NAVIGATION AND SENSING SYSTEM ON A FIREFIGHTING ROBOT

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Abstract. *The surveillance and fire control is known as a hazardous operation, which the firefighters are in front of dangerously when extinguishing the fire or rescuing the victims, which are an inherent parts of the profession. In contrast, a robot can operate autonomously or controlled from a safe distance to run this type of activities, without risking the life of the firefighter. This research focuses on sensor fusion and navigation of a robot with intelligent vision, receiving signals from sensors and specialized control chaotic to reduce human, material and environmental injuries. A real robot moves in spaces with boundaries like walls or surfaces of obstacles. To solve this problem, we consider the motion of the robot in an imaginary space. This imaginary space is obtained by smoothly connecting boundaries of two spaces that have the same shape as the real space.*

Keywords*: Fire Fighting Robot, Chaos, Intelligent Vision*

1. INTRODUCTION

The fire incidents have arisen with the discovery and use of fire are closely linked to advances in human civilization. With the development of national economy and changes in human activities, there are some characteristics in fires that need to be considered. The life and human health, expansion and advantage of the economy and the increasing need for fire safety is immediate concerns that provided the initial incentive for the advancement in science and technology of fire (GUO, *et al.*, 2007).

There is a growing need in mobile robots in unknown environments and challenging. A fire inside a tunnel, a human being trapped under the rubble of a collapsed building or a propane tank fire threatening to explode, is the dangerous situations that need today human intervention to be resolved. This requires the emergence of robust and intelligent robots that can support and replace human intervention in these situations while minimizing the risk to which humans are exposed.

A major advantage of using a robot in the firefighting operation is its potential ability to handle levels of heat and radiation. A robot can be used during a fire in many ways. In addition to fighting the fire with water, can help to analyze the situation by proving a vision camera to the firefighters outside. Locating victims trapped inside a burning building that is essential before you start fighting the fire. A robot equipped with adequate instrumentation could act effectively in the smoke detection and provide oxygen to the victims.

The firefighting and rescue mission is recognized as a risk situation that firefighters face when they are dangerously putting out fires and rescuing victims, being an inherent part of this profession. In contrast, a robot can operate autonomously or be controlled from a safe distance to perform rescue activities without risks with the lives of firefighters. In others words, the robot reduces the need of the firefighting being exposed to some dangerous situations, reducing the dangers to which exposed. According AMANO (2002), we can say that the first rescue from the fire department is the live of the firefighter.

2. NAVIGATION CHAOTIC WITH OBSTACLES

Chaos theory is one of the richest and most mysterious behaviors of nonlinear dynamic systems. Much research has been conducted to establish the mathematical theory behind chaos; for example, chaos control and chaotic neural networks (Freeman, 1994) in search of simple rules.

This section presents a study for trajectories for mobile robots based on dynamic characteristics of chaotic systems for their implementation on firefighting robots (Martins-Filho & Macau, 2004, Jansri, et al., 2004). This is achieved by designing a motion controller with chaotic characteristics. A transitivity topology (property of chaotic movements) ensures full connection with the workspace (Nakamura & Sekiguchi, 2001). This method of construction of trajectories is slated to land exploration missions, with the specific purpose of observation or patrol, where a quick scan of the robot's workspace is needed. As a result, the trajectories of mobile robots seem highly opportunistic and unpredictable to external observers and characteristics of trajectories guarantee a quick exploration of spaces.

Mobile robotics, after decades of continuous development, continues to be a subject of intense research because of its increasing application in different areas and its technological and economic impact. Interesting applications can be seen in the execution of floor cleaning, industrial transport, and mining, scanning areas to find different types of materials and so on. This research discusses how mobile robots are used to transport materials in an area. For the mathematical modeling, let us assume a mobile robot like the one shown in Figure 1. Let linear velocity of the robot $v\left[\frac{m}{s}\right]$ and angular velocity $w\left[\frac{rad}{s}\right]$ are inputs of the system.

