# Department of Electrical and Computer Systems Engineering

## Technical Report MECSE-32-2004

Covert Robotics, Developing Robots for Covert Missions

M. Marzouqi and R. Jarvis

MONASH UNIVERSITY

# Covert Robotics: Developing Robots for Covert Missions

Mohamed Marzouqi and Ray Jarvis
Dept of ECSE, P O Box 35, Monash University, Clayton 3800, Australia
{mohamed.marzouqi, ray.jarvis}@eng.monash.edu.au

**Abstract:** Covert Robotics is a name we have given for a relatively new and interesting research problem in robotics field which is presented in this report. The aim of this research is to create mobile robots with the ability to achieve different types of task (missions) covertly, i.e. without being observed by sentries, possibly hostile, within the same environment. The purpose of this research is to study and analyze the strategies, behaviors and techniques that can be used to achieve the required covertness in a mission.

## 1.0 Introduction

Most of previous and current research works in the field of autonomous navigation systems concentrate on planning an optimal navigation path, where the aim is to minimize distance, time or power [Nilsson, 1969; Jarvis, 1984; Khatib, 1986; LaValle, 1998]. In this research, we present a new, interesting problem in this field which we have called *Covert Robotics*. The aim of this research is to create mobile robots with the ability to achieve different types of task (missions) covertly, i.e. without being observed by sentries, possibly hostile, within the same environment. In a covert mission, being hidden (or unobservable) from others is the main concern to accomplish the assigned task successfully. The purpose of this research is to study and analyze the strategies, behaviors and techniques that can be used to achieve the required covertness in a mission.

A covert mission might need one or more of the following abilities in a robot to succeed:

- navigating from one point to another without being observed by possible sentries,
- hiding from a pursuer,
- tracking a target without being noticed or observed by the target itself,
- monitoring an area from a hidden spot,
- or searching/exploring an environment covertly.

Moreover, a covert mission might be carried out by two or more robots where information should be communicated and shared in order to achieve maximum covertness.

A covert robot can be used in many applications that require security such as in the police field for crime detection purposes, military and spying missions, or even for gaming industries and computer based simulations. As an example, a covert robot can be used in airports or a crowded environment to approach and perhaps track a suspected person without being observed by the person himself. Another example is to guard a secured environment, where it is important to be covert as well as overt at the same time to see the intruder before the opposite happens. A covert robot may be used as well for hostage rescue by sending a small sized covert robot with a camera onboard to the hostage area where it can covertly take number of images to send to the rescuing team to plan a good rescuing strategy. In addition, a covert solution should not necessary be built in a robot, it can be built as well in a handheld device carried by human who can interact with it to achieve a specific covert mission.

A question that may arise here: Can a covert robot perform better than a covert human? Humans have a wide range of sensing and reasoning capabilities that are not yet shared by current robots. However, since machines have the ability to process efficiently large amount of information faster than humans do, a covert robot may perform much better in situations where mistakes are not acceptable and fast and complex decisions are critical to maintain covertness. On the other hand, whether humans can perform better or not, Covert missions are usually dangerous and can put human life at risk. Robots can be used to minimize such risk.

## 2.0 Literature Review

In this section, a survey on relevant research in the field of covert robotics is presented. This literature review shows the weakness and the lack of interest in this area. One reason for this weakness can be due to the narrow fields where covert robots can serve. On the other hand, we believe that the interest will increase in the near future as the trust in robots to do such critical missions grows. The research works presented here are related in some respects to the general problem of covert robotics.

### *2.1 Hiding in Dark Spots*

Hiding in dark spots is a naïve method that was used in number of research problems as a covert behaviour for the purpose of security and surveillance missions [Rybski et al.,2000; Kratochvil, 2002]. In such research, the robot is equipped with a light intensity sensor which is used to search the environment for the darkest area where the robot can stand in to be hidden. One way to find the darkest area in an environment is by allowing the robot (or just the light sensor) to rotate 360 degrees on its position and measure the light intensity at each direction, the robot mark the direction which has the lowest intensity and navigate to it after a full rotation is completed.

This method can be good enough in some cases to make the robot less noticeable when it is in the view field of a sentry. On the other hand, hiding in the darkest place is not always the best place to hide as it might be not dark enough to be unobservable for sentries in the same environment, therefore the success of this strategy will depend heavily on the lighting of environment and the availability of the dark areas. This method can be an effective covert solution if it is used along with covert strategies that allow intelligent decisions to me made when choosing a dark spot than just depending on raw sensors readings.

