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Design and Implementation of an Autonomous Vehicle to Collect Tennis Balls Using Artificial Vision

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***Abstract*— The objective of this work was to design and implement an autonomous vehicle (robot) to collect tennis balls using different digital image processing techniques. The robot was built from an Arduino Nano microcontroller. A radio frequency antenna NRF24L01 receives the data from the control stage and the locomotion system integrated by motors and an odometry system composed of MPU6050 gyroscope encoders; additionally, the system has an emitter module that consists of an Arduino Uno and an antenna with the same characteristics. The prototype consists of two separate subsystems, one for collecting and processing information and the other specific for the vehicle on the ground. It is equipped with a Kinect camera that captures information from a defined area for image processing through a visual control algorithm that detects the balls by color and shape segmentation, determining their location in rectangular coordinates and sending them to the robot through a data transmission system. The Ackerman configuration mobile robot equipped with the wireless communication system receives the coordinates to carry out the movements that are controlled by sensors located on the wheels, with a maximum capacity of 4 balls. The complete running of the system obtained an accuracy of 96.9% in the collection of balls; it should be noted that the tests were carried out with several distractors whose objective was to confuse the system; these tests were carried out at various times the day in a real scenario.**

***Keywords*—Digital image processing; mobile robot; color segmentation; Kinect camera; wireless communication system.**

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I. Introduction

The use of autonomous machines or vehicles to carry out daily tasks is an alternative that little by little has won a greater impact and acceptance in society within areas where human performance could not be effective due to the precision or repeatability of certain tasks. The mistakes, better known as "human error", are common in these fields, often caused by exhaustion. The technological prototype for collecting balls on a tennis court using Digital Image Processing incorporates a reusable intelligent robot that roams a tennis court in search of objects detected by a camera located in a panoramic spot that plans the route and movement of the vehicle automating this repetitive activity.

The contribution of this research is focused on the possible applicability of the prototype in practical applications where currently the work carried out is done by a group of people. The process could be optimized with the use of several robots to increase the efficiency of the process. In this case, detection and collecting tennis balls within a specific field, using digital image processing techniques and an autonomous collecting robot. Similar applications to the one proposed have been developed in various industries, such as automobile segmentation and color recognition. Their methodology has been divided into three stages: vehicle segmentation, detection of the region of interest and color recognition based on morphological operations and a fuzzy system [1].

The study also entitled "Visual control and sensory fusion system for implementing a differential mobile platform". This research presents the implementation of a mobile platform for inland navigation with a visual control system that detects and evades objects by comparing patterns and generating a panoramic image of the environment [2]. Artificial vision systems classify paint cans by color considering the RGB color space, among others [3].

A. Arduino based Mobile Robot

Arduino has numerous documented studies about mobile robots or autonomous vehicles (see Fig. 1) in differential or Ackerman configuration [4]. The instructions for each motor must have intuitiveness. Therefore, developing a mobile robot together with modules created by Arduino for communication in real-time with Bluetooth [5] or Radio Frequency (RF) antennas provides a solution to the problem that has been formulated [6]. The Arduino nano's input and output configuration compensate for space optimization in handling sensors and electric actuators, which is necessary to satisfy the robot's aims [7].

B. Ackerman Configuration

This structure has four wheels, the Ackerman configuration has two wheels mounted in the back of the structure and the other two wheels mounted on a front. The wheels in the front of the platform are steerable in this form. This structure is a car-like vehicle (see Fig 2) [4]. The application for this configuration is for exteriors [8].

C. Encoders

Position encoders are key components for the robot's position, orientation, and motion control.[9] The magnetic encoder detects rotational position information as changes of the magnetic field, converts them into electrical signals, and outputs them.