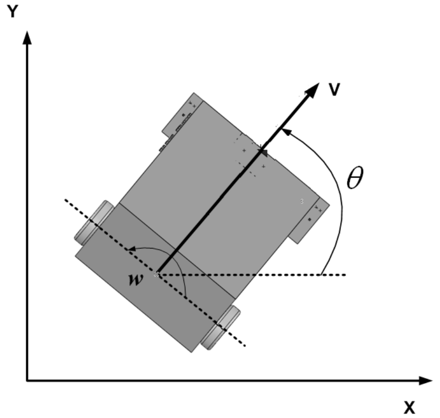


Figure 1. Mobile Robot

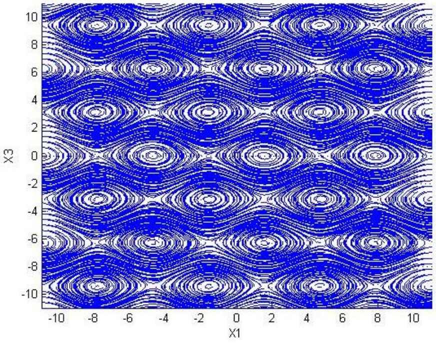
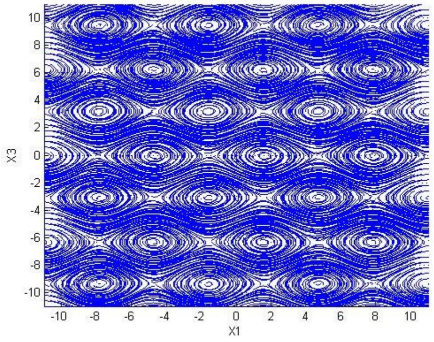
The state equation of the mobile robot is:

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ w \end{pmatrix} \tag{1}$$

Where $(x[m], y[m])$ is the position of the robot and $\theta[rad]$ is the angle of the robot. In order to make the robot move in a chaotic fashion, one system that can be used is the Arnold equation:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{pmatrix} = \begin{pmatrix} A\sin x_3 + C\cos x_2 \\ B\sin x_1 + A\cos x_3 \\ C\sin x_2 + B\cos x_1 \end{pmatrix} \tag{2}$$

The Arnold equation describes a steady solution to the three-dimensional Euler equation which expresses the behaviors of noncompressive perfect fluids on a 3-D torus space. It is known that the Arnold equation shows periodic motion when one of the constants, for example C, is 0 and shows chaotic motion when C is large.

$A=1 \quad B=0,5 \quad C=0$	$A=1 \quad B=0,5 \quad C=0,05$
	

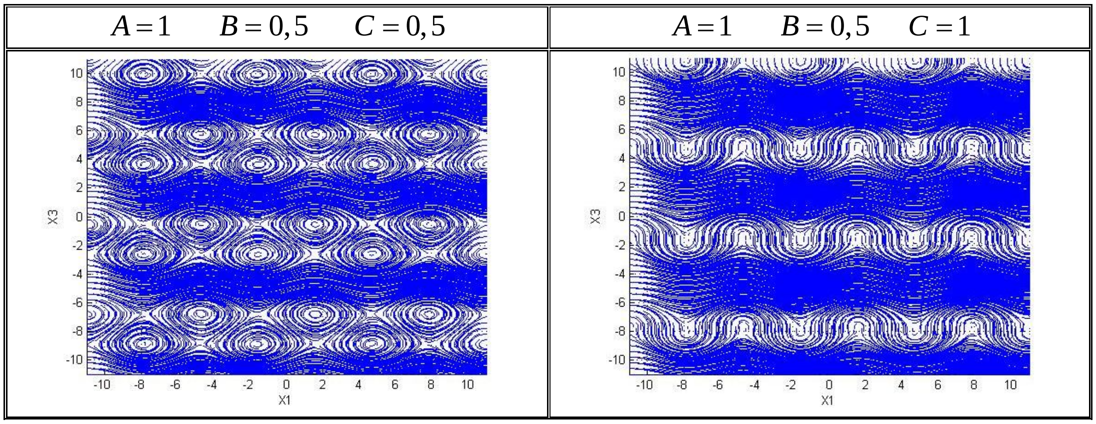


Figure 2. Poincaré section of Arnold flow.

