeeper, take possession of it and pass it to the main player.
- The second tactic is the opposite in principle to the above-mentioned first. It has no protective component, except for the goalkeeper and midfielder. This scheme of the game does not involve long-distance strikes, instead the whole game is concentrated in the center of the field. The three players involved in the attack move the ball directly to the enemy's goal. Despite the different approach to the game, this tactic is quite successful, as the ratio of goals scored / conceded by the results of the RoboCup 2017 competition between B-Human and Nao-team HTWK is 28 goals scored and 5 conceded.

In parallel with the main game of football, in this league are practiced, the so-called mixed teams, i.e. teams that are formed from other members of the cup. This type of game was introduced to develop mechanisms of interaction between robots from different teams, as players have different code bases and approaches to the game. For this type of competition, it is necessary to create special mechanisms of team interaction and tactics, respectively. For example, for a mixed team of B-Human and HUKs, the following tactics were developed based on the elements described above, but with some changes [8].

To synchronize the robots in the field, roles corresponding to the names on the chessboard were introduced. King is a goalkeeper who defends the goal and plays only in a limited sector, respectively. Rooks are two defenders who move horizontally on the field, and their main task is to prevent opponents from scoring. Queen - a robot that plays in the center of the field and plays the lead role. Knight is a player who stays close to the main robot (Queen) in defensive mode and provides support in case of loss of the ball. Bishop is a player who is constantly in the sector of the enemy's goal and is in a state of waiting for a pass to perform a shot and is also an interceptor in the event of a ball ricochet.

Research in this league focuses on the problems of perception with limited resources and unstable data, as well as on fast and reliable walking algorithms. To ensure the process of confrontation of teams in the league also use the above-mentioned basic tactics of interaction of players in the team.

Although this league specializes in the development of software and control algorithms for humanoid robots, the elements of team interaction are at a fairly high level. At the moment, the implementation of more complex game tactics is limited by the physical capabilities of agents. In the future, group dynamics developments from other divisions, such as Simulation League, may be implemented.

Small-Size League (SSL) is a semi-autonomous football work with a diameter of 18 cm and a height of 15 cm. Players are tracked by a global surveillance system, which is located above the field. The information processed by the standardized vision system is sent to both teams, where the decision-making process takes place on third-party computers. In 2010, a standard SSL vision system was introduced, but previously each team used its own cameras and surveillance systems. Over the years, the size of the field has also steadily increased from 3.4x4.9 m in 2006 to 6x9 m today. Despite the assumption that SSL competitions make few useful discoveries, they still operate for 20 years. Due to the small mass of robots and remote computers that work remotely, the game is highly dynamic. The robots show impressive proceeding thanks to looping shots and joint play, which make SSL matches always spectacular [9].

Picture 2. – Small-Size league [10]

The tactics of the game in this league involve two main roles of robots on the field - the goalkeeper and the regular player. The main task of the goalkeeper is to repel the balls that fall into the plane of the goal. The movement of the goalkeeper is carried out along the gate in a straight line. If the predicted trajectory of the ball crosses the goal, the robot moves to the point of their intersection, and otherwise - is opposite the center of the goal. To move to the point where the ball is likely to cross the goal plane, a point motion algorithm with a proportional-differential controller is used. The state of the game, which takes into account the position of the robot, the ball and the target position, is important for the attacking player's algorithm. There may be 4 such states. According to a certain state, the actions of the robot are defined.

State 1: The robot is at a distance from the ball, which is determined by a constant. In this situation, the robot moves to the ball, using the algorithm to move to a given point, until it approaches a sufficient distance. The robot does not come close to the ball to prevent contact during aiming.

State 2: The robot is not in the first position and the ball is not on the same line between the goal and the robot. In this case, the algorithm of motion around the point is used.

State 3: The robot is not in state 2, but the ball is on the same line between the robot and the goal. The robot is right next to the ball.

State 4: The robot is in contact with the ball and performs aiming. After aiming the ball, a kick is taken.

