Computational Vision Applied to The Monitoring of Mobile Robots in Educational Robotic Scenarios

Marcel Leite Rios
Research Group in Technology Solutions (GoTec)
Federal Institute of Rondônia (IFRO)
Porto Velho, RO, Brazil
marcel.rios@ifro.edu.br

José Francisco de M. Netto
Institute of Computing (IComp)
Federal University of Amazonas (UFAM)
Manaus, AM, Brazil
jnetto@icomp.ufam.edu.br

Thais Oliveira Almeida
Department of Science Computer
Federal University of Roraima (UFRR)
Boa Vista, RR, Brazil
thais.oliveira@ufrr.br

***Abstract*— A frequent concern among students and teachers working with educational robotics is about the results gathered through practical activities. Currently, educational institutions and robotics competitions lack of mechanisms that can evaluate the robot's behavior during the accomplishment of the proposed challenges. In this work, we propose the development of a technological solution using Computational Vision, whose purpose is to monitor and evaluate the performance of mobile robots during the execution of Robotics Pedagogic tasks. The developed system, named MonitoRE - Monitoring System for Educational Robotics, was tested on three categories of pedagogic robotics environments, obtaining promising results. Our tool uses an Absolute Location Method with descriptors based on color and shape to analyze the task environments, mapping the path taken by the robot, evaluating the achievements in the proposed tasks. The experiments carried out indicate that the adopted method is effective, performing satisfactory results in robotic monitoring. In addition, it was found that teachers and students felt more motivated, demonstrating interest in using monitored task environments, because it ease the understanding of the difficulties faced by the moving robot in completing the activities, assisting students in the teaching-learning process.**

Keywords*— Educational Robotic; Task Environments; Mobile Robotics; Computer Vision.

I. Introduction

Several technologies have been used to make people's routine more and more dynamic. These technologies are also modifying the teaching-learning process of schools and universities [1]. Educational Robotics is one of these technologies that provide the teacher and his students with an innovative study experience in several areas of knowledge [2]. In addition to motivating students and providing teamwork, robotics allows the development of creativity through constructionism, ranging from assembling parts and gears to programming the functionalities of a robot [3].

Educational Robotics is one of these innovative new tools that have drawn the interest of the educational community from kindergarten to universities over the last few years. Educational Robotics is introduced as a powerful and flexible teaching / learning tool, encouraging students to control the behavior of tangible models using specific programming languages (graphical or textual) and actively involving them in problem-solving activities [4].

In this context, there are several ways to develop Educational Robotics projects, one of them is through Mobile Robotics, with the purpose of exploring the most varied knowledge to meet certain challenges and tasks.

One of the great challenges in mobile robotics is the problem of autonomous robotic navigation. In this scenario, knowing the exact location of the robot or estimating its position and trajectory is a primordial task [5].

In this context, this work presents a study on the use of Computer Vision techniques applied to scenarios (task environments) of Educational Robotics, generating a tool to support the teaching-learning process, called: MonitoRE - Monitoring System for Educational Robotics.

II. Past Work

The use of Educational Robotics helps to implement in schools the ideas related to constructionism, where students learn best by acting in practice. Papert emphasizes that designing and building a tangible and personally meaningful object, finding problems, and solving them is the most efficient way to learn powerful ideas [3].

Practical robotic projects increase students' interest and motivation [6]. The Educational Robotics has events in the form of competitions, national and international, aiming to promote knowledge, as well as inform and clarify society about the use of this educational technology.

The projects involving Educational Robotics provide opportunities for students of different ages to apply and use concepts, skills and strategies learned in the classroom to solve real-world problems [7] [8] [9].

In the educational context the mobile robots are widely used because they allow diverse possibilities of action. Mobile robots have a prominent place because they are not restricted to a single place of operation and, because of this, have a much greater applicability and versatility than the manipulator robots, which are more frequent in the factories [10].

However, one of the major challenges for the roboticist community is to make mobile robots perform their tasks efficiently and safely with minimal human interference, that is, they are autonomous [11]. The localization problem is one of the topics most discussed in the study of mobile robotics, and is

978-1-5090-5920-1/17/$31.00 ©2017 IEEE

of fundamental importance for the accomplishment of tasks that involve mobile robots in real environments [12].

