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A CASE-STUDY VISION

Navigation of mobile robots in formation of convoy

Navegación de robots móviles en formación de convoy

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ABSTRACT

Navigation is presented for a convoy made up of three lay-type robots, which reaches a final point established by means of the master robot's kinematics that can keep Bluetooth communication, knowing the number of robots (slaves) in the formation, which can be incorporated before the route or leave the formation during it. The convoy evades an obstacle which can be in different coordinates of the route established by the master robot. an infrared communication was established for the formation of the convoy keeping minimum and maximum distances between the members of the formation. The results obtained offer a minimum error in the attainment of the final point and the formation is formed during the different displacements carried out in a controlled environment.

RESUMEN

Se presenta la navegación para un convoy conformado por tres robots tipo lego, el cual alcanza un punto final establecido por medio de la cinemática del robot maestro que puede mantener una comunicación bluetooth, conociendo la cantidad de robots (esclavos) en la formación, que pueden incorporarse antes del recorrido o abandonar la formación durante el mismo. El convoy evade un obstáculo el cual pude estar en diferentes coordenadas de la ruta establecida por el robot maestro. se estableció una comunicación infrarroja para la formación del convoy conservando unas distancias mínimas y máximas entre los integrantes de la formación. Los resultados obtenidos ofrecen un mínimo error en la consecución del punto final y se conforma la formación durante los diferentes desplazamientos realizados en un ambiente controlado.

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1. Introduction

In recent years the joint navigation of mobile robots has aroused great interest in different fields of research, this has led to make different types of formations of robotic vehicles, among which the most used is the convoy type, where each robot follows the path traveled by the previous to a distance of separation for safety of the different members, this application is used for distribution of military vehicles, loading industrial materials and public transport. [1, 2] The training is the easiest to implement and acceptable results are obtained, but are limited due to the route is predetermined fixed (line followers, by beacons among others).

For this reason, the present research shows the capacity of three mobile robots (master, slave 1 and slave 2), to perform convoy training, where they move through several routes without any established route, avoiding an obstacle located within a controlled environment, approaching the final point and keeping a Bluetooth communication in real time, by means of the master robot that knows which slave is incorporated or leaving the convoy. Practical results are presented that determine the systematic and sensory error, as well as the capacity of wireless communication to perform convoy training.

2. Description

The convoy is made up of three differential type mobile robots, where each robot has a system of perception, action and information processing, in these subsystems can be found: a NXT brick [3] that makes decisions (master) keeping Bluetooth communication with 2 devices in real time, a pair of motors [4] to move around, ultrasound sensors [5] to avoid collisions, IRLINK and IRSEEKER sensors [6, 7] that send and perceive infrared signals respectively; the master robot differs by having a compassionate magnetic sensor to determine its orientation, the description of the robots is shown in figures **1** and **2**.

Figure **3** shows the environment where the tests are made up of two sections, the first with a size of 180cm x 270cm, white, marked with black lines around demonstrating their limits and the second with measures of 153cm x 160 cm, where the convoy performs the different routes.

Figure **4** presents the result of the parameterization of the magnetic compass sensor (MCS) where the average of 110 samples for 10 different angles is observed. The MCS data are identified in the blue bars and the reference pattern, transporter (T), in the orange bars. As a result, the equation (1) is obtained, which is the sum of errors that tends to 8 %.

$$\sum_{i=1}^{n} \frac{C_m}{T} \tag{1}$$

Figure 1: Master Robot.

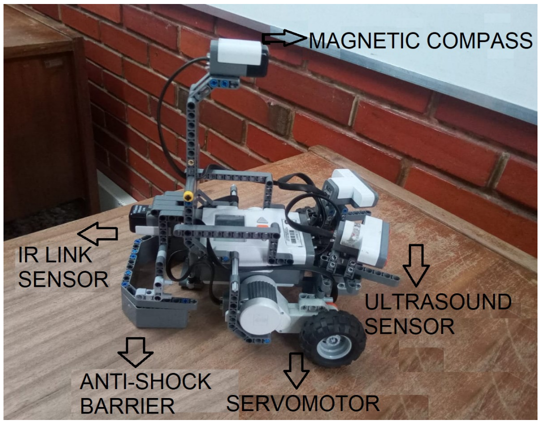

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Figure 2: Slave robots.