Starting from 2018, changes were made to the organization of competitions and two divisions were created: A and B. Division B has traditional rules and parameters (6 robots on a field measuring 9x6 meters). Division A has changed the rules in order to gain more scientific experience in the process of researching tactical algorithms and so on.

Rules of subsection 1. a [11]:

- the automatic referee now independently assigns penalties, and the referee-person only controls appointments and corrects them if necessary;
- robots are completely autonomous, they must place the ball where ordered by the automatic referee (for example, when the ball leaves the field);поле 12x9 метрів;
- number of temas – 8 robots each.

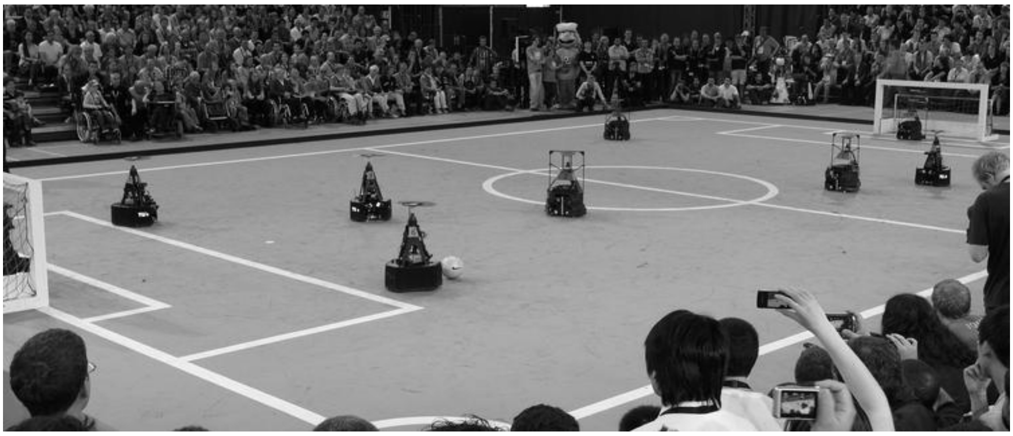
This league is one of the first to appear in RoboCup. Due to the lack of technological development, at the beginning of the existence of the work are not autonomous units, and the whole team is controlled by one computer. The unit, although spectacular in the game, but does not make a significant contribution to the study of robotics, including the development of teamwork.

The Middle-Size League (MSL) is the next league in the first RoboCup. The league has evolved from a robot with slow control on very small football fields surrounded by walls, to football robots with a speed of 4 m/s, capable of leading the ball and accurately pass to a teammate who will score a goal. Today, the field has grown from 3x4 m to 12x18 m. All color coding, on the basis of which the vision of robots worked, has disappeared over the past decade. Instead, in order to establish cooperation between the robots, the last significant improvement was that the robots had to pass the ball to their teammates before crossing the line halfway. Unlike SSL, MSL works completely autonomously, i.e. they have all built-in sensors and computing power. The rules of the game are regulated by the referee box of the automated refereeing system, which can interrupt the match and send the current state of the game to the robots. The human judge also has the opportunity to fine the robots in case of violation of the rules. Although the robots still have wheels, this league is the closest to real football [12].

The development of the league can be divided into 5 periods.

The first period (1997-2001) was a time of formation of the rules of the game, robots, the scientific community. In the beginning, the size of the field was 9x5 m, which was limited by walls, which did not allow the ball to fly out of the game. There was also a special artificial lighting in 300 lux and a special marking of the gate in yellow and blue. In case of game failure, manual relocation of robots was allowed. The size of the team should not exceed 4 players. The main subjects of research were field navigation, computer vision based on color identification of objects and localization. The speed of the robot did not exceed 1 m/s [13].

