VIGICOP: Autonomous Surveillance Robots with Sodar Detection and Autonomous Navigation

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Abstract - The main goal of the project described in this paper is to create a security system using autonomous surveillance robots that use SODAR-like detection system sensors, working with acoustic signals in air environment and navigation base on Geographic Information System and Markov´s models. The surveillance system based on SONAR provides great information from the environment, even lets you see behind objects (rebounds effects) whose manipulation offers a great added value to surveillance The guide system will implement in one hand a local navigation module directed to avoid obstacles based on classical techniques and using the new SODAR sensor. On the other hand a global navigation module will be implemented using preset trajectories and gradient techniques and an auto-location system. One of the greatest challenges obtained is the definition of the VIGICOPVar variable that defines, depending on the environment and safety parameters, the probability of intrusion. Surveillance experts of GRUPO NORTE (multinational company with security expertise of more than 38 years) have worked In the definition and validation of the model. The monitoring robots will be controlled in a centralized way from an alarm center from where you can manage all information relating to intrusion detected. VIGICOP is the low cost surveillance robot which provides new/full information interactive surveillance information.
. Note: VIGICOP is the R&D project name. It is not a commercial name or mark

Index Terms – robot, SODAR, sensors, command, control, surveillance,

I. INTRODUCTION

The application of mobile robots to surveillance tasks has been present in literature for decades (i.e. [1]), and today there are many commercial solutions available, for instance [3]. However, there are many open issues that have prevented this technology becoming pervasive. In this paper we propose to combine novel SODAR sensors and autonomous localization and navigation to improve the performance of surveillance robots in every-day life.

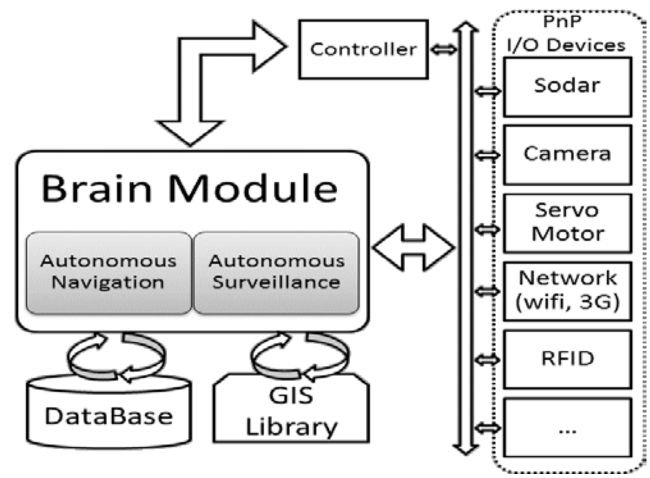
SODAR sensors work with acoustic signals in aerial environment, allowing creation of acoustic maps which can be used for target detection, discrimination and monitoring. The sensor array can also be rotated, allowing an enlargement of the security area. Intruders' camouflage or silent movements would not be able to fool this sensor as it has always been with the image analysis algorithms or simple microphones' signals study.

Another contribution of the proposed system would be its ability to operate semi-autonomously in some situations. Human operators may have different ways to handle the robot depending on the situation. In a normal surveillance time, the robot will follow pre-defined and random paths autonomously. When a human operator needs to check a specific area or a blind spot not reachable by the surveillance cameras, he can take direct control of the robot and tele-operate it. After robot's teleoperation is over it is able to return to its regular/random path without supervision and resume its regular surveillance mission. In order to implement these functionalities autonomous self-localization and navigation capabilities have to be incorporated in the robotic platform.

