Mobile Robotic Supported Collaborative Learning, MRSCL

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Abstract. In this paper we describe MRSCL Geometry a collaborative educational activity that explores the use of robotic technology and wirelessly connected Pocket PCs as tools for teaching and reinforcing concepts of basic geometry. The application can be considered as "robotic aided education" since the robot acts as a mediator in the learning experience, while the students are able to learn concepts that are not related to Robotics. One mayor difference with previous computer based teaching tools is that the robot motions are not absolute, but relative to external references and past moves mapped in the real world. Furthermore, MRSCL Geometry helps students to develop social abilities such as how to communicate with their pairs, and how to interpret and describe information about lengths, positions, and trajectories. Robot autonomous navigation is carry out by developing the teaching activities in a simplified world consistent of clear space and bright color landmarks that are used as the main reference to continuously track the robot position. In this respect, we develop vision algorithms for the real time detection and tracking of landmarks, and we also implement distance estimation and control algorithms for moving and turning the robot accurately.

1 Introduction

Historically, there have been evident problems in teaching and learning of school geometry. One of these problems is the algebraisation of geometry, along with the suppression of geometrical thinking. This issue uncovers, for example, when angle related problems are transformed into algebraic exercises of "solving for the unknown". A direct consequence of the algebraisation of school geometry is that calculation and algebraic manipulation become the main focus of the learning activity, leaving aside the development of geometrical abilities, such as visual reasoning [8].

In relation to measuring concepts, it was determined that less than 50% of US seventh graders can measure the length of a segment when this is not aligned with the beginning of the ruler [3]. According to [11] it is necessary to understand, first, the logic of measurement before being able to use a standard measuring instrument, such as a ruler. This is why methods for teaching measuring concepts begin by using non standard units, such as paper clips or matches, followed by teaching standard units, such as "centimeter cubes", and end up using standard measuring instruments, like rulers. In this respect, a crucial concept in the process of measurement learning is the development of the "measurement sense", defined as the ability to estimate lengths and draw lines of a given size. The construction of this "mental ruler" constitutes a fundamental issue in the development of the "measurement sense", becoming an internal measuring instrument for the student. According to [3], measurement is one of the most important real world mathematical applications, since it bridges two critical realms of Mathematics: geometry as spatial relations and real numbers.

New technologies have allowed the development of software devoted to geometry and measurement teaching, many of which have been developed on Logo environment. For example, Clements et al. show that TurtleMath improves the process of learning concepts such as length [5] and angle [4]. One of the characteristics of the Logo environment that supports these achievements is the fact that it provides instant visual feedback regarding the received instructions. According to Hoyles and Noss [8] [9], a key issue is the fact that the software must provide to the student a "window" onto the mathematical meaning under construction. This means that while the student uses the software to construct models by which they explore and solve problems, their thoughts become simultaneously externalized and progressively shaped by their continuous interaction with the program.

While many software tools have been developed to achieve "computer supported education", there has been practically no research in the field of Robotics leading towards "robotic supported education". A common issue described in the literature is that educational robots are only used to teach Robotics related subjects, such as programming, robot construction, and artificial intelligence, among others. Weinberg et al. [14] introduces robot development as a link for knowledge sharing among different engineering areas, particularly Computer Science, Mechanics, and Electronics. At a school level Wang and Wang [13] use a Lego Robotics kit to teach visual programming to kids between 5-6 years old. Avanzato and Abington [1] introduce a contest that encourages the study and design of robot navigation algorithms such as line and wall following, besides robots collaboration.

Our previous research has been focused on the usability and learning benefits of technologies inside the classroom. Particular emphasis has been made on Mobile Computer Supported Collaborative Learning (MCSCL). We have shown that MCSCL solves problems of coordination, communication, organization, negotiation, interactivity, and lack of mobility detected in collaborative activities for 6-7 year old children [7]. Moreover, the usability improvements introduced by a MCSCL environment produce a significant increase in the learning level [16]. MCSCL has also proved to provide a highly motivating learning environment in high schools, changing the classroom dynamics and promoting collaboration among students [6]. Moreover, MCSCL introduces a space that favors constructivism in order to achieve the creation of new knowledge in a reflexive process directed by the teacher [15].