During the second period (2002-2006) the rules underwent significant changes, namely: the walls located along the perimeter were removed, instead 4 marking columns were installed at the corners; it was not allowed to move robots manually; if the ball was outside the field - the game stopped automatically. At this time, the size of the field increases to 12x8m, with marks for penalty areas and goals. In 2005, automated referee boxing was introduced into the game. Physical components such as the percussion mechanism based on a pneumatic or electromagnetic drive and the displacement system have undergone significant changes. Tactical elements appear for the first time.



Picture 3. – Middle-Size league [14]

The third period (2007) was marked by an increase in the field to 18×12 m, the removal of artificial lighting, marking columns and gates retained colors, but changes led to the need to expand research on dynamically tuned vision systems with real-time coordination system. There are also concepts of dynamically changing the roles of players, planning the path, modeling the game environment, recognizing the opponent.

In the fourth period (2008-2011), the playing field began to look according to FIFA rules - the marking columns were removed, the goal was white, the ball was no longer orange. To improve the efficiency of the ball transfer at each restart of the game, the distance between the ball and the robot should be 1m - an allied player, 2m - an opponent. In 2011, new limits were set: allied player - 2m, opponent - 3m. Currently, the mechanisms of ball handling, multi-work coordination using a set of elementary game schemes, dynamic strategy change during the game, effective modeling tools for dynamic cooperation, arbitrary ball recognition, tracking 3D ball in real life are actively studied time, high-density data synthesis, joint control through goal achievement [13].

In the fifth period (2012-2019), works begin to move quickly (3-4 m/s), using dynamic path planning. This circumstance slowed down the development of cooperation strategies, as the speed of work offset any attempts to implement tactics. To change the situation in 2012, new rules of the game were introduced. The robot could no longer guide the ball through the center of the field from its side of the field to the opponent's side. Instead, the agent had to pass to the player on the team on the opposite side, and it in turn - to hit the enemy goal area. This approach has yielded results. The speed of the robots dropped sharply, but a number of tactics appeared: overlapping the player or overlapping the zone of a possible pass, active interception of the ball, transitions to open zones.

In the current RoboCup Middle Size League, teams have up to 5 units and play according to adapted official FIFA rules. The works weigh up to 40 kg and measure 50x50x80 cm. The playing field fully complies with the rules, except that it is proportionally reduced to 18x12m. In 2014, the rule for passing the ball through the middle of the field was changed to a more general one: “a goal can be scored only after the ball has been received or has been in contact with a teammate within the opponent's field after free movement, at least one meter" [15]. Also, to reduce the dribbling distance of the ball, a rule was introduced that the robot cannot lead the ball more than three meters from the receiving point. Both of these rules promote the development of ball control skills. In order to make progress in playing on regular football fields, RoboCup faces a task in which teams must demonstrate basic football skills on an artificial grass field.

Although the league is closest to RoboCup's ultimate goal, the development of team interaction in the unit is partially hampered by the use of a wheeled agent base. Because the players move dynamically, the introduction of tactical elements is an ineffective solution, due to the ability to quickly cross the robot field to the opponent's goal. To change the situation in favor of increasing the use of group interaction, rules were introduced that forced the use of tactical elements, but did not completely solve the problem. At this stage, the level of development of group interaction remains low.

In the Simulation League (SL), special attention is paid to multi-agent systems and DSS, which are at a fairly high level. Two teams of eleven software agents compete with each other on a simulated football field. When the noise of environmental perception data is simulated for the reality of the game, this league is basically abstracted from the many problems that arise when using real equipment. Software agent developers have the ability to focus on team strategies and the decision-making apparatus. This league has changed little over the last ten years, and still has a large number of participants (in 2015, it was attended by 19 teams). Because the simulator and source code of the winning teams are publicly available, this league is a simple and cost-effective way to start training and research in multi-agent systems [16].

The 3D football league has changed significantly over the last decade. While the first 3D simulations took place in 2006, when players were represented by spheres, today 3D simulations are teams of nine simulated Softbank NAO robots competing with each other. The league developed mainly from an agent approach to modeling, where the embodiments and complexity of humanoid robots, as well as the third dimension of the environment, are important.