As for the navigation of mobile robots, localization methods are used in order to locate the robot in the environment in which it is inserted. These methods allow to calculate not only the position, but also the trajectory traversed by the mobile robot.

In this way, we verified that one of the ways to employ an absolute localization method occurs through Computational View. Then we developed a solution to perform the mapping of the task environment, monitoring the movements of the robot in order to verify if it is meeting the established criteria for the activity.

III. Work Description

This work aimed to analyze an existing need in educational institutions regarding teaching practices through educational robotics. In this way, task environments were established, which were categorized into three difficulty levels, intended for high school students, characterized in order to allow both the mobile robot programmed by the student and the MonitoRE system to obtain their respective parameters for processing.

In this sense, this section describes the general objective of this work and demonstrates the research methodology adopted, presenting the stages of the tasks developed during the scientific research process.

A. General Objective

This work aims to develop and evaluate a technological solution that monitors a trajectory of mobile robots using Computational Vision techniques with the purpose of supporting the evaluation process on task environments no context of Educational Robotics.

B. Research Methodology

In general, this research contemplated a quantitative and qualitative approach. In the quantitative approach statistical data were generated on the accuracy of the technological solution when evaluating the behavior of the mobile robot in a given task environment. Within this approach, the research was performed experimentally, performing certain experiments in robotic scenarios. In addition, the research was carried out empirically, subjecting the mobile robot and the proposed system to situations of trial and error.

In the qualitative approach, teachers 'and students' opinions about the established task environments were obtained, as well as about the technological solution presented in this work. The procedure for collecting data for the opinion survey was carried out using pre-test questionnaires (before the use of the proposed system) and post-test questionnaires (after the use of the proposed system).

The research methodology of this work was organized into four distinct and complementary phases, namely: Conception, Elaboration, Construction and Consolidation, as shown in Table I.

TABLE I. PHASES OF THE RESEARCH METHODOLOGY

Phase	Assignment
Conception	Investigation of the problem: • Systematic Review of Literature; • Knowledge of the State of Art;
Elaboration	Define solution: • Pre-survey questionnaires; • Establish Task Environments; • Specification of the programming language;
Construction	Develop solution: • Establish Criteria and Parameters for System; • Development of the Prototype and Solution;
Consolidation	Evaluate solution • Test solution; • Post-survey Questionnaires;

In the Conception phase, a bibliographic survey was performed on robotic performance evaluation in Educational Robotics scenarios, identifying the works developed with the purpose of verifying the technologies used and results achieved.

In the Elaboration phase, after knowing the state of the art, several algorithms of strategy were studied and tested to find the smallest path in grid maps, seeking to understand the best routes for navigation of mobile robots in completely observable environments.

In the Construction phase, the necessary criteria and parameters for robotic performance evaluation were established, developing a system with Computational Vision, monitoring task environments with three levels of difficulties, automatically assessing the satisfaction of the activity performed by the mobile robot.

Finally, in the Consolidation phase, the prototype was tested and from there, its operation was improved. Experiments and tests have raised the data needed for the quantitative approach. Then, the Post-Test questionnaires subsidized the qualitative approach, raising the opinions of teachers and students who had the experience of using a monitored robotic environment.

IV. Materials and Methods

This section presents the architecture proposed in this work, explaining the configuration of the task environments (robotic scenarios), as well as the modeling and the functionalities of the system.

A. System architecture

The MonitoRE system was developed to create an Interactive Educational Environment, where teachers and students could count on the supervision of a system to support Educational Robotics activities.

The system knows the characteristics of each task environment (robotic challenge scenario), making use of artificial landmarks in the scenarios, which determine the navigability criteria of the mobile robot.

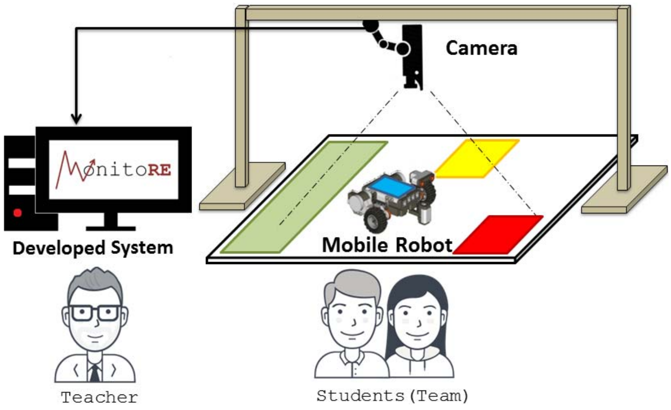

Fig. 1. Proposed System Overview.