Fig. 1 ARDUINO Platform mobile robot

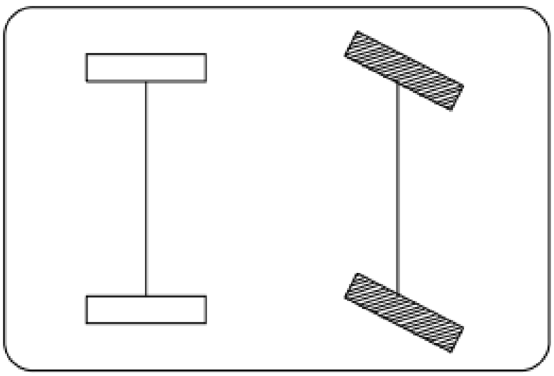

Fig. 2 Ackerman Configuration

The simplest magnetic encoder consists of a permanent magnet and a magnetic sensor. The permanent magnet is attached to the tip of a rotating body, such as a motor shaft. The magnetic sensor is fixed in a state where it is mounted on a PCB board at a position where it receives the magnetic field generated by the permanent magnet. When the permanent magnet attached to the motor shaft rotates, the direction of the magnetic field detected by the magnetic sensor changes. As a result, the encoder detects the rotational position and speed of the motor shaft [10]. The holes in the disk have the function of blocking and unblocking the LED light beam to the photodetector (see Fig. 3). As the disk rotates, the photodetector with an electronic circuit sends a waveform signal to the outputs of the square encoder, and it is proportional with the number of holes in the encoder according to its resolution [10].

D. Image Capture Device

A camera is a black box on the inside and allows the correct amount of light to fall on the surface that is recording the photograph. This surface varies according to the type of camera. In the case of a film camera, light falls on the surface of a film, and in the case of a digital camera, an image sensor records the light. If the amount of light is brighter than required, the image will appear blank, and the details will be missing due to overexposure; and if the light is darker than required, the photo will appear dark, again removing the details from the image [11]

E. Stereoscopic Camera

A stereoscopic camera allows users to capture images that are instantly rendered in 3D. Whether it is a photographic or video camera, stereoscopic cameras contain more than one lens (see Fig. 4), each with its image sensor or frame to create the proper depth in 3D stereoscopic images.

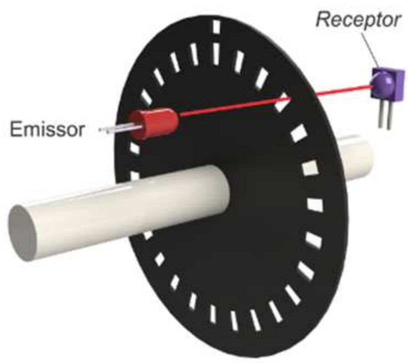

Fig. 3 Main parts of an Encoder

Fig. 4 Stereoscopic camera

There are three basic elements to determine: foreground, background, and zero parallaxes. The foreground is the element in your image that will appear closest to the viewer, while the background is the image that will appear below [12]

F. Minoru 3-D Webcam

Minoru is a camera with a double camera, an original webcam, which achieves simulating 3D images. Each camera acts as an independent lens and forms the combination of the two images. The captures are in different ranges, one capture is red, and the other capture is Cuyan, the 3D sensation is achieved. For this, we have to wear special glasses (see Fig 5). [13]

G. Kinect X-Box

Kinect is smarter than another average webcam. Thanks to its secret trick, this camera has an excellent view: highlight the room with light invisible infrared (see Fig. 6). Along with suitable advanced software can track 48 points of a body in real-time [14]

Fig. 5 Minoru Camera

Fig. 6 Kinect X-Box

II. Material and Methods

This section presents a digital image processing system's requirement in a mobile robot with Ackerman configuration. The mechanical structure was considered capable of supporting the gripper, the camera, and the detected objects. The electronic assembly and communication system were designed to guarantee movement control and object detection. The structure established for the development of this research was systematically divided into several stages. Initially, the identification of the problem was established, starting from the need to optimize and automate the method with which the manual collection of tennis balls is currently carried out in a specific field. Subsequently, a vast collection of related information was carried out. A state-of-the-art of pre-existing techniques that have a certain similarity with the proposed work was developed. Next, the minimum requirements necessary for optimal development and operation of the system were analyzed, and an adequate selection of the required software and hardware was made to meet the expectations and objectives of the system. Once the selection of the devices and software used was made, the design and subsequent implementation of the tennis ball collection system in a specific field were developed. Finally, the operation tests and validation of the correct functioning of the system were carried out through the provision of several scenarios and several tests for adequate verification.

A. Hardware Design and Implementation

1) Implementation of the Ackerman mobile platform: For the implementation of the robot, passive elements were used. There is an Arduino Nano microcontroller, a radio frequency antenna NRF24L01, which is responsible for receiving data from the control stage. The locomotion system is made up of motors, wheels and an odometry system made up of an MPU6050 gyroscope and encoders. An emitter module made up of an Arduino Uno, and an antenna with the same characteristics was included. Finally, a clamp was incorporated into the holding and subsequent storage of localized tennis balls. In this way, the assembled robot was implemented (see Fig. 7).