### *2.2 Insect robots*

Insect robots is a recent topic that has been an interesting research field in the last few years. The aim is to develop robots that are small and may have the capability of flying (micro air vehicles) [Vaughan et al., 2000;

Spoerry and Wong, 1999]. This field has got the attention of many organizations such as military for surveillance and spying missions, and disasters rescue teams for finding survivors in places where human cannot reach (ex. under collapsed buildings).

In number of researches, where these insect robots are used for covert missions, the researchers are heavily depending on the small size on the robot to be unobservable. This assumption is realistic, especially with flying insect robots, where an insect robot is either difficult to be noticeable to an observer, or difficult to be recognized as a robot if it is observed. However, no other covert strategies are used in these researches other than depending on the robot's size.

Robots capabilities decrease along with their size. Insect robots are mainly used to collect information (e.g. take and send images taken by a micro camera on board). Other covert missions may need a larger robot in order to be accomplished (e.g. a mission might include carrying a heavy object). In such cases, different covert strategies should be used as the robot can not depend anymore on its size to stay hidden.

### *2.3 Pursuit-Evasion Game:*

Pursuit-evasion game is a known problem in autonomous robots field [Cheng, 2003; Vidal et al., 2002; LaValle and Hinrichsen, 1999]. This game is about guiding one or team of robots (pursuers) to track/catch one or group of robots (evaders). This game has got the researchers' attentions as it has a lot of challenges where there is the need to address a wide range of problems in perception, mobility, and reasoning.

There are different types of pursuit-evasion games. We are interested here on the type of problems where the pursuer(s) needs to search for, and maintain the visibility of moving evader(s) in a cluttered environment [LaValle et al., 1997; Suzuki and Yamashita, 1992]. As an example in [LaValle et al., 1997], the pursuer mission is to continuously calculate where it needs to be to ensure that the evader doesn't disappear behind environment's obstacle. The pursuer (overt) robot and the evader (covert) robot both have exactly the opposite mission. The pursuer needs to observe the evader most of the time, while the evader tries to be unobserved most of the time.

The hide-seek game which is another well-known research in robotics field that can be classified as pursuit-evasion problem [Moore, 1995; Mann, 2003]. In the hide-seek game (sometimes called *Tag*), the seeker robot is initially standing at a specified location which is called the "base", and the hider robot is given a limited time to find a location where it can hide. The hider stay at its position till the seeker find it, and then escape the seeker while trying to reach the base before the seeker touch it.

The work done on the early described pursuit-evasion problems has shown that the focus is only on developing the pursuer side, while the evader is controlled manually or has a random behavior to escape the pursuer observation. Other evader strategies simply depend on calculating the path to the nearest position that is outside the pursuer field of view in order to stay covert. The research on covert robotics can provide the other half to get a complete robot vs. robot strategy for pursuit-evasion problems.

## 3.0 Understanding Covert Robotics

Being ‘covert’ can be understood in many different ways according to: what we hide?, from whom?, and in what form of covertness? This variety leads to a wide range of covert problems that cannot be handled by a limited time research. Therefore, this section will define the general problem that this research will concentrate on.

### *3.1 Problem Definitions and Assumptions*

In this research, the word ‘covert’ means out of sight or hidden. A ‘covert mission’ is defined here as accomplishing a specific task in an environment (that contains occluding obstacles) without being observed as long as possible by sentries possibly within the same environment. This covertness is achieved in the means of a continuous maintaining of the hider’s location in the environment according to the available information about positions of both the sentries and the obstacles.

A covert mission should have at least the following three main elements: environment, hider (the covert robot), and sentries. In order to narrow the generality of the problem, the following assumptions for each element has been made:

*The Mission’s Environment:*

- The environment is represented in two dimensions space that each of its positions even represents an obstacle or a free space.
- The obstacles are the main medium that can keep the robot hidden from the observing sentries.
- The obstacles are assumed to be higher than the sight level height of both the robot and the sentries. In addition, the obstacles that the robot and the sentries cannot move through are the ones that they cannot look through.
- The environment is bounded and assumed to be indoors.

*The Covert Robot:*

- The robot can only travel within the two dimensional free space of the environment.
- It is assumed to have 360 degrees of vision and with unlimited range of sight line (of course obstacles are opaque). According to the current technology, these abilities are practical and realistic. It is unwise to limit these assumptions as it will add extra difficulties to the problem that can be avoided.
- In addition to the previous assumption, the robot is assumed to have the ability to recognize sentries in its field of view; this means when the robot is observed it knows how many sentries observing it and there exact locations.

