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Proposing Robotics Challenge Centered on Material Transportation in Smart Manufacturing

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Abstract—Educational robotics has emerged as a pedagogical tool, utilizing technological artifacts to engage students' curiosity and interest. It fosters active learning of STEM education competencies while also cultivating essential behavioral skills. Robotic competitions provide students with platforms to collaboratively devise diverse solutions to shared problems, fostering experience exchange, collaboration, and personal growth. Despite the prevalence of current robotic competitions, especially in Brazil, simulating real-world challenges like natural disasters, there is a notable absence of industry-related tasks. This article presents an educational robotics initiative centered around material transportation within smart manufacturing using automated guided vehicles. The proposed robotics challenge was executed in a competition held in Açailândia city, Maranhão, Brazil, yielding satisfactory results and inspiring teams to develop time-limited solution strategies.

Keywords—Educational robotics, STEM education, robotic competitions, material transportation, smart manufacturing.

I. Introduction

THE educational robotics (ER) constitutes a dynamic research domain with the primary aim of fostering active learning. This is achieved by involving learners with artifacts to create, implement, enhance, and validate pedagogical activities, tools, and technologies. A key factor in this endeavor is the creation of an engaging learning environment that captures learners' interest and curiosity [1].

According to [2], ER finds its application within school environments, particularly in subjects that characterize robotics, such as computing, engineering, and technology [3], [4], as well as in science and mathematics [5], [6], or in the intersection of technological and scientific/mathematical knowledge [7], [8]. These diverse contexts highlight the versatile nature of ER, which empowers educators to develop STEM (Science, Technology, Engineering, and Mathematics) activities. The past decade has witnessed a significant surge in scientific publications in this field [9], yet it remains rife with unanswered questions [10].

Beyond fostering STEM-related skills, ER serves as a conduit to nurture behavioral competencies, commonly referred to as soft skills [11]. These attributes encompass an individual's behavioral, mental, emotional, and social capacities, which are honed through experiences, education, and cultural influences [12].

As a potent mechanism for engaging learners in active learning, robotics competitions have evolved into platforms where diverse teams converge to showcase distinct solutions to common challenges. This approach fosters the exchange of experiences, collaboration, and personal growth. Such environments captivate the interests of students [13], [14], and equally engage the mentoring educators [15].

Various authors delineate the competences nurtured within robotics competition environments, including teamwork and constructive interactions among competitors [16]–[18]. These environments facilitate learning through hands-on tasks and practical exercises [19], build resilience and the capacity to navigate frustrations [20], and cultivate skills relevant to the contemporary era [21], [22].

In [20], prominent global competitions in the field are delineated, including the First LEGO League and RoboCup, alongside regional events like the Youth Robotics Tournament and the Brazilian Robotics Olympiad. Typically, the challenges presented in these contests fall under the rescue category, simulating real-world problems such as natural disasters. However, despite these developments, the industry-relevant challenges remain notably absent. To bridge this gap, we propose a robotics challenge centered around the problem of automated guided vehicle-based material transportation. This robotics challenge was executed at an event held in Açailândia city, Maranhão State, Brazil, in 2021.

This article is organized as follows: Section II provides a conceptual framework for Automated Guided Vehicles and their classifications; Section III outlines the rules governing the proposed challenge; Section IV showcases the outcomes derived from implementing this challenge at a regional robotics event; and the concluding remarks of this study are presented in Section V.

II. Automated Guided Vehicles

Automated Guided Vehicles (AGVs), often referred to as flexible and intelligent robots [23], possess the capability to navigate environments autonomously, requiring no external intervention [24]. This autonomy underscores their operational independence. AGVs have emerged as effective alternatives to stationary conveyor belts, streamlining the movement of goods across various stages of production [25].

In the realm of intralogistics today, AGVs have solidified their role as essential components within the framework of intelligent handling and versatile material transportation in Flexible Manufacturing Systems (FMS). This is primarily due to their inherent attributes of flexibility and adaptability [26], [27]. The rapid evolution of AGV technology can be attributed to advancements in sensory and control devices, as well as microelectronics [28].

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(a) Towing vehicle

(b) Unit load vehicle

(c) Pallet truck

(d) Forklift

Fig. 1 Types of AGVs

When selecting an appropriate AGV, the foremost consideration is identifying the task it needs to accomplish. Accordingly, these robots can be categorized into the following types [25]:

- Towing vehicle, depicted in Fig. 1a, is designed to haul loads to designated destinations;
- Unit load vehicle, illustrated in Fig. 1b, is equipped with loading platform for tasks involving loading, unloading, and item transport;
- Pallet truck, shown in Fig. 1c, resembling manual pallet jacks, is designed for lifting and moving loads autonomously;
- Forklift, as seen in Fig. 1d, akin to manual forklift, possesses the ability to elevate loads to higher levels through automated systems.