These states evolve in a 5-D space, which includes 3-D subspaces of the Arnold flow. The states evolution in the 2-D complementary space is highly coupled with that in the 3-D subspace as seen in (3).

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} A\sin x_3 + C\cos x_2 \\ B\sin x_1 + A\cos x_3 \\ C\sin x_2 + B\cos x_1 \\ v\cos x_3 \\ v\sin x_3 \end{pmatrix} \tag{3}$$

The inputs applied to the robot are continuous since the Arnold equation describes a continuous system. We could have used the Rossler equation, the Lorenz equation, or even others well known continuous chaotic systems of lesser dimensions, but choosing Arnold´s equation has the following advantages: (i) Arnold´s equation and the mobile robot equation structures are similar, (ii) It is easy to deal with it because the state variables are limited within a 3-D torus space, (iii) The range of the input w becomes   which is suitable for robot input, and; (iv) The maximum of the state variables are determined by the parameters A, B and C.

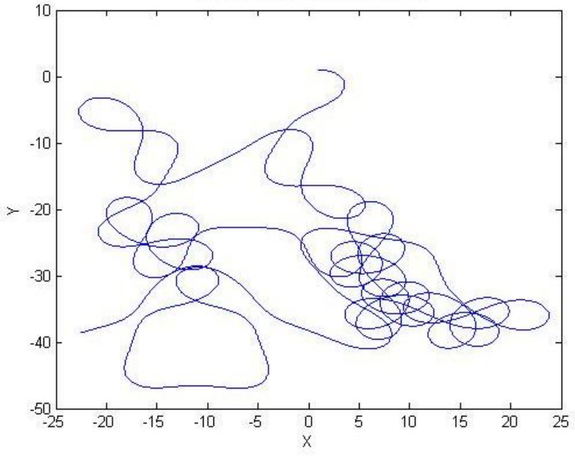


Figure 3. Trajectory of the mobile robot.

Figure 3 shows an example of motions of a mobile robot with the proposed controller, obtained by numerical simulation. The initial conditions were chosen from a region where the Poincare section produces a closed path trajectory. It is observed that the motion of the robot is unpredictable and heavily dependent on the initial conditions chosen.

Automated Guided Vehicles moves in spaces with borders (or boundaries), such as walls or obstacles. To help overcoming this problem, an imaginary space is considered. This imaginary space is obtained by connecting two spaces whose borders have the same shape in a real space. Blowing air on the surface and allowing an elastic deformation allows the robot to move smoothly between the two sides of the border. The AGV moves on a imaginary surface (workspace) described by the mathematical model, while in the real space the robot movement is like it would be perceived from the top view of the imaginary space.

However, for observation, it is necessary to apply the transformation of coordinates of the left system to the right system. That is the reason it is called mirror mapping. In real space, the mobile robot moves and is reflected by the border. To avoid a barrier mirror mapping is considered (Bae, 2004) when robots approach walls or obstacles. Whenever the robot nears a barrier, the new position of the robot is calculated using the equations.

$$A=\begin{bmatrix} Cos\theta & Sin\theta \\ Sin\theta & -Cos\theta \end{bmatrix} \tag{4}$$

$$A=\frac{1}{1+m}\begin{bmatrix} 1-m^2 & 2m \\ 2m & -1+m^2 \end{bmatrix} \tag{5}$$

When the slope is infinitive, it is necessary to use equation (4) and when the slope is not infinitive, it is possible to use equation (5). The procedure employed is based on the principle of mirror mapping, with the variant that the robot´s position will be directly recalculated. The coordinates x and y are necessary in order to allow avoidance of obstacles or crossing the boundaries of the workspace. Examples of trajectories using mirror mapping are shown in Figures 4 and 5, with the coordinates initially set to the boundaries of the workspace for different value ranges. The processing time is 4.4903 seconds for Figure 4 and 4.8490 seconds for Figure 5.