Mobile Robotic Supported Collaborative Learning (MRSCL) introduced in this paper arises from the addition of robotic technologies to MCSCL. The particular MRSCL activity presented in this work, MRSCL Geometry, responds to the need for better tools that can help to teach and reinforce fundamental geometrical concepts, such as advance and retreat, and length estimation. Moreover, MRSCL Geometry helps students to develop social abilities such as how to communicate with their pairs, and how to interpret and describe information about positions and trajectories. MRSCL Geometry also innovates with respect to previous applications of Robotics technology in education in the following features: the robot is not the aim but the mean; students have a high degree of mobility; the learning is constructivist [2] and develops on a collaborative environment [10]; the learning is incidental by allowing the students to be active actors in the activity [12]; the robot is completely autonomous using sensing information to guide its way.

2 MRSCL Geometry

The application consists of three students who have to solve with a robot, in a collaborative way, a geometry problem. The components of MRSCL Geometry are: an autonomous robot, three different landmarks (Figure 1), three Pocket PCs (handhelds) and a set of different sized rulers. The handhelds and the robot are wirelessly connected. The activity is executed over the floor or any other flat horizontal surface with enough space to contain it.

The main idea behind MRSCL Geometry is that the students help the robot to arrive to a predefined place determined by it. In doing so, they must collaborate with each other, and at the same time learn and practice important geometrical concepts such as relative positions and measurement of distances, all of which helps in the creation of their ”mental ruler”. To achieve this goal the robot can only move in linear paths, either moving towards or away from certain landmarks. The role of the children is to indicate the robot in relation to which landmark it must execute each movement in order to arrive to the predefined goal. For this, the students can use whatever rulers they need from the available set.

Figure 2 shows an example of MRSCL Geometry. First, the robot detects his distance to each landmark and the relative angle between them (Figure 2a). Next it generates the problem autonomously and sends it to the students. In it, the robot tells them he is first going to move 100 cm. away from some landmark, next he is moving 50 cm. away from a second landmark, to finally move 70 cm. towards the last landmark. He also tells them the goal is for him to arrive to the green landmark. The children have to find out what is the right sequence of steps, where each child is in charge of one landmark, specified in the screen of his mobile device. After the students determine the landmark sequence to follow, the robot executes the solution proposed by them. Figures 2b and 2c show the paths follow by the robot for two possible answers (showed in the lower part each figure). It can be seen that the answer in figure 2b corresponds to the correct solution of the problem since the robot arrives to the green landmark. Figure 2c in the other hand corresponds to an incorrect solution.

2.1 MRSCL Geometry Main Activity

Each student is given a landmark and a handheld. First, the students must freely position their landmarks around the robot at about one to two meters from it. After this initial positioning, landmarks are not moved except by explicit request from the robot. Next, the robot rotates around its center searching for the landmarks. Once detected, the landmarks act as an external frame of reference for the robot. Using these references the robot can establish at any time its exact position within the frame just by measuring its distance to the landmarks. The landmarks also act as references for the robot motions, particularly for those where it must move away or towards them, as required by the activity.

Next, and according to the position of the landmarks, the robot generates a problem. Each problem consists in a goal corresponding to the landmark to which it wants to arrive and a sequence of three motions, each consisting of a direction (away or towards) and a distance. Since the students are learning measurement concepts, and to facilitate the creation and development of their "mental ruler" [3], we decided to use multiples of ten as the magnitude for the motion distances, and a maximum distance per movement of 2 meters. The base unit for the activity is the centimeter.

Once the robot has generated the problem, it assigns each handheld the reference of a different landmark. The assigned landmark and the problem are then transmitted wirelessly to each handheld which displays this information visually in screen (Figure 3a). The simplicity of the computer interface responds to the importance of centering the attention of the students on their common real-world coordinate plane rather than on the handheld itself. In this way, interaction and collaboration arise in a natural way. It also allows students to express and show their ideas spatially, enabling a better understanding among them. Each student is allowed to select one of the three movements, indicating the robot to execute it in relation to his assigned landmark. When a student selects a movement, his choice is shown visually in every handheld, disabling the movement for subsequent selections. Figure 3b shows a screenshot of the handheld assigned to the green landmark after the second movement has been selected in the handheld assigned to the mixed landmark. As it can be seen, at this point the handheld assigned to the green landmark can no longer select the second movement.

Once all the students have selected a movement, the robot asks each student individually if s/he agrees with the proposed solution (Figure 3c). If every student answers "yes" the message "Come to an Agreement" displays on the handhelds, after which they reset to the state shown in figure 3a. The consensus requirement forces the group to discuss their ideas and points of view. Cortez et al. [6] proves that this required consensus stimulates description and explanation of ideas in a face to face interaction. This ideas and concept externalization by each student provide the "window onto mathematical meanings" described in

[8]. Throughout debate students externalize thoughts, allowing the observation of the whole process of creation, evolution, change, and maturation of concepts.