AGVs find application within FMS with the primary objective of enhancing cost and time efficiency in production processes [29]. They are equipped with centralized controllers responsible for decision-making tasks such as determining the optimal routes to destinations, executing material transportation, and facilitating subsequent unloading actions [26].

The attributes of route planning, material transportation, and unloading have emerged as pivotal aspects in the development of the proposed robotics challenge. The following section will offer a comprehensive overview of the competition's particulars.

III. Proposed Robotics Challenge

The inception of this project was driven by the ambition to formulate a challenge for the FIRA Brazil Maranhão Regional event. This event was held at the Federal Institute of Education, Science, and Technology of Maranhão in the city of Açailândia on October 29th and 30th, 2021.

The Federation of International Robot-soccer Association (FIRA) stands as one of the oldest and most prominent robotics competitions globally, originating in 1996 with a focus on robot soccer. This competition holds the distinction of being the world's oldest of its kind, and it continues to maintain its significance in the realm of robotics. FIRA Brazil, established as a regional chapter in 2019, serves as a localized extension of FIRA. Its primary purpose is to foster a robotics event that qualifies Brazilian teams for an annual participation in the FIRA RoboWorld Cup.

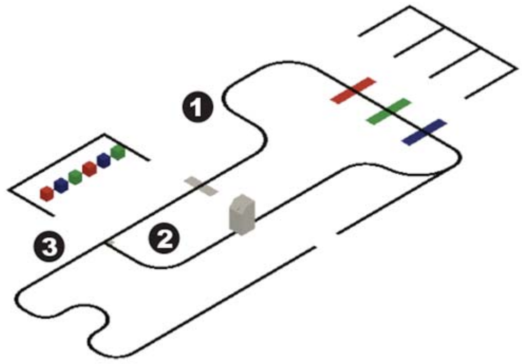

Fig. 2 Proposed arena for the "Mission Impossible" challenge

Within the array of competitions comprising the Youth League of FIRA Brazil, the "Mission Impossible" category unfolds around the concept of a surprise challenge. This challenge is unveiled to participating teams on the event's first day. Teams are then tasked with programming and developing their robots to execute the disclosed mission on the subsequent day. This dynamic draws parallels to hackathons, where teams pool their creative prowess to devise optimal solutions within tight time constraints. Guided by this framework, the challenge was structured to be both practical and achievable. This entailed considering components readily available to the participating teams, in addition to the time constraints inherent to the competition. As a result, the core activities of an AGV were identified. These activities, widely practiced by robotics teams in various challenges, encompass functionalities such as line following, obstacle avoidance, color identification, and material collection. These activities are standard components of robotics training and necessitate commonly used elements such as motors, color sensors, light sensors, and distance sensors. Given that a considerable number of teams employ LEGO robotics kits, the proposed challenge was designed to be attainable using up to four sensors, aligning with the number of input ports on the controller blocks.

In line with these considerations, the arena for the "Mission Impossible" competition was meticulously designed, as depicted in Fig. 2. The challenge is formulated around three pivotal components: the time allocated for execution, the arena configuration, and the scoring methodology. Each of these components will be expounded upon in the subsequent subsections.

A. The Time

Time management plays a pivotal role in this challenge, serving two primary objectives: firstly, to establish the mission execution within a specific timeframe, ensuring the

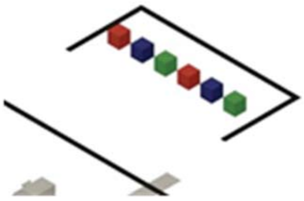

Fig. 3 The loading area

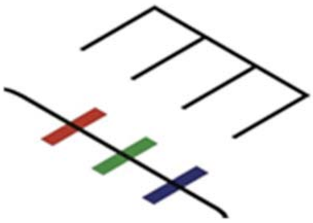

Fig. 4 The delivery area

precise scheduling of the event; secondly, to encourage teams to develop strategic approaches for maximizing point accumulation while working within the constraints of limited time. This dual focus not only hones teams' time management skills but also cultivates their proficiency in allocating time effectively. The designated execution time for the challenge has been established at 5 minutes.