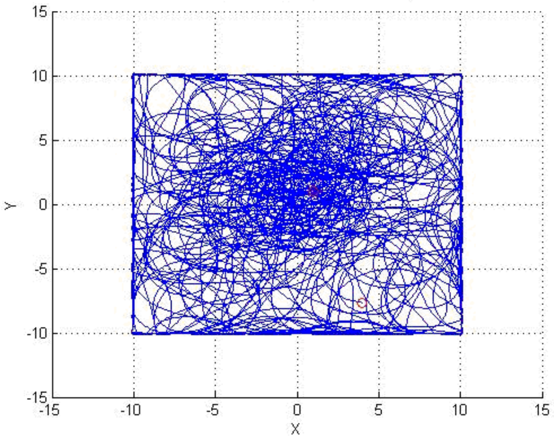


Figure 4. Mobile robot trajectories with boundaries.

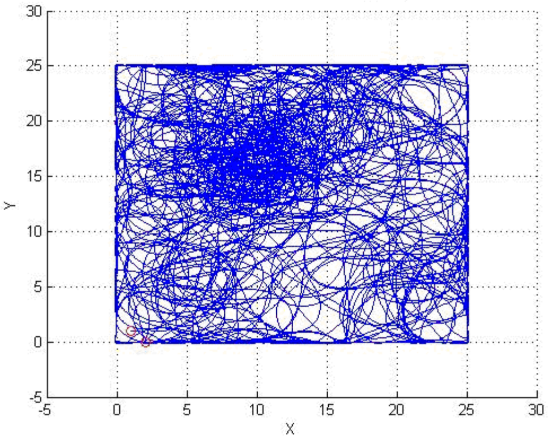


Figure 5. Mobile robot trajectories with boundaries.

To continue our analysis, we applied an obstacle with the same parameters shown in Figure 5. This generated Figure 6, but with a processing time of 3.4524 seconds, less than that obtained in the simulation without an obstacle with the same parameters.

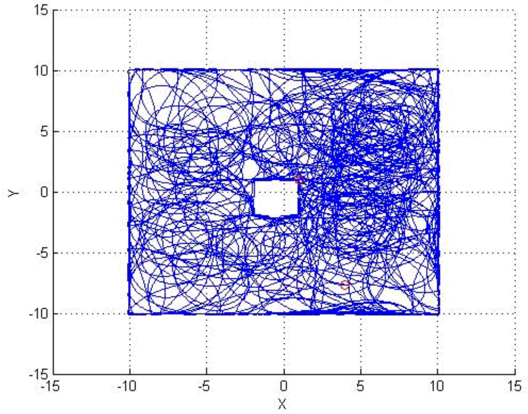


Figure 6. Mobile robot trajectories with boundaries and one obstacle.

With a larger obstacle near the boundary, the robot maps the space as shown in Figure 7. With 8000 seconds in the simulation time the processing time is 5.0652 seconds.

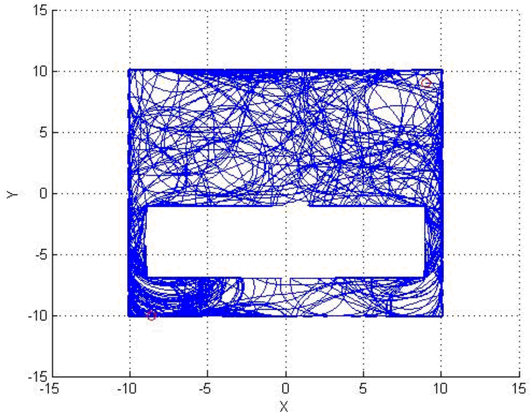


Figure 7. Mobile robot trajectory with boundaries and one obstacle.

Increasing the number of obstacles (Figure 8) and with a simulation time of 6000 second, the processing time increases significantly to 150.9973 seconds.

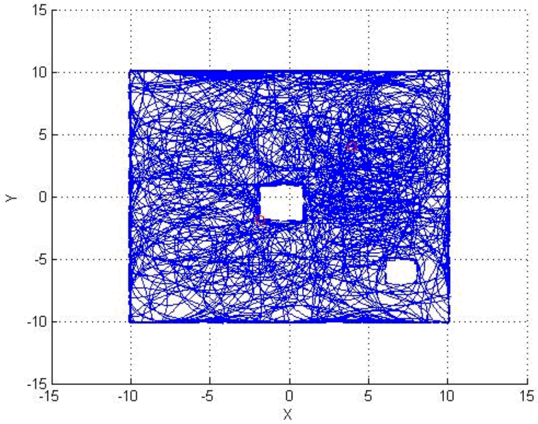


Figure 8. Mobile robot trajectory with boundaries and two obstacles.