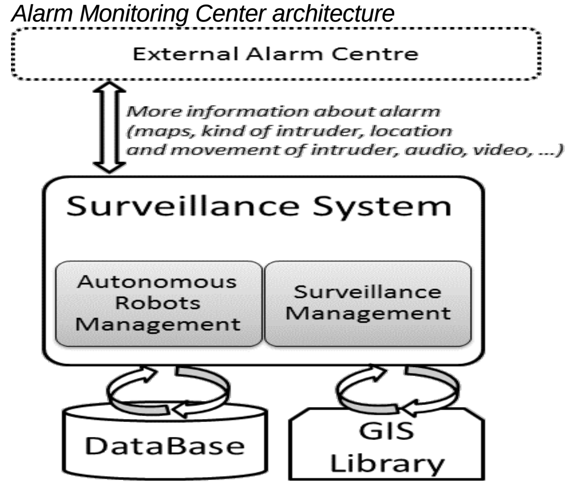
II. VIGICOP SYSTEM ARCHITECTURE

VigiCop system has defined four modes of operation:

A. Autonomous robots architecture



B. Alarm Monitoring Center architecture



It is a web platform with the following features:

- Automatic robots discover.
- Drivers device management. That characteristic allows PnP functionality – previous check security parameter of each robot -.
- From the platform each of the equipments assigned within the same group can be managed. From the application it can be added and removed group equipments, managed the state signals and warnings provided in every one, both for errors and alarm signals if an intruder detection.
- Reception and viewing of audio / video from the camera and microphone built into the robot. The management application system allows reception of both video / audio and it also permits the viewing / listening of them both. This will encode the video streaming allowing the application to consume this content management. This application also allows through a series of control movements of the camera built into the robot in its two axes, to focus on an area of at least 120 degrees around the robot vision.
- Send audio signal from the application to the integrated speaker on the robot. When a presence is detected, it is possible the activation of a series of integrated speakers on the robot which send an acoustic signal and even voice across the network.
- Receive and display the signal from the acoustic sensor. The acoustic sensor signal can be translated into an image changing over time, which can encode a video. The video signal can be seen from the management application through the same transmission via streaming.
- Control unit remotely. The robot can operate in two modes, one independent and one assisted.
- Survillance Management. User friendly module. The module assists user to define the level surveillance, ViGiCOPvar, surveillance maps, etc.
- External Alarm Centre Communication. The system implements interfaces with Alarm Centres. The goal is the information which intrusion is documented.

III. SURVILLANCE OPERATING MODES

VigiCop system has defined four modes of operation:

A. Acquiring Mode

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Once the scheduler has assigned a surveillance sector to the robot, and through an autonomous navigation mode, the robot is able to run sequentially all the surveillance area. At regular intervals the robot stops its movement and defines a control point obtaining an active acoustic image and a visual image which associates with the checkpoint. These images are stored in the BBDD management system for further comparative analysis, monitoring mode (Surveillance mode)

B. Surveillance Mode

Routinely, the robot runs along the assigned surveillance sector, so that when it reaches a checkpoint, it stops motion and acquires an acoustic image This image is compared with the one obtained in the acquisition mode, analyzing their differences and detecting the presence of targets, which are classified as outsiders. Each target position is estimated 2D and a video image is acquired.

Thus, the robot's movement within the surveillance area can be quasi-random (avoiding trajectory analysis by outsiders) or defined

C. Tracking Mode

For the intruder / intruders detected the robot activates the monitoring mode, directing periodically a narrow acoustic beam to each of the targets, calculating with precision its position, size (calculating an estimate of its sodar section), speed and trajectory. Analogously the scene is captured on video by pointing the camera at the intruder, as well as passive listenings of the array of microphones are made for its monitoring and subsequent analysis

Regardless of the preliminary operation modes, the robot randomly performs a passive listening of the microphone array, detecting the presence of acoustic signals and estimating where the angle of arrival is and then calling on the tracking mode

It also has other modes which are not included within the monitoring as eg travel mode based on load, the load mode / stand by, etc.

IV. SODAR SENSOR

A. SODAR-like detection system

Within the set of surveillance sensors based on the emission of a signal and its reception reflected on a target, this project is focused in SODAR-like systems, which work with acoustic signals in aerial environment.

The basic functions in a detection and surveillance system are two:

1. To detect with the maximum probability the set of present targets within a predefined space of surveillance.
2. To establish with the maximum precision, the current position of every target and to predict its future path.

These features are called respectively surveillance and monitoring.