After consensus has been reached, the robot executes the proposed solution. In this way the students get 3D feedback of their hypothesis, measurements, and estimations. If the solution is not correct, the robot executes the wrong sequence of commands, after of which it returns to its initial position restarting the problem (Figure 3a). If the solution is correct, the robot asks the students if they want to continue playing. If this is the case, the robot moves randomly to a different starting position, asks the students to reposition the landmarks, and generates a new problem.

2.2 MRSCL Geometry vs. Logo Computer Applications

Just as the Logo applications described in the introduction, MRSCL Geometry delivers immediate visual feedback to the students. Nevertheless, and exceeding Logo applications, MRSCL Geometry executes in the real world while Logo develops on a virtual setting. MRSCL Geometry does not require the child to understand the analogy between virtual and real, diminishing his cognitive load. The virtual environment of Logo is limited to the use of non standard measuring units because the measuring and estimation must be done in pixels. MRSCL Geometry, by the contrary, allows measuring in standard units in a real environment, thus not needing additional levels of abstraction. The same occurs with the "measurement sense" which builds up on real units, not needing the child to learn to estimate in a virtual environment for later extrapolation of such knowledge to a real setting.

Another difference is that in MRSCL Geometry the students can "get into" the problem and move through it. Moreover, each child sees the problem in a different way according to his position in relation to it. This triggers a necessity in the children to see the problem through the other eyes of the kids, thus raising their empathic abilities. This necessity to observe from different locations also develops their spatial imagination.

3 Robot Autonomous Navigation

Since the point of view of the robotic technology, the implementation of MRSCL geometry requires to provide the robot with fully autonomous navigation capabilities. Robust autonomous navigation has been a main research topic for the Robotics community [references] during the last decades, being mapping, localization and path planning some of the main research issues. In MRSCL geometry we solve this problem by developing the activities in a simplified world (playground) consistent of clear space and bright color landmarks that are used as the main reference to continuously track the robot position (see figure).

By sensing the distance of the robot to a specific landmark and also detecting its bearing angle to the set of landmarks the robot can attain at each moment an estimation of its absolute position in the playground. Using this estimation the robot can take adequate control actions and leads its way to complete the learning activities. In this rest of section 3, we describe the main features of the robot sensing capabilities while in section 4 ARREGLAR we describe the details of the motion control scheme.

3.1 Robot Range Sensing

For distance measurement an off-the-shelf sonar was used. To improve the accuracy of real time distance estimation during movements, a Kalman filter was implemented. The only state variable corresponds to the actual distance to the landmark measured. The model of the filter is defined by the equation ARREGLAR . When sampled it turns to ARREGLAR where tau corresponds to the sampling time and ”w” is white gaussian noise caused by movement perturbations. Since the sonar measures distance directly, its measurements are defined by ARREGLAR being ARREGLAR the real distance and ”q” the measurement’s noise.

3.2 Robot Visual Perception

The purpose of the vision algorithms is to detect and follow in real-time some predefined landmarks. The landmarks consist of a colorful square (main color) enclosed by a larger square of a secondary color (Figure 1). Due to hardware limitations the camera on the robot transmits only binary images. Given a RGB maximum and minimum, the transmitted binary image corresponds to the pixels contained in such RGB range. We will define ”main color” and ”secondary color” as the color of the landmark’s inner and outer squares respectively. The ”main image” and ”secondary image” are the binary images acquired using the main and secondary color ranges respectively.

Detection Algorithm This algorithm determines whether the camera is seeing a particular landmark according to its main and secondary colors as defined in section ARREGLAR 3.2. The algorithm is shown in figure 4a. The right hand images correspond to the outcome of each step. First, the camera acquires the binary main and secondary images according to the corresponding colors of the requested landmark. Next, it segments the main image into regions, defined as groups of connecting detected pixels. Noise filtering eliminates regions with smaller area than the minimum predefined acceptance area. Subsequently the Secondary Color Enclose Index (SCEI) is calculated for each region. This index corresponds to the fraction of the contour o the region whose color corresponds to the secondary color. The SCEI of each region is calculated by dividing the number of detected secondary pixels of its contour by the total amount of contour pixels. In the image next to ”SCEI Calculation” the secondary image detection (grey) has been put on top of the main segmented image; each SCEI value of each region is also shown. Finally, the region with greater SCEI is selected. If it is SCEI is greater than the minimum predefined SCEI acceptance value the region is detected as the landmark, returning the position of its horizontal center of mass (vertical line in last image). If its SCEI does not surpass this acceptance value, then no detection value is returned.