With different boundaries, Figure 9 is generated with a processing time of 165.0989 seconds.

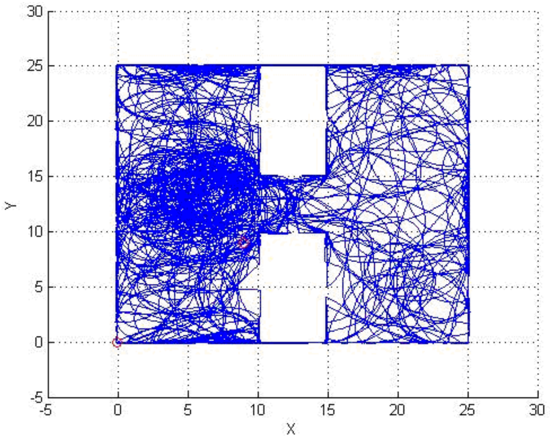


Figure 9. Mobile robot trajectory with boundaries and two obstacles.

3. INTELLIGENT VISION

Vision is the most important sense for humans. Without any physical contact, it gives us an extraordinary quantity of information about the environment, conceding us to interact with it. Thus, it is natural that many operations have been developed to group the machines with some sense vision. However, vision is our sense more complex (FRANCE, 2005). The human vision system works with a pair of stereo images to help in determining the third dimension from two-dimensional images from each eye. Each eye captures its own view and the two images are sent separately to the brain for processing. The brain blends the two images by a combination of similarities and adding the small differences, thus detecting the three-dimensional image (CARQUEIJA, 2003).

Figure 10 shows a typical problem situation in which two cameras looking a scene, capture two-dimensional representations of the same three-dimensional object. In an appropriate processing allow the two images are recombined, regenerating the three-dimensional information misplaced. The feature extraction of depth can be obtained using some trigonometric observations

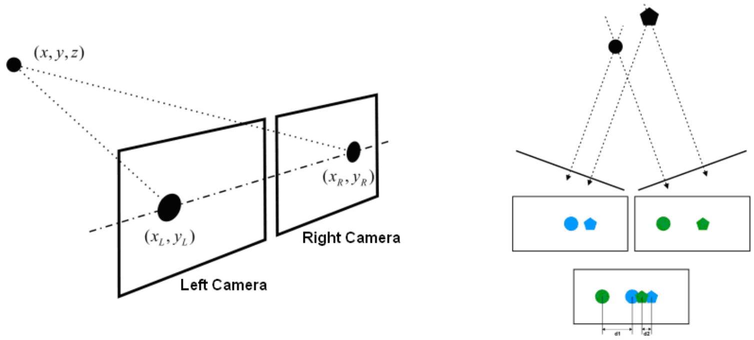


Figure 10. Typical problem in stereo vision (Calin, 2007).

3.1. Calibration

The calibration of the camera image is a process that calculates the parameters that explain the projection of a three-dimensional point (3D) world, at a point (2D) image. Such parameters include the internal geometry and optics of the camera as well as it's positioning and orientation in 3D space. The use of correctly calibrated imaging cameras allows solving problems related obtaining 3D position and orientation or 3D reconstruction of objects from images. This allows, among other tasks, the 3D tracking of an object, the 3D reconstruction of the geometric shape of objects or scenes or to calculate the position and orientation(s) camera(s) associated with a given image. (Zhang, 1999).