*The Sentries:*

- A sentry can only travel within the two dimensional free space of the environment.
- A sentry can be standstill (surveillance camera) or moving (human/robot).
- The robot can only be observed by a sentry if it gets in that sentry’s field of view.

### *3.2 Problem Dimensions*

Covert robotics is not a single problem that needs a single solution; different covert applications may need absolutely different solutions. Such applications may vary according to one or more of the following questions:

- Is the Environment known, partially known, or unknown?
- Is the sentry(s) movable or stationary?
- Is the sentry(s) locations are known or can be predicted?
- What are the vision directions and ranges of the robot and sentry(s)?
- Are the robot and the sentry(s) moving at the same or different speeds?
- How many sentries in the environment, or what there maximum number?
- What are the capabilities of the robot(s) involved?
- Is the robot spying, escaping, or just hiding from the sentry(s)?
- Is there a target that needs to be reached during the mission? Is it moving?
- Does the mission fail once the robot being observed, or it does have another chance to escape and hide?
- What other information about the environment and the sentry(s) that can be used to achieve more covertness?

Different combinations of the answers of these questions can lead to different applications even if they are sharing the same objective: "to achieve the mission covertly". Special requirements for each application can lead to generate a solution or strategy that might not be useful for another application, however, a general solution may be possible to be designed and customized to deal with each application alone.

Moreover, given different applications that a covert robot might be used in, a single covert robot might require more than one covert ability to achieve its covert mission. As an example, a robot guarding a secure environment should have the ability to search its environment covertly for an intruder, if the intruder is found then it may need to follow it covertly and approach it. It is obvious that the appropriate system that we should build for this case is a combination of each ability solution, where the robot should determine its state to decide which ability it should switch to.

### *3.3 Uncertainty in being Covert*

"What is called 'foreknowledge' cannot be elicited from spirits, nor from god, nor by analogy with past events, nor from calculations. It must be obtained from men who know the enemy situation". Sun Tzu, The Art of War.

Different humans can perform differently in a covert mission when complete information about the environment or the sentries is unavailable. The reason is that all decisions and taken actions are made upon possibilities and assumptions about the sentries' locations and their intentions. Uncertainty and incompleteness are two difficulties that not only facing humans, but also robotic systems. Therefore, due to the nature of covert missions, a good robotic solution for a covert application does not always guarantee the mission's success. The only way to face this central difficulty is by making use of the available information about the sentries and the environment to perceive, infer, decide and act efficiently to achieve the maximum possible covertness.

On the other hand, even if the hider does have all the information it needs to stay covert during the mission, the success is still not guaranteed in some situations as the hider may forced to get into a position where it cannot hide forever and avoid being observed (e.g. getting into environment trap).

## 4.0 Procedures and Research Outcomes

A suitable method to tackle this research problem in general is to divide it into layers of complexity. We have started with known environment and a single covert robot as the lowest layer. After satisfying this layer, an extra complexity will be added to move to the next more complex layer. This method is appropriate for the nature of this research as the outcome of each layer can be fed to the next layer to help understanding and satisfying it. During the first year of this research, number of significant problems in the area of covert robotics has been solved which can be summarized as follow:

***4.1 Planning a covert path between two points in a known environment*** [Marzouqi and Jarvis, 2003]

A basic covert ability that a covert robot will need in mostly any covert mission is to move from one point to another without being observed by hostile sentries within the same environment. The 'most covert path' can be defined as a path with the minimum exposure to being observed (visible) by possible observing entities anywhere in the free space of the environment.

A new approach has been developed to tackle this problem for the case of known environment. The approach has been simulated and tested on two different situations: known and unknown sentries' locations. In both test cases, the results were efficient and promising. To add some reality to this approach, it is assumed that the sentries' looking direction is unknown and therefore visibility might be mutual (i.e. if the robot can see a sentry then the sentry can see the robot). To apply this assumption, each sentry is assumed to have 360 degrees of vision and with unlimited range of sight line, which is similar to the robot vision ability.

Two co-operative algorithms have been developed in our approach, the Visibility Map algorithm and the Dark Path algorithm. The Visibility Map algorithm is based on the concept of giving a visibility value for every unoccupied location in the environment map, while the Dark Path algorithm combines both the Visibility Map algorithm and a short collision-free path planning algorithm 'Distance Transform' [Jarvis, 1984] to find a reasonable covert path between two points in that environment.