In Figure 1 it is possible to observe that the teacher must prepare the task environment in a classroom, using a structure to support a webcam camera that must be fixed vertically to a height of 1.50 cm (one meter and fifty centimeters) of the task environment. The camera, connected to MonitoRE, will capture the images so that the system can process the segmentation and detection of artificial landmarks in the task environment using descriptors based on color and shape. The extraction of these parameters allows the system to trace the trajectory of the mobile robot verifying the satisfaction of the same in the development of the activity.

The task environment is composed of artificial landmarks, including the mobile robot, allowing the MonitoRE system to identify and evaluate the overlap of colors and shapes established in the environment. In this way, teachers and students can use any type of Robotic Educational Kit.

The MonitoRE system was developed with Web Technology, using HTML and CSS to define layout, configuration and organization of the system pages. The construction of the logical part of the system was developed in Python programming language with support of OpenCV Computational Vision library.

B. Task Environments

One of the initiatives of this work was to create task environments that allow the application of evaluation methods that are effective and that collaborate for the presentation of reliable results. In addition, it becomes a primary task to build task environments that challenge students' knowledge as well as to facilitate the analysis of the trajectory of the mobile robot in its navigation missions.

The task environments proposed in this work (measure 120x90 cm) are completely observable and deterministic, because if the sensors of an agent (robot) allow access to the complete state of the environment at each instant, such environment is said to be completely observable and if the next state of the environment is completely determined by the current state and by the action performed by the agent, we say that the environment is deterministic [13].

The configuration of the Task Environment for Level 01 (Checkpoints) is intended for students who are starting their studies through Educational Robotics.

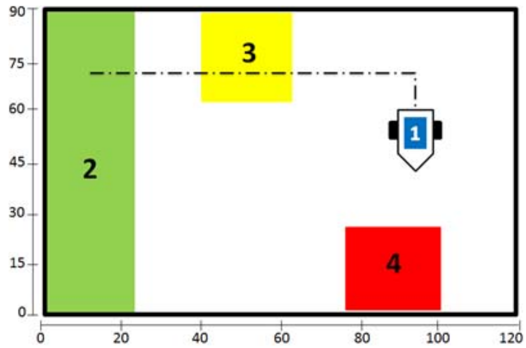

Fig. 2. Task Environment for Level 01 - Checkpoints.

The Figure 2 shows the characteristics of the Task Environment for Level 01 (Checkpoints), where the mobile robot, marked with the blue color (identified in the figure with the number 1), must leave the starting point of green color (identified by number 2) And reach the yellow (identified by number 3), obtaining 25 (twenty five) points, and red (identified by number 4), obtaining a further 25 (twenty five) points and then must return to the beginning (identified by number 2), obtaining another 50 (fifty) points. In this activity the mobile robot, if it meets all criteria, can reach 100 (one hundred) points.

The configuration of the Task Environment for Level 02 (Rescue) aims to challenge the students who are in the intermediate phase of studies in the area of Educational Robotics.

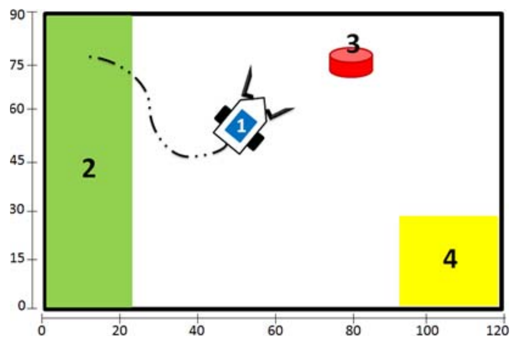

Fig. 3. Task Environment for Level 02 - Rescue.