B. The Arena

The arena regions are categorized into three distinct sections: the loading area, the delivery area, and the movement area. The loading area is defined by a rectangular region marked with black lines, forming a 'C' shape. This area comprises six colored cubes symmetrically positioned and spaced at 5 cm intervals, as depicted in Fig. 3. These cubes symbolize the loads, representing products from specific production lines. Each cube is assigned a different color - red, blue, or green - to indicate its type.

The delivery area consists of three compartments, each corresponding to one of the load colors. These compartments are marked with fields aligned with their respective colors and positioned beneath the path that the robot follows. When the robot reaches one of these markers, it transitions into object delivery mode. The delivery space has dimensions of 23 cm in width and 35.3 cm in depth, as shown in Fig. 4.

Furthermore, the movement area encompasses the pathways available for the robot's navigation. This area features three distinct route options, each delineated by lines that the robot must follow. At the start of the competition, the robot is positioned to the right of indicator 1 in Fig. 2 and directed towards the loading area. The robot identifies the loading area through a double gray marking along the path.

At the intersection of paths 2 and 3 in Fig. 2, a silver marker is situated to the left of the movement direction. At this juncture, the robotics team decides whether the robot should take one of two paths: path 2, which involves navigating around an obstacle (depicted as a milk box in the figure); or path 3, which features a winding route with a line gap and reduced points.

TABLE I
SCORE FOR THE TYPE AND CONFIGURATION OF LOADS DELIVERED

Cargo color	Delivery quality	Score
Red	Perfectly	+20
Red	Partially	+10
Blue	Perfectly	+20
Blue	Partially	+10
Green	Perfectly	+30
Green	Partially	+20

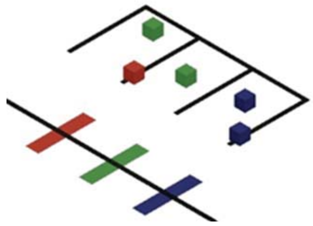

Fig. 5 Example of final delivery configurations

C. The Score

The team's overall score is calculated at the conclusion of each round, considering four factors: the chosen path of the robot, cargo delivery, obstacles overcome, and any manual interventions during robot operation.

The initial factor (path) pertains to cargo delivery, where the robot travels from the loading area to the delivery location. After starting, specific scores are assigned to different paths: retracing path 1 (in the opposite direction) results in a penalty of -10 points; path 2 with an obstacle earns +20 points; and path 3 with winding and a gap rewards +10 points. Each score is determined based on the path's difficulty due to obstacles. These scores are assessed after each cargo delivery round.

The second scoring factor assesses the quality of cargo delivery by evaluating the arrangement of loads at the end of each round. Two delivery scenarios are considered: partially delivered configuration, when the load touches the delivery area, and perfectly delivered configuration, when the load is fully within the delivery area. Scores also vary depending on the color of the cargo, with green loads earning higher points. Table I provides an overview of the scores for each color and delivery configuration.

Fig. 5 illustrates the final arrangements of deliveries, showcasing a partially delivered red load, a perfectly delivered green load, a perfectly delivered blue load, and a partially delivered blue load, culminating in a total score of 70 points.

The third scoring factor involves surmounting obstacles. Points are awarded for each obstacle overcome: the central obstacle (path 2) adds 30 points; the reducers (path 3) contribute 10 points each; and crossing the gap (path 3) earns 10 points. All obstacle scores are calculated during the round and summed only once.

In a real-world scenario, the central obstacle might represent individuals involved in an accident on a factory floor or within a warehouse. Consequently, a penalty of -30 points is applied if the robot collides with this obstacle.

Fig. 6 Team conducting tests before the competition

Another penalty is also applicable, constituting the fourth scoring factor, relating to team interference by physically touching the robot to restart the mission. Interference penalties are as follows: one interference incurs a penalty of -5 points; two interferences result in a -10 point deduction; three interferences lead to a -20 point deduction; four interferences carry a penalty of -30 points; and five interferences result in a deduction of -45 points.

All scores have been assigned after considering the difficulty of each associated task. Variable scores for different scenarios create a range of strategic possibilities for accomplishing the mission, necessitating teams to engage in critical and creative evaluation.

The graphic layout of the arena can be accessed through Robotics Challenge Arena: http://dx.doi.org/10.13140/RG.2.2.23215.92327. The next section will present the results obtained from implementing the challenge in a robotics event.

IV. Results and Discussion

On the first day of the event, we furnished registered teams from diverse locations and institutions across Maranhão, Brazil, with a comprehensive guide outlining the challenge's rules and intricacies. This material, available in Portuguese, can be accessed at Mission Impossible Challenge Guide: http://dx.doi.org/10.13140/RG.2.2.36637.69600. Simultaneously, the competition arena was introduced, offering teams the opportunity to run tests and formulate effective problem-solving strategies, as depicted in Fig. 6.