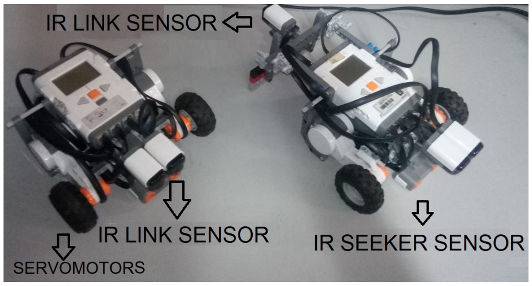

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Figure 3: Controlled environment.

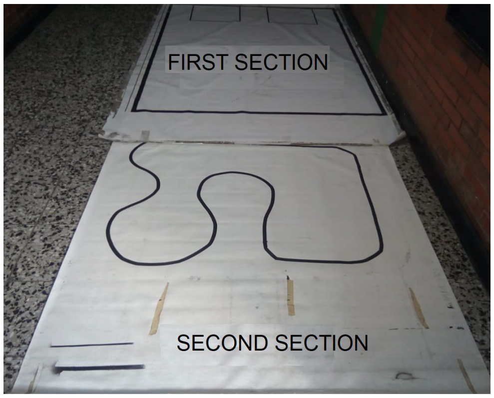

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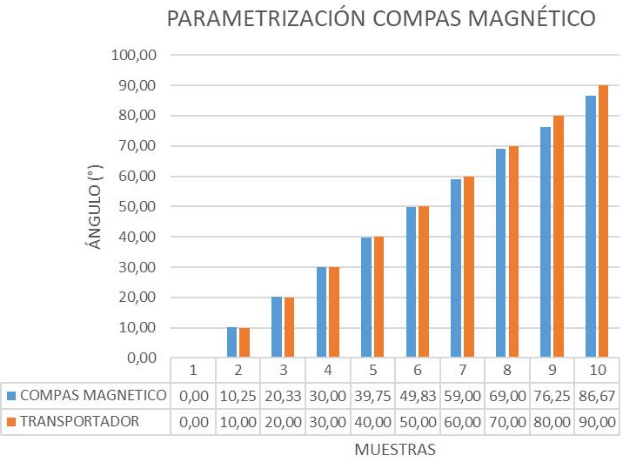
Figure 4: Obtaining the error for the magnetic compas sensor.

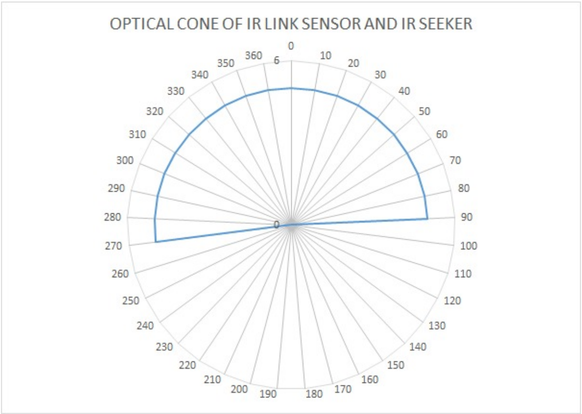


	1	2	3	4	5	6	7	8	9	10
🟦 COMPAS MAGNETICO	0,00	10,25	20,33	30,00	39,75	49,83	59,00	69,00	76,25	86,67
🟧 TRANSPORTADOR	0,00	10,00	20,00	30,00	40,00	50,00	60,00	70,00	80,00	90,00

Source: own

Some functional tests were done to the IRLINK and IR SEEKER sensor which keep infrared communication, opting for an optical cone ranging from -90° to 90°, as shown in Figure **5**.

Figure 5: Parameterization of IR LINK and IR SEEKER sensors.