Traditionally, surveillance systems have used mono-sensor antennas with a fixed radiation pattern. If you want to monitor a larger surveillance area than the one covered by the radiation pattern, these antennas have to be positioned mechanically by a rotor that rotates with constant speed or by a pair of servomotors. Each of the function (surveillance and monitoring) requires a specific antenna system that leads to the existence of several independent systems associated with different functionalities

These kinds of systems can target almost instantly the antenna beam to any position in space, facilitating a new generation of surveillance systems, which allow to combine the tasks of surveillance and monitoring, called multifunction radars. Multifunction radar has several ways to operate, using for each of them a set of parameters: waveform, energy, PRF that must be designed properly.

In surveillance mode the space is divided into a set of sectors, applying to each of them a different refresh rate, depending on the operational scenario, the danger of the sector or the system load. It allows you to confirm quickly the new detections, initiating a new track or discarding a false alarm. In monitoring mode, it allows to monitor several targets simultaneously, with individual and adaptive parameters in terms of its danger, distance, manoeuvrability etc. Similarly it may acquire and initialize faster tracks.

B. Elements of an acoustic radar

The acoustic radar sensor consists of the following elements:

- Array of sensors (microphones and / or speakers): between 8 and 32 sensors placed in a linear array. Based on further analysis may be located in a rotating system or several switchable arrays.
- Acquisition signal system composed of a bank of A / D converters (microphones) and D / A (speakers).They permit to transform the electrical signals to an average format for further processing.
- Adaptive signal system: consisting of a set of rectifiers to adapt the electrical levels of signals between the sensors and A / D and D / A converters.
- Average processor (DSP / FPGA) to implement all signal processing algorithms (conformation, target detection, etc.). It also integrates the controller system in charge of managing the remaining items, setting the task to run at any time and communicating with other modules.

Among the main features that integrate acoustic radar sensor are:

- Creation of acoustic maps of monitoring environment: using the array sensors and beamforming algorithms the radar will be able to create acoustic maps of the area of surveillance of 90 degree opening between -45 and 45 degrees and a maximum distance of 10 meters, with an accuracy of 0.5 meters at the maximum distance.
- Target Detection: After the proper processing of the acoustic map, a list of possible targets in the surveillance space is obtained by fixing their position in relation to the robot.
- Target Discrimination: taking into account the characteristics of the array of sensors and the environment monitoring as well as the background information or the one obtained by other robot subsystems, we can carry out target classification distinguishing between static targets (walls, furniture, etc.) and dynamic ones.
- Enlargement of the security area: through mechanical rotation of the sensor array or the switching of different arrays of sensors with different orientation, the surveillance could be extended to 360º
- Monitoring targets: A detected targets log will be stored making possible to establish a tracking of their position in every moment
- Autonomous operation or guided mode: there are two modes:
  - Standalone Mode, in which the acoustic radar sensor performs a continuous monitoring of the surveillance area generating an alarm upon new targets detection and guided mode, used to confirm the presence of a target based on information coming from other sensors of the robot.
  - Dynamic Performance: The mentioned functions imply a static operation, meaning that the robot does not move. The algorithms used to extend the systems work where the robot moves at a constant speed are analyzed.´
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V. AUTONOMOUS NAVIGATION MODULE

One of the requirements for VIGICOP surveillance system is that robots can operate autonomously, that is, the robot should be able to make certain high level tasks as “patrol this area” , “go to that position” , etc. In order to do so, our robots need to solve the classical problems of mobile robotics: local navigation, global navigation, and self-localization.

A. Local Navigation Sub-Module

The goal of this sub-system is to give the robot the ability to avoid dynamic obstacles, that is, it will drive the robot once a target is established. This module is based on traditional techniques, particularly VFH [2].