To implement the game in this league, the central server simulates a two-dimensional virtual field in real time. The two teams, completely independent of the mobile players, are connected to the above server via a Sokect connection. The game takes place within the rules

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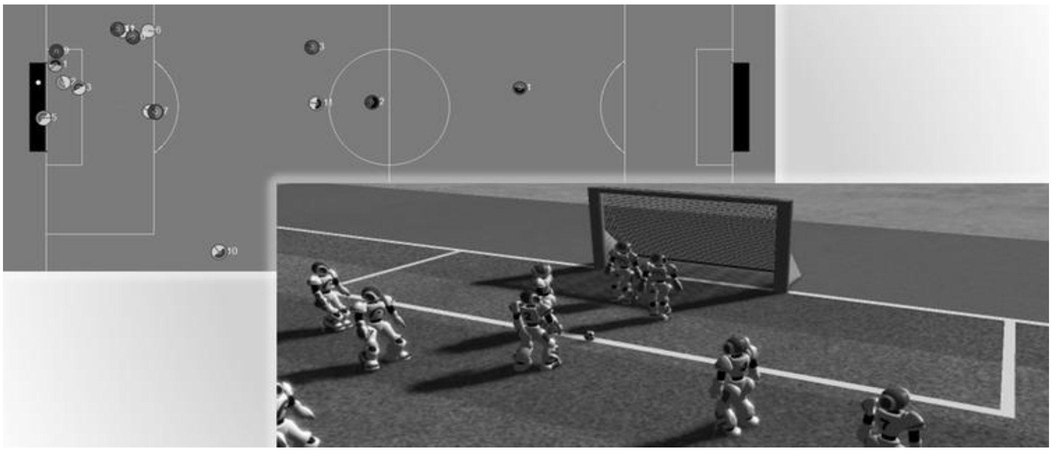
of real football. Each team includes 12 players: 10 outfielders, one goalkeeper and a coach. During the game, each game agent receives from the central server data on the current state of the game (physical, visual and acoustic). This information is processed by the agent and a model of the game world of the current state is formed by the corresponding software module of the robot. According to the situation, the agent sends his reaction. Each robot can operate 10 times per second. One such interaction with a game server is called a "loop". Visual information is sent an average of 6-7 times per second. During a standard ten-minute game, the agent receives visual information approximately 4,000 times and is able to respond 6,000 times [18].



Picture 4. – Simulation league[17]

Analyzing the situation on the playing field, the agent responds according to the following algorithm:

1) Assessment of the subjective state of the game according to the game model;
2) Execution of global action in accordance with the strategic algorithm;
3) Generation of a primitive command for the physical body (movement in a certain direction with a given force, rotation of the body by a certain number of degrees, hitting the ball at a given angle and force).

The central server delivers information with some noise, i.e. the data has inaccuracies related to the distance and angle to other players. This distortion of the data creates little difference between the actual state of the game and the data received by the robots.

The main task of 2D football is to find the best solution at the moment from all possible states of the environment, to obtain information from sensors and to build an accurate model as accurate and undistorted as possible. Each agent builds his own subjective model of the world and determines the optimal response to influence the game situation. You can define a set of states and a set of reactions.

A set of states is a sequence of information about the state of the playing field and the situation on it. The set includes the positions of opposing players, allied agents, ball placement, physical parameters of the game, visual information, etc. This data is formed in the form of a fixed length vector, which includes variables that fully reflect the state of 22 objects (10 teammates, 11 opponents and the agent himself).