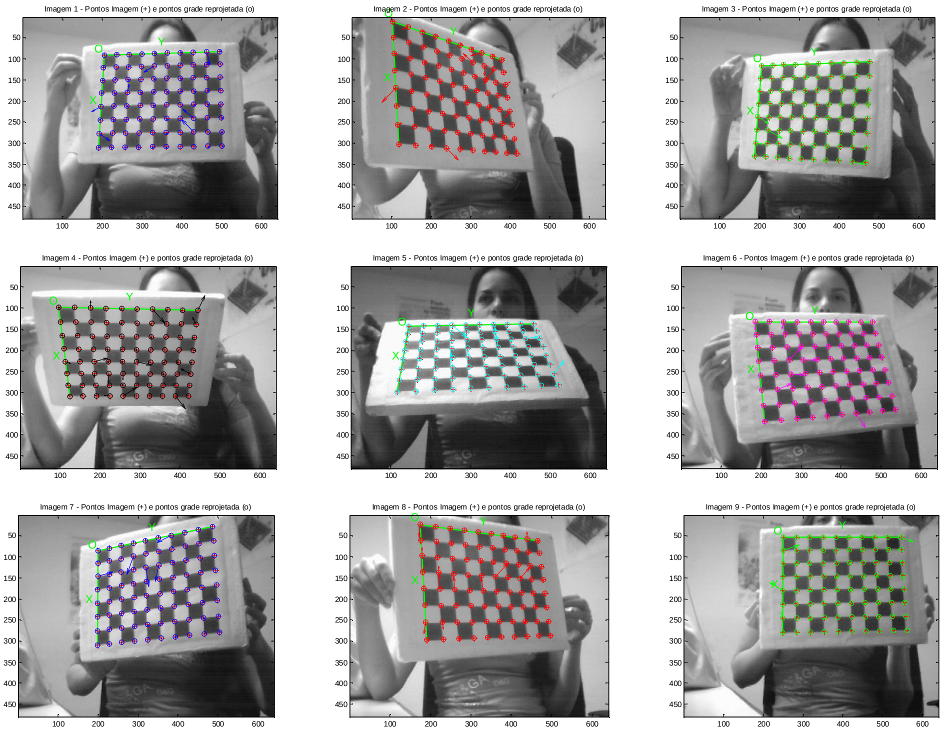


Imagem 1 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 2 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 3 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 4 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 5 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 6 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 7 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 8 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 9 - Pontos Imagem (+) e pontos grade reprojetada (o)

Figure 11. Images Calibration from right camera.