Fig. 7 Assembled robot

B. Software design and implementation

The software used for ball recognition and location and odometry is MATLAB. Various algorithms were used to recognize objects based on their color and shape, in addition to the program that controls the mobile robot. It has an operating principle based on four stages, each of which has its programming and specific functionality, as seen in the generalized function cycle (see Fig. 8). Within the Matlab programming language, several stages were developed as follows:

1) Obtaining Images: A Kinect Xbox360 was used with the "Kinect for Windows Sensor" plugin, which allows Kinect to input images and detect object distances, necessary for the algorithm in the MatLab software. To verify correct operation, image capture and infrared depth sensor test were performed. The camera works like any other USB camera, but the depth sensor generates an additional data matrix of 640x480, the distance in mm of each pixel (see Fig. 9).

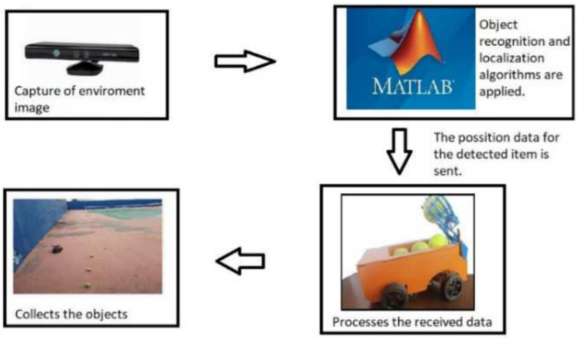

Fig. 8 Final scheme of operation

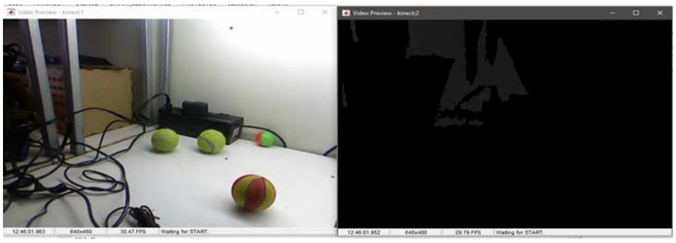

Fig. 9 Obtaining images from the Kinect

2) Image Processing: The images obtained through the Kinect were suitable to be entered into the detection algorithm, where an image conversion was made from the RGB color space to an HSV model. This generates a perspective similar to that of human vision. (see Fig. 10) The picture shows the image captured by the device in the RGB model and the HSV model. As shown in Figure 10, the HSV model allows better control over the color to be detected since different shades of green must be used to detect tennis balls. A color range of 200 to 230 was assigned to segment the image and detect existing green objects. With the result of this first stage, the capture is filtered throughout morphological operations applied within the field of digital image processing, using a structuring element. The operations used are erosion, which reduces or makes the pixels of the image thinner; dilation that expands or enlarges the pixels of the capture; the result is a relatively clean image which, according to the authors' criteria, is suitable for entering the detection algorithm (see Fig. 11).

3) Ball detection algorithm and location. For the detection of tennis balls, the data obtained in the processing of the images were used. These were entered into the algorithm at the same time that the depth sensor measurement was taken. Figure 12 shows the flow chart of the ball detection and location algorithm. In the entered image, the characteristics of the figures or closed forms are analyzed by considering the value of the area and perimeter of the detected elements; with the obtained values, an array of vectors was applied that provides a numerical value. It indicates if the enclosed figure of the image is circular and has the dimensions of a tennis ball.