A set of possible actions are operations that an agent can perform, such as hitting a ball, passing, dribbling the ball, positioning, intercepting, blocking, capturing, marking, forming. The first three actions (kicking the ball, passing, dribbling) are attacking, the other four (blocking, capturing, marking, formation) are defensive, while the middle two actions (positioning, interception) can be used as an attack and in defense for players who do not own the ball. The actions are defined as follows [18]:

- kick – hit the plane of the gate;
- pass - a blow to a teammate;
- dribbling - driving the ball in front with periodic contact or periodic jumping in the right direction;
- positioning - being in a place favorable for attack or interception of the ball;
- interception - possession of the ball in the fastest way;
- blocking - preventing the opponent who owns the ball to perform any action;
- possession - actions aimed at preventing the ball or taking;
- marking - blocking a specific enemy player in order to prevent the transfer of a pass to him;
- formation - the location of players on the field to protect.

In a 2D football league, the main issues to be solved are the environmental information that is passed on to each agent and is relative and noisy, as well as the vector of each player's position, which is unpredictable due to the constant actions of agents during the game.

Since the main purpose of this division of competition is to study the methods of group interaction, abstracting from the physical problems of agents, the level of development of interaction between team units is the highest among other leagues. The unit is the easiest and cheapest way to start research in this area. Scientists have developed and applied a large number of approaches, such as Hard-coding, Layered learning, Reinforcement learning, Artificial neural networks and others.

Humanoid League. The league is working to achieve the ultimate goal of RoboCup - to defeat the FIFA World Cup. In this unit, teams of humanoid robots play football on a field measuring 9x6 m. It is allowed to use robots of three sizes: KidSize, TeenSize and AdultSize. The leagues have achieved impressive success. If in the first years agents could only take penalties, now players can run the ball across the field and make a shot. Several teams of engineers have developed standardized robots that can be used by other teams. Although the league benefits greatly from the huge advances in the miniaturization of sensors, computers, and battery and materials technology, creating a competitive humanoid robot still remains a challenge [19].

It is the youngest division of the cup competition, which was founded in 2002. In general, the development of Humanoid League can be divided into 4 periods of development.

 ISSN 1560-8956

In the first, the main task for the robots was to balance on one leg and kick the ball. At the next stage, electronics, body mechanics, and environmental perception systems were improved to bring robots closer to the capabilities of the human body. The third period was marked by the creation of group interaction of players on the field. Because before this competition was not held like a classic football game, but there were only penalties, balancing on the leg, cross around the field. During this period, teams of 2 and then 3 players begin to form. The last stage of robot improvement was the development of commercial platforms, which made it possible to reduce the threshold for entering the competition. These platforms basically have the functions of walking and hitting the ball. Additional skills for team competitions are refined personally.

Picture 5. – Humanoid league [20]

The first period (2002-2004) was marked by the establishment of the league and the creation of the first humanoid robots. The starting competition took place in Fukuoka, Japan. Back then, the platforms just created by Japanese industry cost a lot of money. The first samples were not available to research institutes and students due to their cost and maintenance costs. The IEEE Spectrum article notes that the price was up to $ 150,000. Such samples were not able to act autonomously. All elements of calculation, power, perception of the environment were placed outside the body of the robot. Management was carried out remotely. The sizes varied from 20 to 180 cm [21].

The first competition consisted of three tasks: balancing on one leg, free demonstration, kicking the ball (penalty). To stimulate the development of their own robots, teams that used commercial platforms were fined 20%. Thus, every year the capabilities of robots improved and the variety increased. In 2004, the platforms became completely autonomous. The task of balancing on one leg was replaced by walking around the playground. Tasks for passing the belt and balancing on an inclined plane were also added. The results of the competition were summarized according to criteria such as reliability, walking technique, ball control and overall performance. At the same time, it became clear that such an evaluation scheme for robots of different sizes is impossible. In the same year, changes were made to the structure of the league, which divided the robots into three groups: H-40, H-80, H-120, which indicated the size in centimeters, respectively.