The Visibility Map Algorithm measures the visibility degree at each possible non-obstacle location and assigns the measured value to that location. This operation creates a special map which we have called the *visibility map* of the environment. Different assumptions about the observing sentries can lead to create different visibility maps. For the case of $n$ known sentries' positions, each free location in the created visibility map will have a value equal to the number of sentries observing it. This value would be in the range $[0, n]$. Since going through all possible locations in a map is infeasible, the environment is represented as a tessellated map each of its cells is a free space or an obstacle

A more interesting aspect of this approach is the case of unknown sentries' locations. In this case, each sentry can be possibly located at any free space location in the environment. Therefore, to find the visibility map, it is assumed that there is a sentry standing at each free space. This result in a visibility map that each of its free space cells have a value equal to the number of other free cells that are visible to it, which should be in the range from 0 to the total number of free space cells. The following figure, Fig 1, is an example of a visibility map of an environment where obstacles are represented in black. The visibility degrees are presented in grayscale, where a cell gets darker as it becomes more hidden, and vice versa.

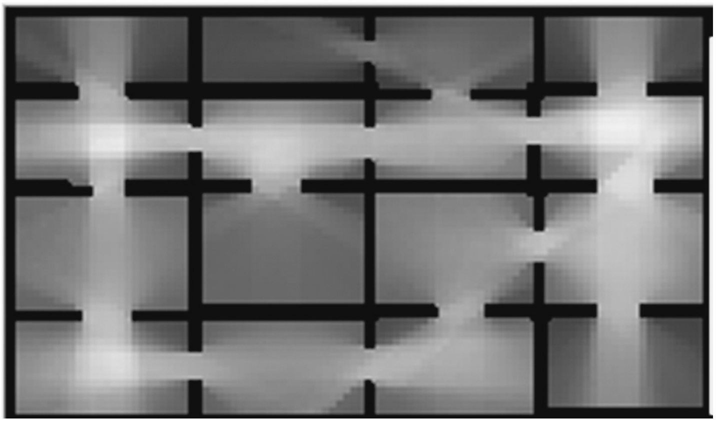

Figure 1: an environment visibility map for the case of unknown sentries' locations

Having the visibility map of the environment, the dark path algorithm is used to find a reasonable covert path. Initially the cell that represents the goal location is given a cost equal to its visibility value. Then, each non-obstacle cell is assigned a value of one greater than the least value of its neighbors, adding to that its own visibility value. Therefore, each cell in the resulting array will contain a number that can be represented by the following equation:

*Cost = least 8-neighbors cost value +Distance cost +Visibility cost*

the value at each cell – which can be called "visibility-distance cost" – can be described as the visibility of the cell adjusted by the visibility cost and the distance cost to the goal's cell. Using the visibility-distance cost at each cell, we can now find a covert path for any start point in the free space by simple steepest descent. The behaviour of the generated path is inherited from both the visibility map and the distance transform algorithms, where there is a kind of balance between finding a short path and a covert path. The following figures (Fig 2 and 3) are two examples of generated covert paths.

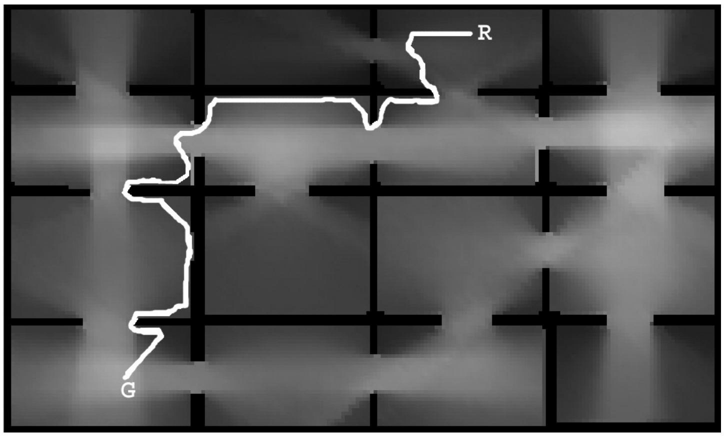


Figure 2: The white line represents a covert path between the robot (R) and the goal (G) for the case of unknown sentries' locations. Most of the path is passing through the dark areas of the visibility map.