The Figure 3 shows the characteristics of the Task Environment for Level 02 (Rescue), where an object needs to be rescued and placed in a predetermined location. In this challenge, the mobile robot, marked with the color blue (identified in figure 1), must leave the starting point of green color (identified by number 2) and freely roam the environment in order to find and perform the rescue Of a victim, a stationary cylindrical object of red color (identified by the number 3). Then place it in a safe place, yellow marking (identified by the number 4), getting 50 (fifty) points. Finally, the robot must return to the beginning (identified by the number 2) and obtain a further 50 (fifty) points. The maximum score to be obtained by the mobile robot in this activity is 100 (one hundred) points.

The configuration of the Task Environment for Level 03 (Center of the Earth Trip) aims to challenge students who are studying more advanced aspects in the area of Educational Robotics.

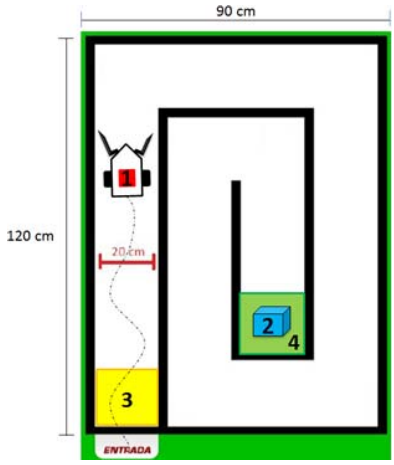

Fig. 4. Task Environment for Level 03 - Center of the Earth Trip.

The Figure 4 shows the characteristics of the Task Environment for Level 03 (Center of the Earth Trip), where the mobile robot, marked with the red color (identified by the number 1), from the yellow entry (identified by the number 3), You must follow the path to the center of the green spiral (identified by the number 4), where you must capture a blue colored object (identified by the number 2). You should then return with the object along the same path to the starting position, fulfilling the challenge.

In this task, the mobile robot gets 50 (fifty) points when it can reach the center of the spiral and another 50 (fifty) points if it can bring the object to the starting point.

The developed system has specific functionalities, built through polynomial algorithms with the purpose of monitoring and analyzing, in real time, the actions of a mobile robot in a given task environment, supporting teacher and students in the activities of Educational Robotics.

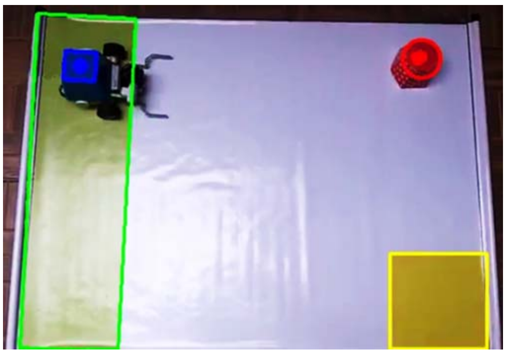

Fig. 5. Demonstration of Mask in Task Environment for Level 02 - Rescue.

The Figure 5 shows the application of the masks on the identified colors for each artificial landmark in the Level 2 Task Environment. The movements of both the square blue mask which identifies the mobile robot and the circular mask in red which identifies the object / victim will be traced through the center point of the respective color. The green rectangular mask on the place of departure / arrival and the yellow square mask on the rescue site are analyzed by the size of their total area.

The system interprets the data obtained through segmentation and binarization of images, where the conditions for analyzing and comparing the overlapping of masks are established, which represent the regions of interest. These parameters are compared with the criteria established for the task environment, measuring the performance of the mobile robot in the accomplishment of the activities.

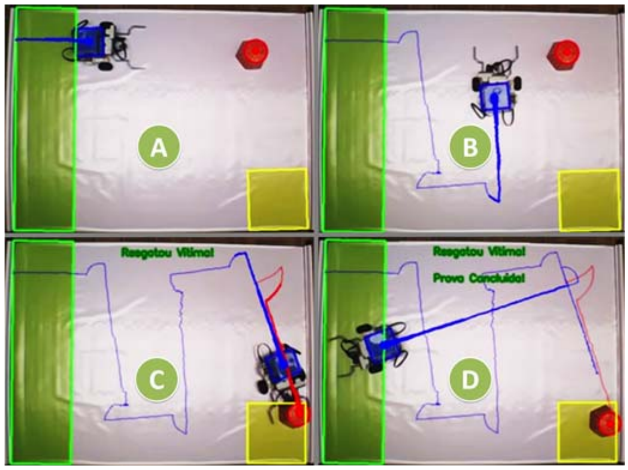

Fig. 6. Action Recognition in the Task Environment for Level 02.