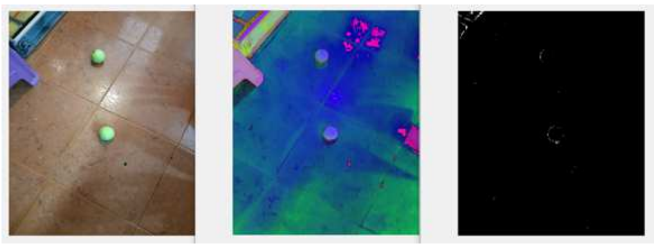

Fig. 10 Images processing

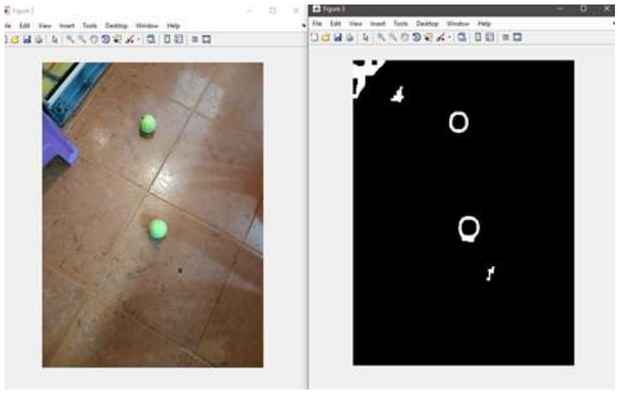

Fig. 11 Filtering and selection of images

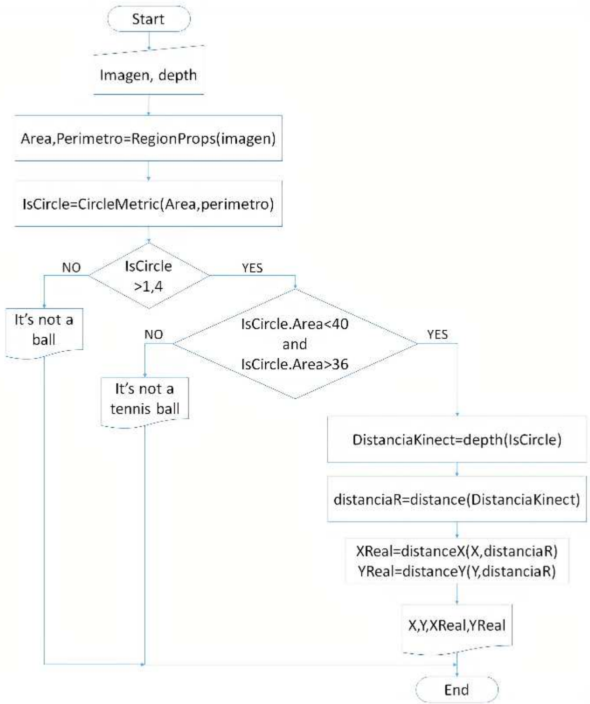

Fig. 12 Flow diagram of the ball detection and location algorithm

Suppose the numerical value of the perimeter is less than 1.4. It is stored with the name "IsCircle", then the area of the detected geometric figure is calculated, which must be within a range of 36 to 40 (pixels). If this condition is met, the algorithm ensures that it has detected a tennis ball. The next step is to calculate the value of the depth of the detected object, having to generate an ordered pair of coordinates. These correspond to the value in which the robot must move in the X and Y axes, respectively, in the work area defined for the detection system. Table I shows several values (perimeter and area) that could be generated when capturing some objects with a circular shape, affecting the system's correct operation.

4) Navigation algorithm: For the detection, location and collection of tennis balls, it is considered that the range of the system. The Kinect camera is in a fixed position is 210x160 cm, which generates a working area of 3.36 m^2. In this way, each movement of the mobile platform is monitored, achieving the correct displacement on the map.

TABLE I
CIRCULAR OBJECTS AND THEIR AREA

Object	IsCircle	Area
Tennis ball	1,30	40
Soccer ball	1,24	500
Circular object	1,09	200
Square object	3,60	600
Rectangular object	2,63	200
An object without a defined shape	10,63	300

The navigation algorithm obtains the information of the detection and location of the balls in the map that provides the real position. The position is in pixels of the robot's location is obtained from the various objects detected in the capture. To reduce possible errors that the system may present. The robot has colors that contrast with the various objects' movement environment. Under these conditions, an infinite loop of repetitions is made for the different movements of the mobile robot, where the vehicle moves from its base to the different locations where several tennis balls have been detected. Fig. 13 shows the flow diagram used for the navigation of the robot in the delimited workspace.