The idea of this method, as illustrated in figure 1 is to calculate the heading direction using the concept of potential fields, or force fields. This method is known as the virtual force field (VFF). The VFF method works as follows:

1. Each detected obstacle (at (i,j)) applies a virtual repulsive force $F_{i,j}$ toward the robot. This force magnitude is inversely proportional to d^2, where d is the distance between the obstacle and the robot.
2. Next, all virtual repulsive force vectors $F_{i,j}$ from the detected obstacles are added up to yield the resulting repulsive force vector F_r.
3. A constant-magnitude virtual attractive force F_t is applied to the vehicle by the target. The summation of F_r and F_t yields the resulting force vector R.
4. The steering of the robot is aligned with R to avoid obstacles present in the environment.

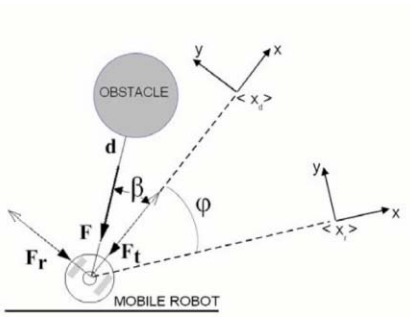

Figure 1: Calculus of the heading direction using VFH

Local Navigation Module uses the SODAR module functionality. The aim is to keep the robot in a safety margin of 50% of the margin size that is achievable in the case of ultrasound.

B. Global Navigation Sub-Module

This module deals with the problem of generating new paths, for instance, when returning to pre-defined paths after human tele-operation of the robot or coming back to the charge station. These routes can be generated either by setting a destination or by intermediate points.

We propose the use of a gradient propagation technique, which basically consists of calculating the minimum cost path from the target to the current location of the robot (a shown in Figure 2).

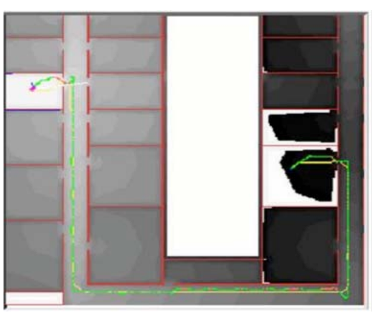

Figure 2: Gradient propagation

The main idea that involves the gradient method [7] is to define the navigation function at a point to be the cost of the minimal cost path that starts at that point, which can be expressed as:

$N_k = min_{P_k} F(P_k)$

, where the path P_k starts at that point *k*. In the general case, travelling along the gradient of *N* is a minimum cost path to the defined target. However, computing the values of previous equation at every point is difficult, since the size of the configuration space can be large, and finding the minimal cost path involves iteration over all paths from the point.

In this paper, we do not attempt to solve this problem. Instead of that we use a wave front algorithm. We assign a value of 0 to each target in this algorithm. In each iteration, the points with value *n* are expanded to their nearest neighbours, giving them a value of *n*+1 if they are not already assigned, and are not obstacles. This process is repeated until every point has been assigned a value.

In this module we can tolerate the location accuracy is small. It will distinguish between different areas (rooms, corridors in an office building for instance). In that way, our requirement is that the path tracking will be performed with precision in the benchmarks not exceeding 100% the size of the robot. This method has been tested in limited resources robots with a good performance.

C. Self-localization Sub-Module

Autonomous self-localization ability is the process of estimate the position of the robot on a given map using only the information given by range sensors. There are many methods available to know our position depending on the number of sensors that the robot incorporates: laser, camera, infrared, etc [6].

In order to implement a self-localization mechanism, two approaches can be considered:

1. Local localization, when the initial robot position is known.
2. Global localization, when the robot does not know the initial position.

In the surveillance robot designed we propose to use a localization technique using Markov models to robustly track the robot position. Markov model estimates the position of the robot using probability distributions. These distributions represent the belief *Bel* of the robot about its location, that is, the probability of being at each state *s*. These probabilities *Bel(s)* are updated when the robot reports it has moved or turned, and when it observes particular features of the environment.

In order to formulate this system, we can say that a Markov model consists of a finite set of states *S*, a finite set of actions *A*, and transition probabilities for all $s, s' \in S$ and $a \in A$. Initial proposition of an action model will be formulated as the probability the new state is *s*' if an action *a* is executed in state *s*. We also define a set of observations *o*. The probability that sensors reports observation *o* (feature *o*) when the robot is in state *s*. Note that we assume the Markov assumption, that is the transition and observation probabilities are determined only by the current state of the robot (the log of actions can be summarized by the last state and action).