According to Figure 6, in frame A and B, the system monitors the task environment by tracing the trajectory of the mobile robot. In frame C, the system recognizes the victim's rescue (red circular mask) when it reaches the indicated area (yellow square mask). In frame D, the system recognizes the overlap of the mobile robot (blue square mask) on the start and finish area (green rectangular mask), informing that the test has been completed.

V. Results and Discussion

This section presents the results obtained before, during and after the use of the MonitoRE system, evaluating the impact of this technological solution on the robotic educational environment.

A. *Pre-Survey*

In order to identify the profile of future users of the system, as well as raise the needs and expectations for the development of the technological solution, a Pre-Test Questionnaire was developed and applied in a sample of 54 users, involving students and teachers of the informatics course of the Federal Institute of Rondônia (IFRO).

The interviewees were asked about the possibility of having experienced a situation in which their mobile robot was evaluated in a delayed or doubtful way by the judge (referee of the competition). The results showed that 45% of the interviewees did not go through this situation, 35% of the respondents had their robots evaluated in this way and 20% of those interviewed did not experience this situation.

Next, the respondents answered on the factors that they consider decisive to evaluate the level of knowledge of the students in the challenges of educational robotics. On this factors, it was pointed out that 45% of the interviewees considered the task environment decisive in this regard, 40% of respondents considered the structure of the mobile robot decisive in this question and 15% of the interviewees considered the time of travel to carry out the decisive activity in this question.

The interviewees were questioned about the expectations with practice of educational robotics, raising hypotheses about the need to use mechanisms that could support the teacher or the referee by automating the evaluation process of educational robotics tasks.

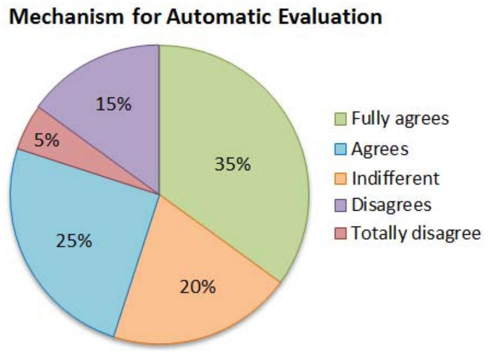

Fig. 7. Graph on Automatic Valuation Mechanism.

As shown in Figure 7, as to the need to create mechanisms to automate the evaluation of tasks with robotics, 35% of respondents fully agree with this statement, 25% of respondents agree partially with this statement, 20% of respondents are indifferent to this statement, 15% of respondents partially disagree with this statement and 5% of respondents disagree completely with this statement.

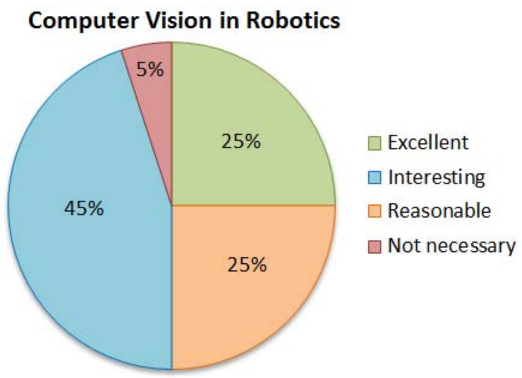

Fig. 8. Graph on the Use of Computer Vision in Robotics.

As shown in figure 8, as to what users would think if a robotics competition had a computer vision system to evaluate the behavior of the mobile robot, 45% of respondents found that the proposal was interesting, 25% of respondents found the proposal to be excellent, 25% of the interviewees found the proposal reasonable and 5% of respondents found the proposal unnecessary.

B. System Accuracy Analysis

After the development of the MonitoRE system, several tests were carried out to evaluate the accuracy of the implemented Computer Vision system.

The metric used to analyze the vision system was the average error rate in relation to the pixel variation during robotic tracking with its respective standard deviation, taking into account the proposed task environments on two conditions: invariant illumination and variant illumination.

The results of the experiments in each task environment, placed in situations of invariant illumination and variant, are presented in Figure 9. This graph demonstrates the standard deviation associated to the variation of existing pixels in the composition of the masks used as a parameter in the vision system.