In the second period (2005-2007) the competition of robots up to 60 cm (KidSize) was accepted as the main one. Initially, the humanoid type of robot was considered primarily as a problem of kinematics and motion on two limbs. Sight and orientation in space were not yet required by the rules of the competition. The VStone team, which created the first robot that moved freely and had a 360-degree vision system, was very successful in this unit. This sample has won several competitions in a row. Humanoid TeenSize continued to take the penalty shootout, which was later transformed into an extended task with elements of catching the ball and hitting the plane of the goal. The ball was randomly placed in front of the goal in advance. The task of the robot was to cover the distance from the opposite end of the field to the ball, to determine the ball on the field, to capture it, to lead it to the point of impact and finally to execute the blow.

Another innovation during this period was the abolition of free demonstration of robot skills. Instead, the tasks took into account the number of goals scored and the time during which the exercise was performed. It is also forbidden to use sensory sensors that have no analogues in the human body (omni-vision, LI-DAR, ultrasonic sensor, IR-sensor, etc.). The rapid development of robots has complicated the competition. At this stage, new rules were introduced, such as walking on an uneven surface, a double pass, bypassing the ball with several obstacles.

The third period (2008-2011) was marked by the establishment of team tactics. Most teams before 2008 successfully developed the mechanics of walking, balancing on one leg, walking on different structures. The main attention was paid to the localization of work in the field and environmental perception systems. Also, with the increase in the number of team members from 2 to 3, it became important to implement the interaction of robots in the field. The TimbRo University of Bonn and the Darmstadt Dribblers of the Technical University of Darmstadt have made significant progress in this area, winning several times.

With the development of power and coordination systems in space, team fights became possible, as a division of robots weighing more than 40 kg, which were vulnerable to falls and injuries, continued to compete in the form of exercises. However, KidSize players up to 120 cm in size have already been able to compete in teams. As the change of rules was aimed at the development of systems of perception and orientation in space, columns and lines for marking boundaries were removed on the playing field. Also, artificial lighting was changed in favor of natural, the size of the field was increased, the game gate became more in line with analogues according to standard rules.

The introduction of tactics in this league was not intended to improve group dynamics, but only to make team play possible, because so far the work has been demonstrated individually. The whole task, which consisted of tactical abilities, was to identify opponents and allied players. This improvement made it possible to perform such an exercise as passing the belt.

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In the fourth period (2012-2019) corporate platforms are developing rapidly. Companies such as Robotics and Virginia Tech, in collaboration with the University of Bonn and others, are developing robots with basic skills that can be used as a basis for RoboCup teams.

Instead of developing their own robot from scratch, teams have the opportunity to gain platforms that have basic skills such as walking, kicking the ball and climbing after a fall. Unlike the Standart Platform League, which uses a standard type of platform, the Humanoid League must be individualized by participating teams. In parallel with the use of corporate platforms, many teams develop their own design solutions that improve individual skills.

In 2013, the judges' committee made some changes to the rules. The gate changes color to yellow and marks for orientation on the field are removed. These innovations complicated the orientation and localization in the field. The size of the KidSize division has also changed by 50%. Now works of this class could reach a height of up to 90 cm [22].

This league did not make significant contributions to the development of team interaction, as it focuses on improving the physical skills of robots.

Rescue Robot Leagues. The Rescue Robot League (RRL) is developing agents to help those who take action to deal with the aftermath of a natural disaster. Such conditions include an earthquake or an accident in an industrial environment. The goal is to keep a person out of danger areas by providing the same intelligence and manipulation skills in these circumstances. The skills required by these robots are very different from robot soccer players. The former require advanced mobility skills to be able to move in an unstructured environment, such as a destroyed building or a chemically contaminated object. Important sensors and algorithms for mapping the environment and detecting signs of potential victim life are also needed to obtain information at a distance from the disaster site. Moreover, since only one supervisor is allowed in the competition, it is important to have multi-tasking controls, especially if the control is performed by several such jobs. Unlike football leagues, RRL allows both stand-alone and remote-controlled work. Over the years, complex manipulations have been added, such as the ability to deal with natural disasters to clear the area of debris, inspect enclosed spaces or close the valves of certain mechanisms. In addition, the league significantly contributed to the development of automatic mapping, which led to the creation of standard mapping tools. The transition from 2D to 3D mapping is underway. Recently, the league has reorganized its competition scheme from conditions that are fully focused on the task itself - to conditions that are more focused on performing various manipulations. This type of competition has been designed to improve the accuracy of the assessment of individual robot capabilities. Based on the general trend of the competition, the league began to develop tasks for drones and scenarios in the open air.