Because the main and secondary images must be analyzed together, an error arises when the images are out of phase. For this a phase parameter was introduced, which indicates how many pixels one image must be moved when being compared with the other. Another possible error occurs when analyzing the contour of a region that touches the border of the image. In this case the contour includes the ”out of view” pixels, but those pixels are assumed not part of the secondary detection. Because the SCEI does not take into account neither size nor shape, landmark orientation is not a problem.

The implemented algorithm completes three detections per second under any visual condition. When visual distractions were placed, less than %1 of the detections proved false. Even though the algorithm proved robust, real landmarks were not detected nearly %1 of the times.

Tracking Algorithm This algorithm allows real time tracking of a detected landmark without the need to execute a complete new detection, thus diminishing processing time and improving tracking speed. Figure 4b shows the algorithm with the corresponding outcome of each step. After the landmark has been detected, a Landmark Image is stored. This binary image corresponds to the region of the inner landmark's square (best SCEI region defined in section ARREGLAR 3.2.1). A new image of the color of the inner square (main color) is then acquired, segmented, and filtered. Subsequently the matching index of each region is computed. This index is defined as the number of pixels in the region that match with the landmark image. In the example of figure 6 the landmark image, represented by gray dots, has been placed over the main segmented image. This illustrates, for example, that region 4 has 8 matching pixels while region 3 has none. Finally the region with the greatest matching index, in this case region 4, is assumed to be the new position of the landmark, updating the landmark image for the next iteration.

In the previous example the detection of the inner square has been deteriorated by eliminating two corners pixels. This shows how the algorithm tolerates imperfect detections, as well as time varying landmark orientation, and size. Due to the outer frame of the inner square, its detection will never merge with other similar colors (unless there is partial occlusion). A drawback of the algorithm, due to its recursive nature, is that if by any chance it tracks an erroneous object, it will continue to follow that object, completely loosing the landmark. Nevertheless, this problem was solved by performing a complete detection after a number of tracking iterations. Experimentally, this algorithm performs 8 - 10 tracking iterations per second, determined by the camera transmitting speed.

4 Implementation

4.1 Architecture

The architecture of MRSCL Geometry is shown in figure 5a. WiFi communication cards were used on Pocket PCs to permit the activity to be self contained. The Robot also had a Pocket PC with WiFi, which acted as Robot Controller and communication media with the three children.

4.2 Robot

The robot used is the Palm Pilot Robotic Kit (PPRK) available at Acroname (figure 5b). Its size is about 25 x 20 x 10 cm. It has three omnidirectional wheels by which it is capable of moving in any direction independent of its orientation. Each wheel is attached to a hacked standard servo controlled by a microcontroller. For communications the board uses a serial port (RS-232) with a transmission speed of 9600 bauds.

Vision is accomplished through the CMUcam. This camera has a RGB resolution of 80 x 143 pixels. It uses serial communication (RS-232) with a maximum transmission speed of 115.200 bauds. This limitation does not allow real time color video, needing about 5 seconds to transmit a full resolution color image. Nevertheless, the cam can transmit binary images at a rate of 17 frames per second. In binary mode, maximum and minimum RGB values must be provided. The binary image indicates which pixels are inside this RGB range. In this mode resolution decreases to 80 x 44 pixels. The camera is mounted on a servo to allow independent rotation. This servo controls the relative angular position of the camera with respect to the robot.

The handhelds used in the application were HP's Jornada 560, 206 MHz, 64 MB RAM, color display, PocketPC 2002 operating system. The devices were used in combination with a Wi-Fi "Low Power WLAN Card" (IEEE 802.11b) to achieve wireless communication. Serial communication was carried out through its RS-232 link. Since the handheld on the robot needs to communicate with the servo board and the cam, a multiplexer board was constructed. The whole robot is energized with 5 volts.

4.3 Control Systems

For the correct performance of the application, two control systems where developed. The first controls the trajectory of the robot while the second controls the angular rotation to achieve an accurate relative angle measurement.