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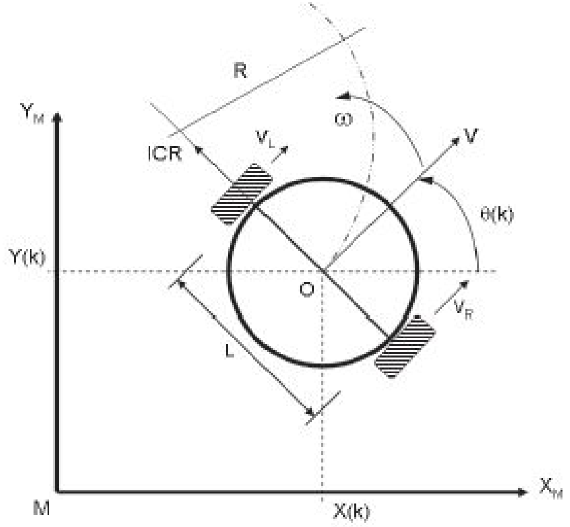
3. Methodology

The fundamental problems for this research were: to try to get the master robot to take the convoy to the final point avoiding obstacles [8–10] and to keep a wireless communication (Bluetooth) in real time between the robots to know which is inside or outside the training.

Figure 6: Diagram of a differential platform in space [8].



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To solve these problems, the robots were built in a differential configuration to facilitate their movements in the plane, represented by equation (2), where the two-dimensional location represents the position and orientation of the master robot, as shown in figure **6**.

$$P = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \tag{2}$$

A first approximation for the kinematic model of differential platforms is based on studies carried out by different authors [8–10], where the following equations are used.

$$w(t) = \frac{(V_L(t) - V_R(t))}{b} \tag{3}$$

$$v(t) = \frac{(V_L(t) + V_R(t))}{2} \tag{4}$$

Where: $w(t)$ is the angular velocity, $v(t)$ the linear velocity and V_L and V_R are the velocities of the tires. By taking into account some physical aspects of the mobile robot, traction axis (L=15cm), wheel radius (r=2.6cm), and the measurement recorded by each encoder (θ), a general expression is determined for the linear distance travelled by each wheel (Xm_n) represented in equation (5), [9].

$$Xm_n = 2\pi * r * \theta \tag{5}$$

It replaces (5) in (3) and (4) generating two expressions represented in equations (6) and (7) in a vectorial way applying all the constants provided by the master robot.

$$X = \frac{(Xm_L + Xm_R)}{2} = 0{,}0226 * (\theta_L + \theta_R) \tag{6}$$

$$= \Delta D = [0{,}02260{,}0226] * \begin{bmatrix} \theta_L \\ \theta_R \end{bmatrix}$$

$$\theta = \frac{(Xm_L - Xm_R)}{b} = \alpha(\theta_L + \theta_R) \tag{7}$$

When calculating, two physical constants are obtained (0.0226) that represents the linear movement and (0.1733) that represents the angular displacement of the mobile robot, these results were implemented in LabVIEW® to perform a straight line movement and another angular movement by means of a 30 % pwm as shown in figures 7 and 8 [9].

Several tests show that the appropriate values for linear motion are within the range of 10 cm, where the lowest average error was 0.46 % and standard deviation was 0.23 %. Therefore, their cumulative error is minimal within the system, as shown in Figure 9.

Figure 7: Linear distance algorithm for the master platform, implemented in LabVIEW®. [9].