In the future, it is expected to create a new format of competition, which will allow group performance of tasks. Currently, the league does not deal with problems of team interaction. All demonstrations are held individually [23].

Picture 6. – Rescue Robot league [24]

Rescue Virtual Robot Leagues. The virtual rescue league uses high-quality simulation of the crash site, including destroyed and burning buildings. In addition, all the skills of the robots involved in the virtual competition, such as sounding and moving, are modeled fairly accurately. The advantage of this league is that large-scale scenarios can be reproduced realistically, as well as deploy several homogeneous and heterogeneous robots. Although no real equipment is involved, problems such as perception, mapping, self-localization, or path planning are similar to real league. Due to the larger number of robots and the larger scenario, agents need to work together to eliminate the disaster in time.

The rescue competition is reminiscent of a large-scale disaster, let us say, an earthquake in the city. Unlike the real league, the details of virtual robots are more abstract. The unit uses different types of agents, such as robots belonging to the ambulance crew, fire brigade or police. Agents of different groups have different skills: a police robot can clear a blocked road; fire brigade agent - extinguish the fire. The main task of the league is to coordinate the actions of various agents and to minimize damage to the environment and civilians. In addition to interesting research tasks in the field of multi-agent planning, the key issue is to work with limited and uncertain information. Because agents have only local and inaccurate perceptions, and communication is limited, it is difficult to get a quick, consistent and global view of the disaster [25].

This league is a tool for modeling a group interaction, the experience of which can be used on real sites Rescue Robot Leagues, RoboCup @ Home and RoboCup industrial leagues. There is also an opportunity to explore alternative methods of agent interaction as opposed to playing football in RoboCup Soccer.

RoboCup@Home. In 2006, the first RoboCup @ Home competition was held. This is a competition, the main purpose of which is to develop service robots. Personal service work should be a helper in household chores, from finding lost items to mixing drinks and cooking or helping to buy groceries. One of the main factors in the development of the league is the development (close to the product) of finished robots. There are various complex tasks of robotics: from localization, object recognition and language to mobile manipulations, which must have robots. The complexity of the tests gradually changes from year to year. If most teams were able to perform a certain test in one competition, then next year this task will be more difficult. Over the years, a wide variety of robots have been developed. This allowed the league to create a fairly large set of solutions, but also slowed down the development of the league because in this case it is more difficult to design standard modules. In 2016, the league decided to introduce two standard service robots (Softbank, Toyota), as in the standard football league [26].

This division does not study group interaction. At present, there is only the prospect of future implementation.

Picture 7. – RoboCup home [27]

RoboCup industrial. In recent years, competitions in the Logistics League (RCIL) and the RoboCup @ Work demonstration league have been held under the general RoboCupIndustrial league. The idea is to solve problems related to production scenarios that use mobile work. In RCIL, teams of mobile robots must control the material flow in production, providing machines with raw materials and supplying the final product to implement production plans and orders that arrive dynamically during the game. In addition to the safe navigation of a group of robots, the tasks also include planning and scheduling individual production tasks. The focus of the RoboCup @ Work league section is on complex tasks in the field of mobile manipulation. The main goal is to create a mobile robot equipped with a manipulator that can assemble parts [28].

This division does not study group interaction.

Each league has its own characteristics and adapted to its local task strategy of interaction of agents where possible. In some departments, such as RoboCup industrial, the tactics of cooperation are not implemented due to the lack of a team as a whole. For RoboCup Rescue team interaction algorithms have a different specificity in contrast to RoboCup Soccer, because the task and type of competition are intended to coordinate rescue actions, not games. Features, as well as the presence of logic for the interaction of robots are described in table 1.