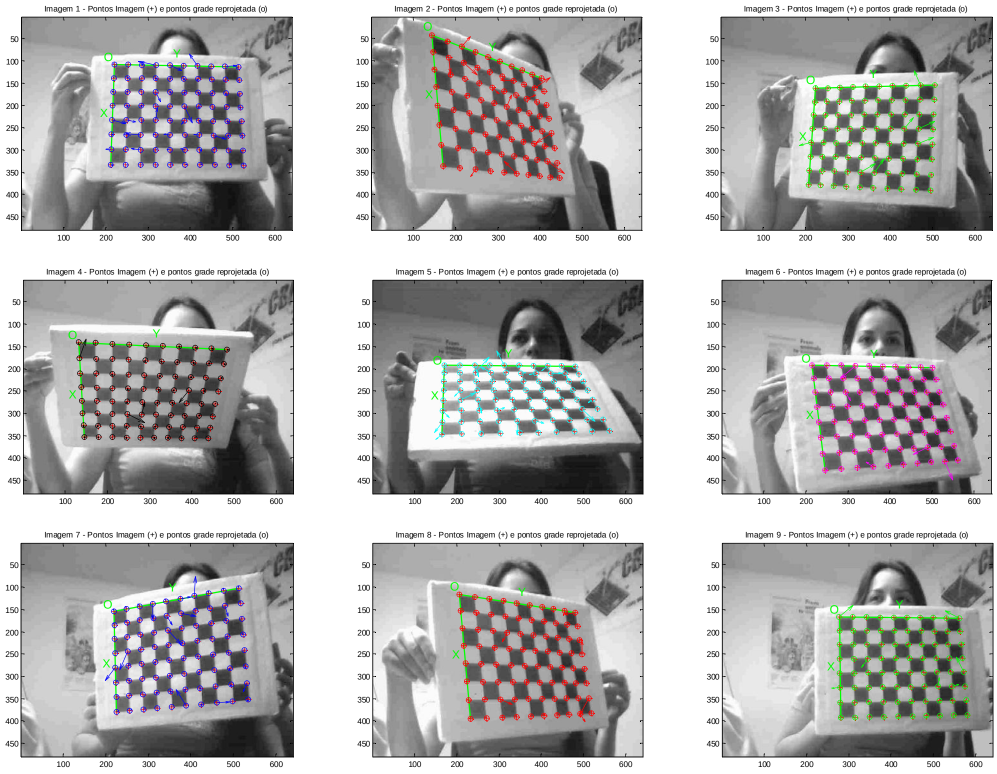


Imagem 1 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 2 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 3 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 4 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 5 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 6 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 7 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 8 - Pontos Imagem (+) e pontos grade reprojetada (o)
Imagem 9 - Pontos Imagem (+) e pontos grade reprojetada (o)

Figure 12. Images Calibration from left camera.

3.2. Region depth maps with stereo matching algorithm

Acquiring reliable depth maps displaying the distance from the surface of two cameras (stereo vision), have important applications in robotics and autonomous systems. In a typical stereo vision system consisting of two cameras, the disparity correlated with any point in an image can be viewed as the apparent shift between this point and its counterpart in the other image. The point of this reconstruction technique is the determination of homologous points between two images, since that determination depends on the quality and accuracy of the reconstructed scene.

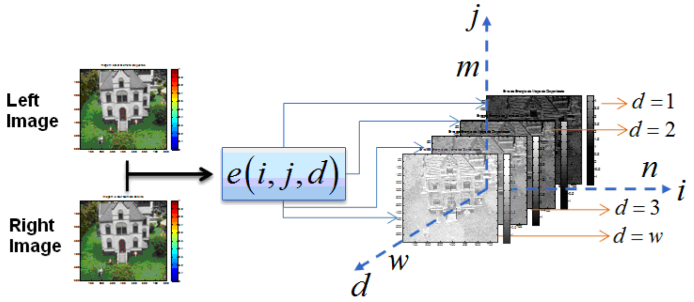


Figure 13. Construction of error energy matrix.

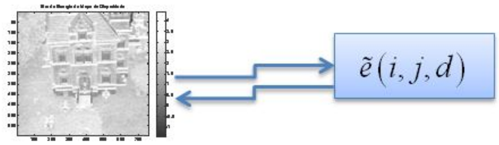


Figure 14. Smoothing of energy matrix for all disparity values.

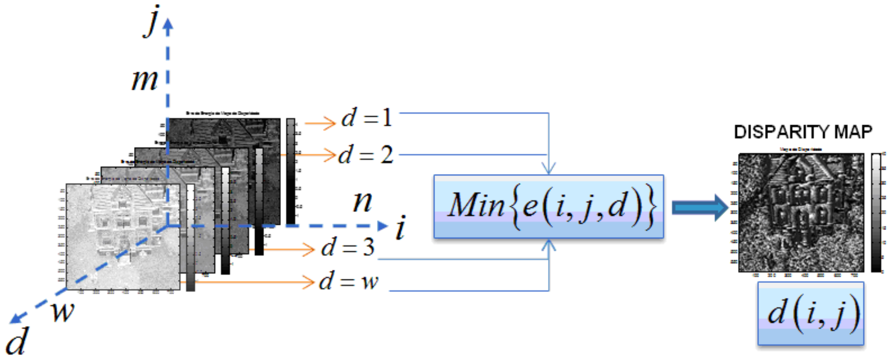


Figure 15. Generation of disparity map for points of minimum energy.

4. CONCLUSION

The main question of this research associated with mobile robots in service environments is the creation of autonomous detection and recognition systems to improve navigation and to perform tasks that are more robust and efficient. To answer this question, this work proposes a new technique for navigation systems, incorporating chaotic behavior in the navigation to improve obstacle avoidance and also employing the methodology of coordinate systems mirror mapping in the robot´s control. Finally, this work was based on the chaotic dynamics of the Arnold equation to integrate mobile robot and the behavior of the equation was analyzed. In addition, presented the controller design so that the dynamic mobile robot is characterized by the equation studied.

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