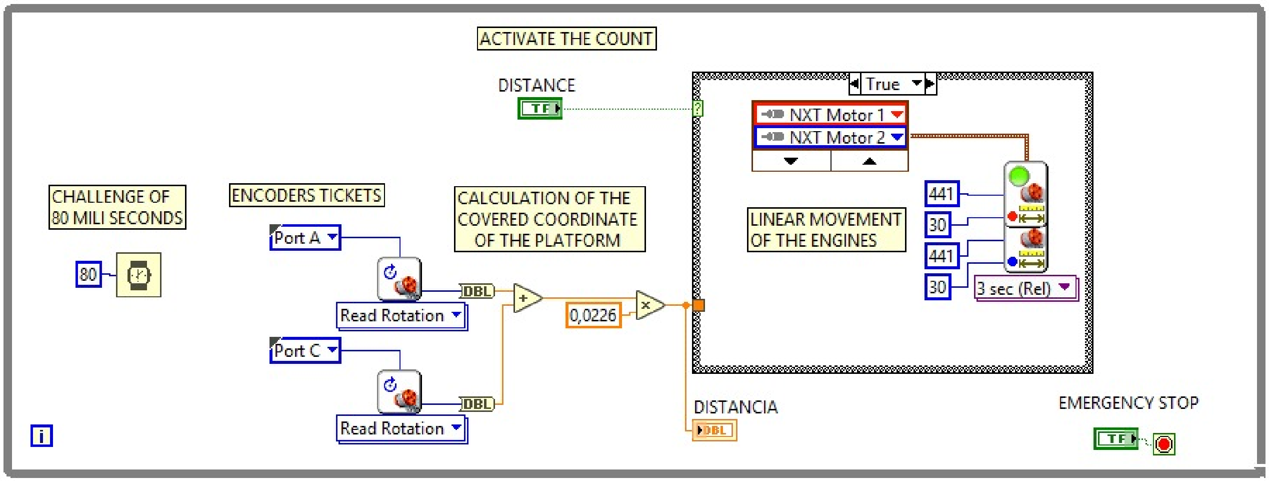

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Figure 8: Algorithm of angle traveled by the master platform, implemented in LabVIEW® [9].

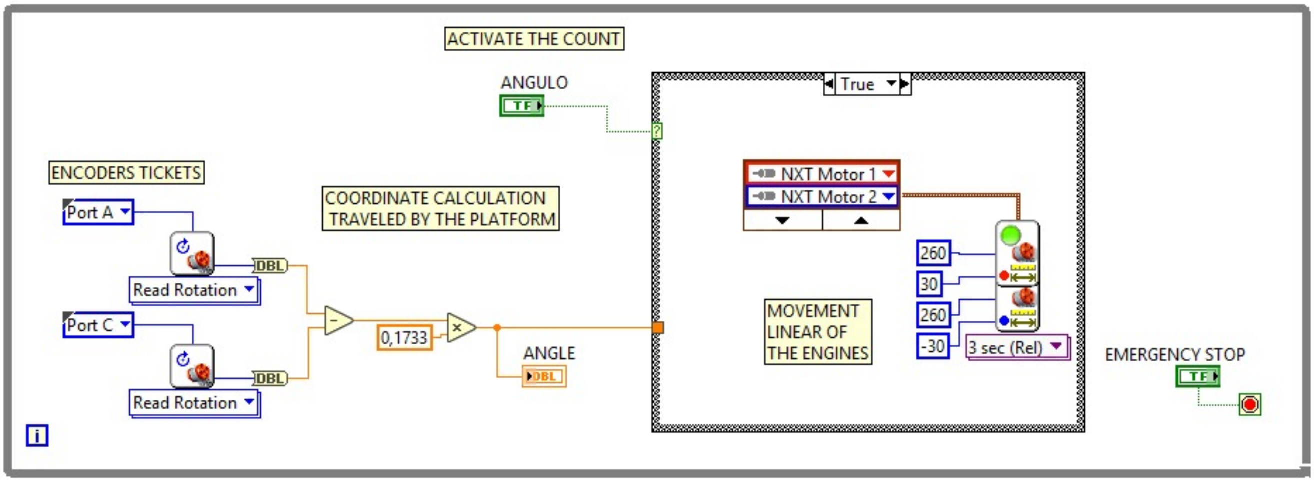

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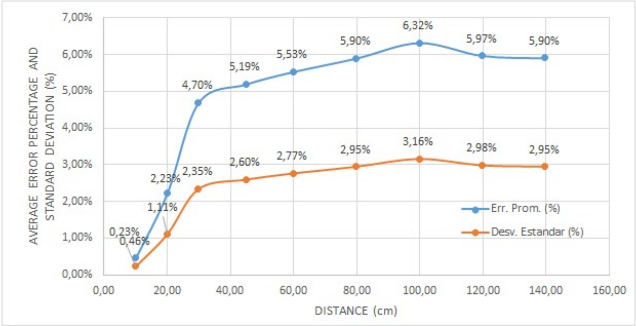
Figure 9: Average error and standard deviation of linear motion.