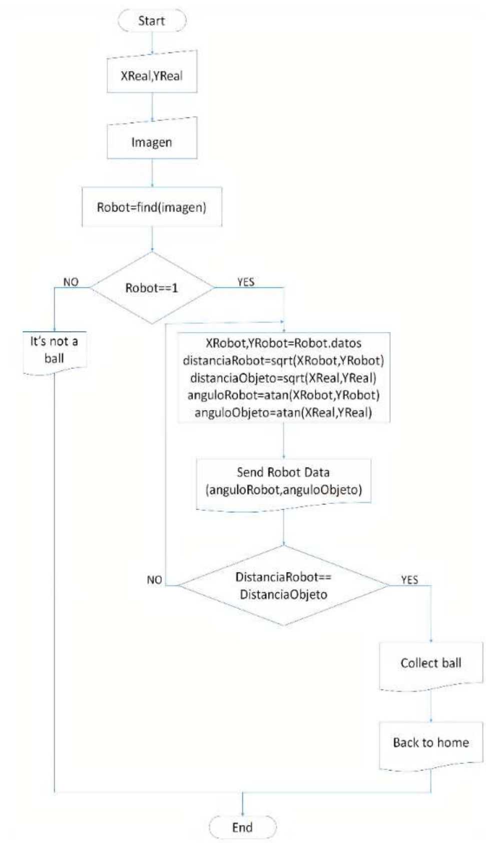

Fig. 13 Navigation system flow diagram

5) User Interface in Matlab: For the user to view the entire execution process, an application was developed in the graphical environment of Matlab (Guide), which shows a user interface that allows interaction through buttons to access the system. It consists of display screens, i.e., the camera, the location of objects within the image, the communication port between the application and the robot. Finally, it identifies the location coordinates of the various objects detected in the captured image in the programming environment. The image displayed on the camera represents the capture made of the environment where the device is operating. This image shows the location of objects to frame the objects that comply with the identification characteristic previously established in the programming in a colored box green. The Detected Objects screen indicates the X and Y-axis position in which the objects recognized in the previous stages are located. All the elements previously exposed are visualized in Figure 14.

Fig. 14 GUIDE Development Environment.

III. RESULTS AND DISCUSSION

For the validation of the results, various tests were applied in 5 different scenarios. Each of them consisted of 6 tests with 5 repetitions. Each one of them, in each test, the number of distractors varied, and the number of tennis balls was maintained. In scenario 1, there was a ball to collect the number of distractors that increased to 6, and the same way for each scenario. The average effectiveness in each of the scenarios was higher than 88%, which establishes the percentage of objects detected in the image and collected in the work area that meet the characteristics of circumference and area previously determined. Table II shows the total average efficiency of all the scenarios, including an ideal scenario with several tennis balls with 0 distractors. The system's efficiency is 96.9% of balls collected by the robot from all the tests applied.

TABLE II
DATA OBTAINED REGARDING THE EFFICIENCY IN EACH SCENARIO

	No.	Number of balls	Number of distractors	Balls collecting in the test	Efficiency
STAGE	1		1	1	100
1	2		2	1	100
	3	1	3	1	100
	4		4	1	100
	5		5	1	100
	6		6	1	100
				Efficiency average	100
STAGE	7		1	2	100
2	8		2	2	100
	9	2	3	2	100
	10		4	2	100
	11		5	2	100
	12		6	2	100
				Efficiency average	100

STAGE 3	13		1	3	100
	14		2	3	100
	15	3	3	3	100
	16		4	2	66
	17		5	3	100
	18		6	2	66
				Efficiency average	88.667
STAGE 4	19		1	4	100
	20		2	4	100
	21	4	3	4	100
	22		4	4	100
	23		5	3	75
	24		6	4	100
				Efficiency average	95,833
STAGE 5	25			4	100
	26			4	100
	27	4	0	4	100
	28			4	100
	29			4	100
	30			4	100
				Efficiency Average	100
				Total Efficiency average	96,9%

IV. CONCLUSIONS

The essential requirements for the structural of robot design have been established based on the device configurations and the ball collection capacity that the robot can contain according to the work area. The evaluation of the artificial vision system is for the calculating of the real coordinates. It shows the accuracy of 99.088% and 98.264% in the X and Y axes, respectively. The robot's efficiency was determined with an average value of 96.9%, which was obtained through tests in different scenarios, depending on the number of balls to collect and the number of distractors.

It was possible to make a collecting robot with high precision and efficiency when collecting tennis balls by applying various techniques that involve the wide field of electronics and artificial vision through digital image processing. According to the tests carried out, it is considered that the locomotion system could be improved to reduce the time spent on the task of collecting balls. Based on the above, it was proposed that a new version of the prototype should have a control system implemented to reduce execution time.

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