Markov model is partially observable because the robot may never know exactly which state it is in. Instead of that, we maintain a belief of its current state in form of the probability distribution *Bel*(*s*) over the states $s \in S$.

This probability distribution is updated in two ways: When an action *a* is executed, the new probabilities are calculated as

$$\mathrm{Bel}(s_t) = \int p(s_t | a_{t-1}) \cdot Bel_{t-1}(s)$$

That is, we can define belief of the robot being in the state *s* at time *t* as the actual state conditioned by all past measurements *Bel*(s_{t-1}) and all past actions a_{t-1}. This is known as prediction step.

When a sensor observation is made, the probabilities become:

$$\mathrm{Bel}(s_t) = \eta \cdot p(o | s_t) \cdot Bel(s_{t-1})$$

This is known as the observation step. Note that the result distribution may not converge to 1 after measurement update step, for this reason the final result is normalizated by a constant η.

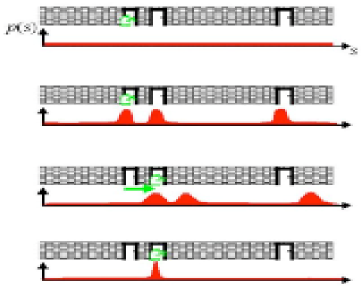

Figure 3: Probabilistic localization intuition

In figure 3 we present a classical intuition of this formulation (from [4]). In the figure we can observe a simple corridor with three doors. The robot starts from an unknown position at time *t*=0. Probability distribution about robot location *Bel* is represented by a red function. This distribution is uniform in the first row of the figure (the flat red line). The real position of the robot is represented by the green line

In the second row an observation has been made. The system has detected the robot is in front of one of the doors of the environment. As the robot does not know which of the doors it is observing, *Bel* distributes the probability among the three doors. In a second step the robot moves to the right and applies the motion model. The uncertainty associated to the execution of the action (modeled by $p(s_t|a_{t-1})$) increases the uncertainty, as shown in the third row. In the last row, the robot has made a new observation, detecting a new door. When integrating the probability of getting this observation (the same as in the second row) with the previous log (distribution in the third row), the new distribution of *Bel* has correctly estimated the real position of the robot.

It deserves a special mention, the interrelation between the Autonomous Navigation module (AN) and GIS (Geographic Information System) module. The AN used the maps defined in the GIS module and informs about the estimated position. This information is used by the Autonomous Surveillance module in order to know the acoustic map obtained in acquiring mode to compare with surveillance mode.

VI. COMPETITIVE ADVENTAGE OF VIGICOP

Thanks to the use of SODAR sensor with additional information of video and image sensors, this system allows to obtain improved information (Augmented Surveillance Data ") of the intruders, being much more superior to that obtained by convencional systems

This information consists of 2D position, the parameters cicmenaticos (speed, acceleration), the number and relative size of the intruders, the paths followed by the intruders, as well as the images associated with them

.Besides, The Sodar system permits to define adaptive detection thresholds and therefore allows to control system probabilities in relation to the detection and false alarm.

The alarm is documented with lots of information, allowing the Police Station to understand the situation better.

The parameterization, the analysis of information, and the new type of information is the main characteristic security companies value, enabling them to provide new quality services at low cost.

SODAR system costs are very low because it uses low frequencies, and the electronics costs are less.

Construction based on open interfaces and plug & play, new devices are annealed automatically by the robot controller and it also updated the control software of the central station.

VII. CONCLUSIONS AND FURTHER WORK

The completion of this project is driven by the quest for a competitive and economic solution to enable the introduction of these technologies in the security sector, because such systems provide the company a low cost solution to provide a security system generation customers who are unwilling to assume the high costs of surveys involving hiring skilled and they do not want to stay in traditional systems using detection sensors and surveillance cameras fixed deposit rates. Therefore, it is a new service of high performance and cost incurred by the sector.

VIII. ACKNOWLEDGEMENT

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