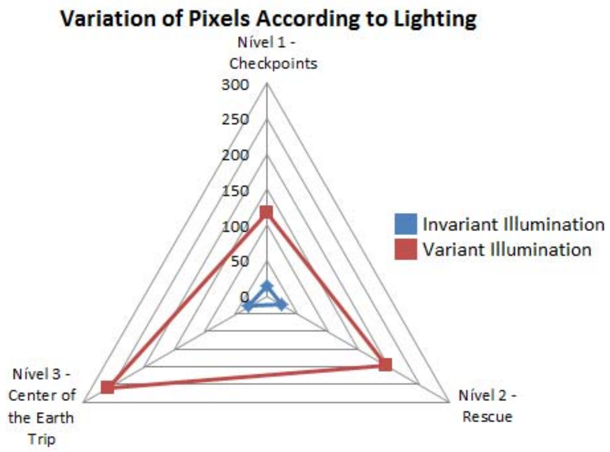

Fig. 9. Graph About Pixel Variation/Dispersion on Image.

As shown in Figure 9, it is possible to observe that the invariant illumination on the task environments allows the system to have an accurate precision, with low error rate and with little oscillation in the standard deviation, where the results were promising. However, when the lighting is variant on the task environments, the system obtained a significant increase in the error rate, due to the variation of the standard deviation values established for the masks, compromising the accuracy of the system to recognize the trajectory developed by the robot mobile.

In this sense, the accuracy of the system depends directly on the definition of the color thresholds and the lighting on the task environment. In order to reduce this dependence, larger threshold intervals were adopted for the colors of the task environments that suffer greater variation with the incidence of luminosity, besides setting environments of tasks with high contrast of colors. In any case, Educational Robotics tasks supervised by the MonitoRE system must take place in a controlled environment, that is, in a classroom or in a laboratory that provides invariant lighting.

C. Post-Survey

The post-survey was conducted to evaluate the opinions of students and instructors on robotic challenges scenarios established and on the automation feasibility assessment robotic performance. Sample of 46 users: 93% said they found interesting and enjoyed the experience, 7% considered normal, 86% said they were satisfied with the usability of the proposed system and the scenarios established, 14% said that the scenarios can be enhanced and customized; 95% considered the correction of the proposed efficient system, however, 5% said that in some correction moments presented failures; 84% reported having obtained a learning return with the proposed system, 16% said they did not add learning. The Figure 10 shows the graph of established post-trial.

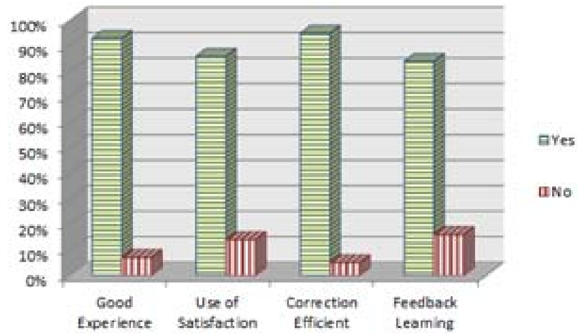

Fig. 10. Graph Survey of Information Obtained with User.

It is interesting to note the considerable change in users after experiencing an environment monitored by computer vision to determine the performance of a mobile robot in the established scenarios.

Each level of robotic scenario seeks to explore different abilities of students to find the solution of the problem, since the installation and configuration of the mobile robot to carry out the process of perception and action on the environment, as well as the development of an effective program for the system computational robot can navigate to the most optimized way possible tasks environment.

The measuring system with image processing makes use of a descriptor based on color to evaluate the robotic behavior, tracing the path traveled by the mobile robot in the established scenarios, presenting to the student and to the evaluator a report with the result of the proposed activity. The bringing of the scenarios and evaluation tool allows you to create an environment conducive to the teaching-learning process in educational robotics.

All users reported feeling greater motivation and interest in educational robotics, considering the practicality of using the tool presented. Its applicability to various scenarios, allows for greater flexibility in setting up and building educational robotics scenarios. This tool can be widely used for teaching, learning and testing robotic concepts in different areas of knowledge.

VI. CONCLUSION

This article proposes the use of three levels of educational robotics scenarios (task environments) to enable to automate the evaluation of mobile robot performance through image processing.