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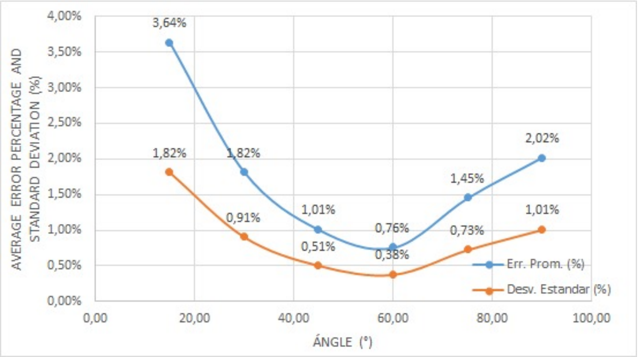
On the other hand, figure **10** shows that the values suitable for angles close to 60° have the lowest average error (0.76 %) and standard deviation of 0.38 % and angles close to 30° must be avoided as they have the greatest error in the movement of the robot.

Figure 10: Average error and standard deviation of angular motion.



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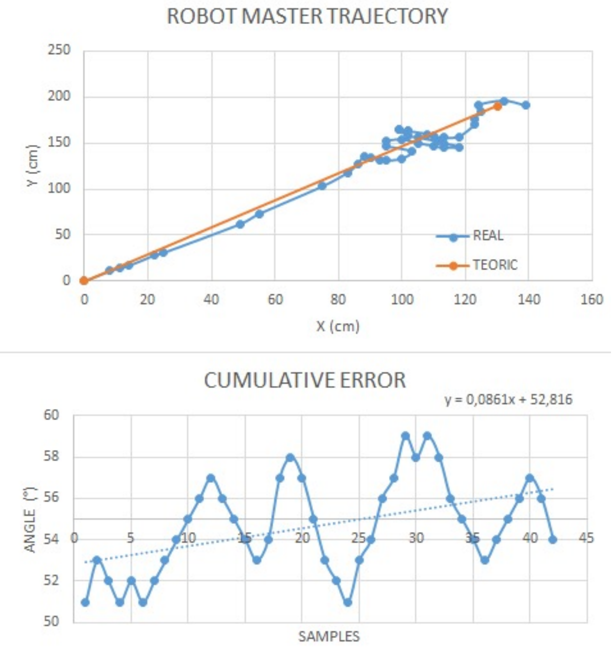
When comparing the error of the values given by equation (7) with the error of the data of (MCS) for a given point, the lowest value is taken from φ for equation (8) which represents the matrix of the kinematic model [9].

$$P = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} = \begin{bmatrix} -0{,}0226 * sen\varphi & -0{,}0226 * sen\varphi \\ 0{,}0226 * cos\varphi & 0{,}0226 * cos\varphi \\ -0{,}1733 & 0{,}1733 \end{bmatrix} * \begin{bmatrix} \theta_L \\ \theta_R \end{bmatrix} \qquad (8)$$

By means of the tests carried out it was observed that the behavior of the MCS is appropriate for angles from 0° to 90° reducing the cumulative error of the master robot that calculates its current and final position by means of (8).

Figure **11** shows the real vs. theoretical displacement of the master platform, showing a systematic error of 6 %, generated by the odometric and magnetic compass errors.

Figure 11: Master robot cumulative error.