Each participating team engaged in two rounds, and the higher score between these rounds was considered as their final score. The confines of the competition arena were limited to a space accessible to a single team member. As seen in Fig. 7, a team member is shown positioning their robot at the challenge's starting point.

Fig. 8 showcases the round results for each team. To maintain team anonymity, names such as "Equipe 1," "Equipe 2," and so on, were substituted based on the final event ranking. Notably, "Equipe 1" and "Equipe 2" both achieved 80 points in their best rounds. However, "Equipe 1" secured a higher score in Round 2, while "Equipe 2" chose not to participate, leading to the former emerging as the champion and the latter as the runner-up of the competition.

Fig. 7 Competitor positioning his robot to start the challenge

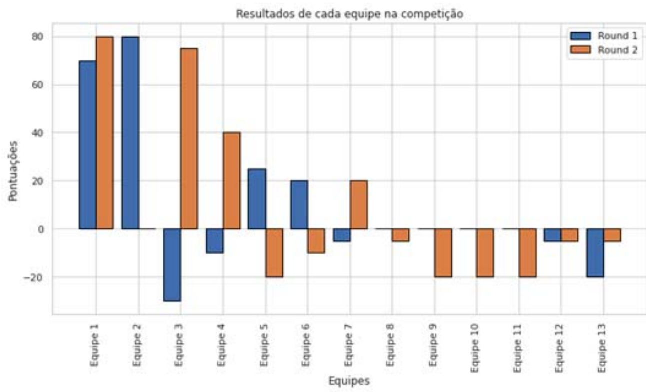

Fig. 8 Graph with the scores achieved by each team

The same Fig. 8 graph reveals a significant number of negative scores across rounds, attributed to teams' inexperience with time-constrained challenge formats. Furthermore, the 2021 Maranhão event marked the inaugural state edition of FIRA Brazil.

Table II presents statistical measurements for each round, including minimums and maximums, means, standard deviations, 1st and 3rd quartiles, and medians. In Round 1, the median indicates that half of the teams scored zero or below, while 75% managed up to 20 points. The champion team secured 80 points, while the lowest recorded score was -30 points. Interestingly, the standard deviation was 3.36 times larger than the mean of all teams' scores, highlighting performance discrepancies among them.

In Round 2, half the teams achieved -5 points or lower. The third quartile and maximum score mirrored those of Round 1. The lowest score recorded was -20 points. Notably, the standard deviation in this round was 4.16 times greater than the score mean, indicating even greater variability in scores among teams. These results can be attributed to specific challenges encountered during training and round execution. Examples include sensor calibration under varying ambient light conditions and variations in object color readings.

TABLE II
STATISTICAL DATA OF THE RESULTS ACHIEVED BY THE TEAMS IN THE TWO ROUNDS

Round	A	B	C	D	E	F	G
1	-30.0	80.0	9.615	32.37	-5.0	20.0	0.0
2	-20.0	80.0	8.462	35.20	-20.0	20.0	-5.0

A - Minimum
B - Maximum
C - Means
D - Standard Deviation
E - 1st Quartile
F - 3rd Quartile
G - Median

V. CONCLUSION

To evaluate the effectiveness and success of the proposed robotics challenge, in addition to quantitatively assessing individual team results, a qualitative examination of executed or intended strategies is essential. This analysis reveals the diverse strategies employed by teams to resolve the tasks. Significantly, certain teams identified rule prohibitions, penalties, and opportunities, devising procedures that resulted in high scores, expanding beyond the initial challenge scope.

Of the various strategies adopted, the approach employed by the champion team, "Equipe 1," stands out. They chose to collect multiple loads and deliver them concurrently. Despite being a slower approach, this method allowed the robot to accumulate more points by navigating the delivery path just once, thereby minimizing the chances of errors during this critical phase.

The presence of low and even negative scores is an unfavorable aspect of the proposed robotics challenge, exposing task execution or integration challenges faced by teams. It is advisable to thoroughly examine the root causes, as discussed in the results section, and reevaluate the challenge's difficulty level in light of the participating teams' real-world constraints.

Conversely, the proposed robotics challenge and the strategies executed by teams underscore the notion that robotics demands more than just logical reasoning and technical skills like mathematics, electronics, and computing. It necessitates proficient textual reading and interpretation abilities. These competencies aid in visualizing and comprehending objectives, penalties, and opportunities. This reaffirms the high interdisciplinary and multidisciplinary potential of educational robotics as a potent teaching and learning tool.

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