Table 1

Features of the divisions of the tournament "RoboCup”

Division	**Platfo rm***	**Contr ol type** **	**Type of competition**	**Competi tion method** ***	**Availability of group interaction**	**Obtaining environmental data** ****	**The main goal of the league**
RoboCup Standard Platform League	H	A	Football	R	+	I	Development of software and control algorithms for humanoid robots.
RoboCup Small Size League	W	SA	Football	R	+	I	Development of algorithms for interaction and control of intelligent multi-robots / agents in a highly dynamic environment with a hybrid centralized / distributed system.
RoboCup Middle Size League	W	A	Football	R	+	I	Design, control and interaction of several agents at the level of mode of action and perception.
RoboCup Simulation League	H	A	Football	C	+	C	Development of artificial intelligence and team strategy.
Humanoid League	H	A	Football	R	-	I	Miniaturization of sensors, computers and the development of battery technology and materials.
RoboCup Rescue	W/C	C	Crossing the obstacle line / performing a rescue task	R/C	+	I	Development of rescue robots in general.
RoboCup industrial	W/H/C /M	C/A	Execution of tasks of production process and logistics	R/C	-	I	Development of industrial robots in general.
RoboCup @Home	W/H/ M	C/A	Performing household tasks	R	-	I	Development of robots for household tasks.

* H - humanoid, C - caterpillar, W - wheel, M - mixed;

** C - controlled, A - autonomous, SA - semi-autonomous;

*** R – real, S - simulated;

**** C - centralized, I - individually;

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Conclusion

During the 24 years of RoboCup's existence, steps have been taken both in hardware development and in creating team tactics. In general, two areas of competition have developed: robot soccer and competitions in applied areas such as rescue, industrial and domestic.

Divisions such as RoboCupHome, RoboCup industrial, RoboCupRescue and Humanoid league do not currently use group dynamics elements on test sites. The exception is the RoboCupRescue simulation league, where the simulated environment uses robot synchronization to perform a common task.

The RoboCup Soccer tournament has two main types of team interaction - centralized (where all control is performed by one computer) and individualistic, as a group of individual agents. The first centralized type means team control as a single artificial intelligence. With the help of this scheme the first competitions of robot teams were realized. This type has no scientific value because it is not a model of group control. The second scheme envisages the interaction of the team as a group of independent artificial intelligences, which currently has the resources to improve. There are also two types of data agents receiving. Centralized data acquisition through a central server is used in the Simulation league, because the work in this unit focuses on the algorithms of group dynamics and it is believed that the robot can monitor the situation at the level of the human player. Leagues where there is a real hardware component use individual acquisition of environmental data through robot sensors. This scheme is adopted to improve the hardware component of environmental analysis, but imposes limitations in the form of lack of complete information about the environment for decision-making.

Analyzing the current areas of robotics in the framework of RoboCup, we can say that the greatest success in the study of group interaction was achieved by Simulation league [29]. However, there are a number of imperfections of the algorithms, namely the presence of only local elements of tactics, such as overlapping the opponent to prevent the return of the pass, passing the pass closer to the gate to the allied player, and so on. It can also be added that there are no such elements of strategy as planning according to the state of the game (transition from attack to defense of the whole team), calculation of several steps forward probable positions of players, separation of individual "special" players. Today, the competitions "Drop-in player challenge" in the Standart league are actively used, which are completely absent in the Simulation league. A similar principle of assigning roles to a team of 11 players in a centralized data acquisition scheme has the potential to increase the number of victories.

Further research requires a more detailed analysis of team interaction algorithms and their combinations, especially the winning teams. A significant "obstacle" to the analysis is the rapid development of computing power, which can significantly increase the efficiency of real-time algorithms. Therefore, algorithms that were previously rejected, with the growth of capacity can provide a qualitative leap in efficiency.

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