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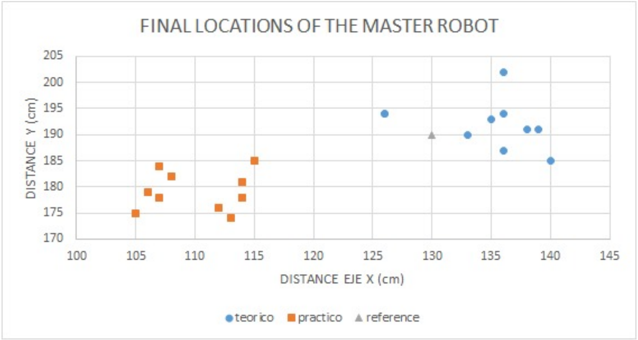
When observing the different final locations of the robot, precision, range and standard deviation are calculated, choosing errors less than 20 % so that the convoy fulfills the objective of approaching the final point as shown in Figure **12**.

Figure 12: Final master robot location for the desired coordinate x = 130, y = 190.



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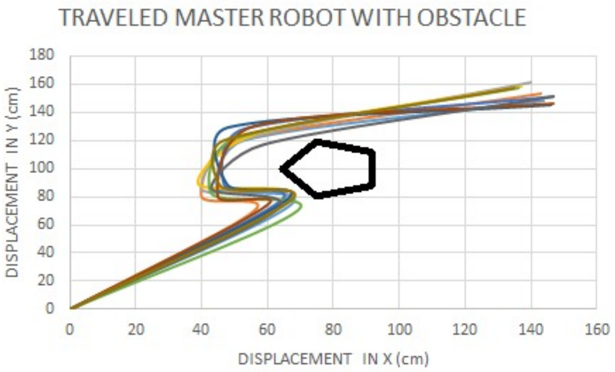
Several tests were performed placing an obstacle (three-dimensional pentagon) in the trajectory of the convoy, a reading range was determined for distances greater than 10cm and less than 30cm, when detecting the obstacle within this range the master robot rotates 90°, advances 20cm and recalculates the trajectory to go to the end point as shown in Figure 13.

Figure 13: Convoy travel for a final coordinate at x = 140, y = 150 with obstacle.



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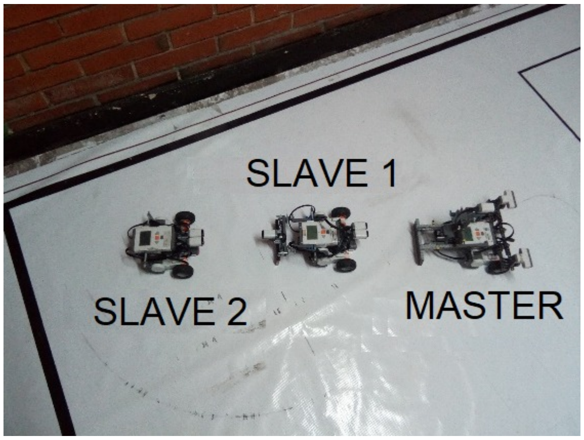
To always maintain the convoy formation, there is a separation distance between the robots of 10 to 20 cm, using ultrasonic sensors, to follow the master robot, we used the infrared communication determined by the IRSEEKER and IRLINK sensors, as shown in Figure 14.

Figure 14: Convoy training within a controlled environment.



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Finally, a Bluetooth communication is established to send data from the master robot to the slave robots in order to define which one is integrated into the convoy before the route or which one abandons the training during the route.

4. Conclusions

Three mobile robots were trained in a convoy, where by means of sensors they move within a controlled environment reaching an established end point, keeping a Bluetooth communication where the master knows in real time which slave joins or leaves the training.

By means of the physical characteristics of the master robot, its current position is known, with a systematic error of 6 %, an approximation to the final point with an average error of 20 % and an infrared communication that is kept in a range of -90° to 90° to look for linearity in the formation.

By implementing Bluetooth communication in real time it is known through the master robot which slave is joining or leaving the training, knowing in turn the number of robots that are part of the training.

5. Future jobs

Establish an algorithm that sets autonomy for slave robots, as they are dependent on the master robot, if this does not work, cannot perform training in convoy.

Use more robust platforms that can reduce the percentage of error in terms of perception, performance, communication and system processing.

Implement a more stable communication, since the robots are affected by the environment, sometimes being unable to integrate into the training.

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