Then the scenarios were subjected to experiments by computer vision, using a digital camera and a performance measurement system, using color-based descriptors to compare the criteria established by artificial landmarks in each type of activity.

To validate the feasibility of robotic scenarios proposed in light of the evaluation by image processing, the opinions of students and instructors were obtained and analyzed. The sample who answered the questionnaire was possible to understand user satisfaction before the robotic scenarios presented.

From the evaluation, it was shown that the majority of users are interested in using the monitored work environment, facilitating understanding of the difficulties faced by the mobile robot carrying out the activity. Another aspect praised by users is the result of activities in real time, showing the details of the behavior and performance of mobile robot.

The results showed that the simplicity of the interface and the applicability of the proposed methods allows work becomes flexible to meet various educational demands in robotics and computer vision. Therefore, the proposal presented in this work can be integrated with educational projects of technical and higher education as well, it can be adapted to the elementary and high school.

Future work will be used to study other application possibilities, determining other types of scenarios, using forms of descriptors to identify the mobile robot or to characterize artificial landmarks scenario without necessarily using colors. Consequently, new metrics will be set in order to configure task environments to explore various possibilities for robotic programming.

Finally, it is expected that this work will contribute to enable educational robotics scenarios with different levels of complexity, allowing the instructor / teacher to evaluate the tasks and robotic challenges with greater efficiency, obtaining detailed feedback on the robotic behavior through results real time of the proposed activities.

REFERENCES

[1] M. L. Rios and J. F. M. Netto, "Uma Abordagem Utilizando Visão Computacional para Monitoramento de Robôs Móveis em Ambientes de Tarefas na Robótica Educacional," *Simpósio Brasileiro de Informática na Educação - SBIE*, pp. 480-489. 2016.

[2] E. Hamner, L. Zito, J. Cross, B. Slezak, S. Mellon, H. Harapko, and M. Welter, "Utilizing Engineering to Teach Non-Technical Disciplines : Case Studies of Robotics within Middle School English and Health Classes," Frontiers In Education - *FIE*, pp. 1–9, 2016.

[3] A. Khanlari, "Robotics Integration to Create an Authentic Learning Environment in Engineering Education," Frontiers In Education - *FIE*, pp. 1–4, 2016.

[4] D. Alimisis, "Robotic Technologies as Vehicles of New Ways of Thinking About Constructivist Teaching and Learning: The TERECoP Project [Education]," *Robot. Autom. Mag. IEEE*, vol. 16, no. 3, p. 21,23, 2009.

[5] R. Martins, S. Bueno, L. Mirisola, E. Paiva, and P. Ferreira, "Localização em Robótica Terrestre: Fusão Entre Odometria por Múltiplos Encoders e GPS," *Simpósio Brasileiro de Automação Inteligente - SBAI*, vol. X, pp. 1043–1048, 2011.

[6] G. El-howayek, "Introducing Computer Engineering Major for First Year Students Using Robotic Projects," Frontiers In Education - *FIE*, pp. 1–4, 2016.

[7] M. Bers, "Project InterActions: A multigenerational robotic learning environment," *J. Sci. Educ. Technol.*, pp. 537–552, 2007.

[8] S. H. Whitehead, "Relationship of robotic implementation on changes

in middle school students' beliefs and interest toward science, technology, engineering and mathematics," *Indiana Univ. Pennsylvania*, 2010.

[9] P. Samuels and L. Haapasalo, "Real and virtual robotics in mathematics education at the school–university transition," *Int. J. Math. Educ. Sci. Technol.*, pp. 285–301, 2012.

[10] J. Carvalho-Filho, L. Molina, K. Bensebaa, E. Carvalho, and E. Freire, "Estimação de Posição e Orientação para Robôs Móveis," *Simpósio Brasileiro de Automação Inteligente - SBAI*, 2009.

[11] A. A. de S. Souza, "Mapeamento Robótico 2,5-D com Representação em Grade de Ocupação-Elevação," *Tese Doutorado - Univ. Fed. do Rio Gd. do Norte*, 2012.

[12] S. Thrun, W. Burgard, and D. Fox, *Probabilistic Robotics (Intelligent Robotics and Autonomous Agents)*. The MIT Press, 2005.

[13] S. Russel and P. Norvig, *Artificial Intelligence*, 3ª. Elsevier, 2013.