Linear Movement Control The objective of this control is to maintain the robot moving in a straight direction, advancing or retreating, according to the corresponding activity movement. Because of the omnidirectionality mobility of the robot, it can rotate while moving. Figure 6 displays the control algorithm here described. First, the robot detects and centers the corresponding landmark in its field of view (FOV). Next it begins moving, either forward or backwards according to the activity. Until the moment the robot completes traveling its predefined distance, it visually follows the landmark keeping it always in the center of its FOV. To determine if it has traveled the predefined distance, the robot continuously measures its distance to the landmark. The efficiency of the control depends on the speed at which the robotic vision processes the landmark following algorithm.

Rotation Control This algorithm controls the robot and the rotation of the camera in order to estimate accurately the relative angle between landmarks. The algorithm is divided into two stages, "robot's search" (stage 1) and "cam's search" (stage 2). Initially, the robot rotates clockwise searching for the required landmark. When detected, it centers it in the cam's FOV. During this first stage, the camera's position on the robot remains unchanged (camera supporting servo doesn't move). Next, the algorithm passes to the "cam's search" stage where the robot stays halted while the camera rotates clockwise searching for the next landmark. Once detected, the camera centers on it, measuring the angle difference of its supporting servo motor. The accuracy of the measurement corresponds to the servo's precision, commonly less than one degree. Since the servo has a maximum rotation capability (around 210), the camera is initially rotated to its leftmost position so that in stage 2 it can scan through the entire servo's angular range. If subsequent angles need to be measured, the algorithm passes to a third stage. The robot rotates while the camera remains "anchored" on the landmark through the visual tracking algorithm (ARREGLAR section 3.2.2). When the cam gets to its leftmost position again, the robot centers on the landmark, stops, and "cam's search" executes.

5 Conclusions & Future Work

The MRSCL environment introduced opens new perspectives in the scope of interactive educational robots, taking advantage of handheld mobility and portability, thus providing support to a face-to-face collaborative work. In particular, MRSCL Geometry's wireless network allows students to explore the problem through different physical points of view, developing their spatial thinking abilities. Since each student has control over just one part of the solution, collaboration and discussion emerges naturally, providing a dynamic "window" into the mathematical meanings in construction. Finally, MRSCL Geometry is a tool to geometrically solve a geometrical problem, abolishing the algebraization flaw in mathematical teaching, allowing students to develop their geometrical abilities and visual reasoning. Due to the simplicity of the interface and the reduced set of activity's rules, not much training is required for the children to use the application, diminishing the overhead introduced by this new technology.

In relation to robotic vision, real time landmark detection and tracking were required. Due to limitations in the camera's transmitting bandwidth, algorithms based on binary images were developed for this purpose. These algorithms, based on well-chosen landmarks, proved to be efficient and robust, accomplishing all the real time requirements of the activity.

Our future work focuses on the experimental validation of the activity. We want to validate the fact that students using MRSCL Geometry attain a better learning and understanding of geometry, measurement and estimation than students who doesn't use this technology. To do this, we will follow a methodology similar to the one used in our previous research [15], using one experimental and two control groups. Throughout the experiment, the experimental group will work with MRSCL Geometry while control group 1 will work with a similar collaborative activity implemented without technology. Control group 2 will remain unaltered from its regular class activities. Students will be examined through a pretest, posttest and delayed posttest. In this way we will be able to determine whether the learning differences, if any, arise from the collaborative activity itself, the MRSCL technological improvement or both. The delayed posttest will also retrieve information about how deep-rooted where the learned concepts.

6 Ackowledgment

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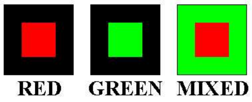

Fig. 1. Landmarks used in MRSCL Geometry. The inner and outer color square design was chosen for the robot to achieve a robust visual detection.

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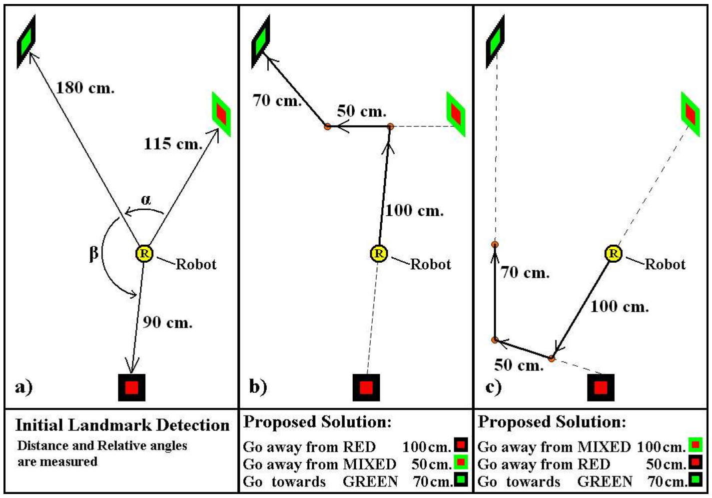
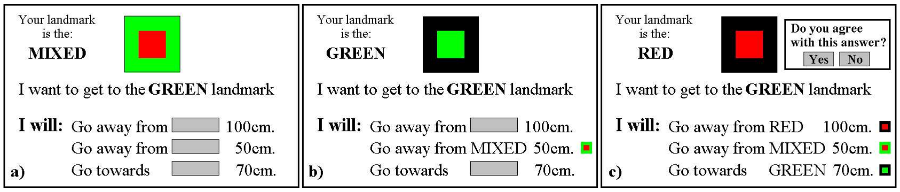


Fig. 2. The initial landmark setting is detected by the robot (a). (b) shows the path followed by the robot when the correct answer (in the lower part of the figure) has been proposed. (c) shows the followed path for another (erroneous) answer.



Your landmark is the:
MIXED

I want to get to the **GREEN** landmark

I will: Go away from 100cm.
Go away from 50cm.
Go towards 70cm.

a)

Your landmark is the:
GREEN

I want to get to the **GREEN** landmark

I will: Go away from 100cm.
Go away from MIXED 50cm.
Go towards 70cm.

b)

Your landmark is the:
RED

Do you agree with this answer?
Yes No

I want to get to the **GREEN** landmark

I will: Go away from RED 100cm.
Go away from MIXED 50cm.
Go towards GREEN 70cm.

c)

Fig. 3. a) Screenshot of the handheld assigned to the mixed landmark upon receiving the problem. b) Screenshot of the handheld assigned to the green landmark after the second movement has been selected in (a). c) Screenshot of the handheld asssigned to the red landmark after the three children have chosen their moves.

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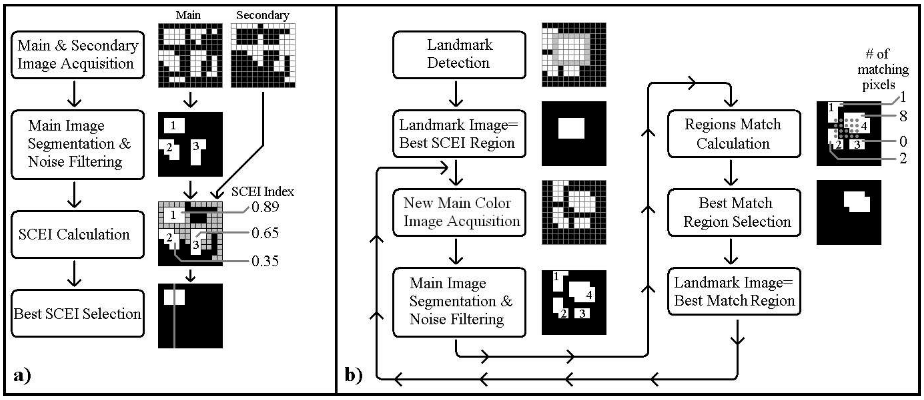

Fig. 4. a) Detection algorithm. b) Tracking algorithm.

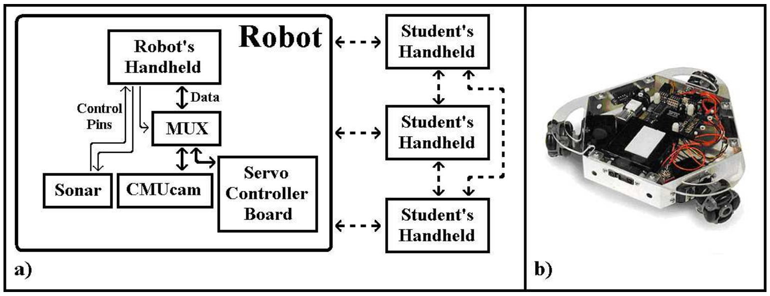

Fig. 5. a) Architecture of the robot. b) the robot.

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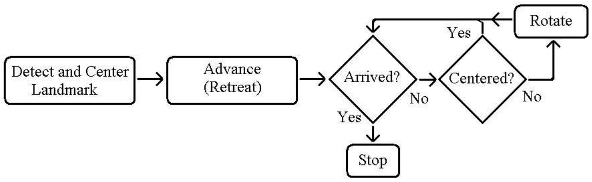

Fig. 6. Linear movement control.