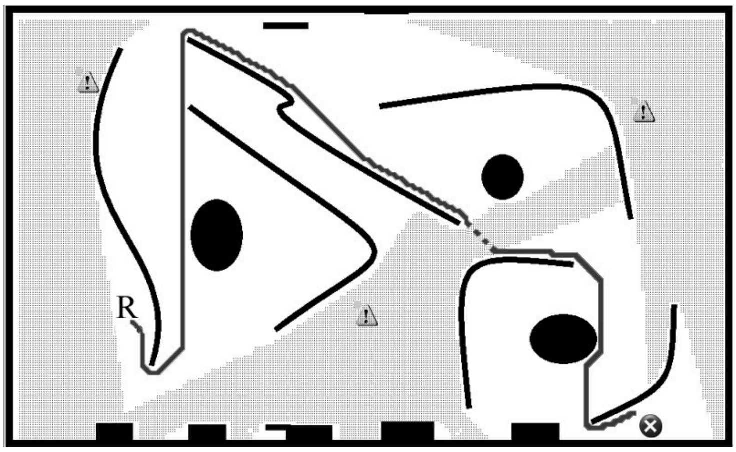


Figure 3: The shaded areas are observed by the (triangle) know location sentries. The path from the robot (R) to the goal (X) guarantees a minimum observing time where the robot will only be observed at the dashed part of the path.

Another application where this approach has been applied and shown good results is when a robot has to approach a target without being observed by the target itself as long as possible. Fig 4 shows a generated covert path that enters the view field of the target (the shaded area) from where the distance to approach the target is the shortest possible.

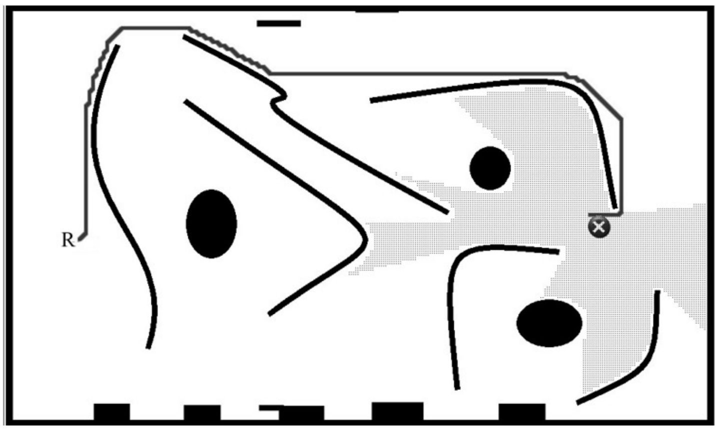


Figure 4: the robot (R) approaches the target (X)covertly. The shaded area is the target's view field.

In general, our approach has shown the ability to give acceptable covert paths for different situations in different types of environments. More details and results are presented in [Marzouqi and Jarvis, 2003].

A part from finding a covert path between two points, the visibility map (which has been described earlier in the case on unknown sentries' locations) allows us to understand the environment in terms of the exposure of each non-obstacle location to the rest of the environment. This tool can be useful in other applications of covert robotics. Another aspect of the visibility map, which has the opposite concern, is to looks at the *bright areas* (see Fig 1) where the visibility is high. One possible application to take an advantage of the high visibility areas is to search a whole known environment using an optimal time, where the most visible areas are good places to observe from.

***4.2 Hiding in known environment*** [Marzouqi and Jarvis, 2004a]

While a robot is performing a covert task, it heard someone entering its environment that might be an enemy. Given this situation, if we assume that this robot mission fails once it being observed, where is the best place for the robot to hide?

The research on covert robotics has been extended to tackle another problem in this field, which is *hiding*. Hiding from possible observers in an environment is another important ability in covert robotics. There are different ways to hide, the following are some reasonable ways:

- Hiding in a position or place that the sentry cannot reach and observe (ex. an insect size robot can hide in narrow spaces where larger entities cannot reach). However, this way of hiding will depend on the environment and the ability of the robot to reach places that the sentry cannot reach.
- Hiding in a place that is the last expected by the sentry to look at. This way of hiding will depend on how much knowledge the robot has about the sentry and the ability to predict the sentry's actions. This ability is impractical as such information about the sentry is mostly unavailable.
- Hiding in the farthest location from the sentry. However, if the robot's mission fail once observed then this way might not be efficient as the farthest place from a sentry is not necessary a place that the sentry cannot see.
- Hiding in a position that the sentry cannot observe such as dark spots in the environment. However, such dark spots might not be available or they are not dark enough to be unobservable.
- Hiding in a position where the sentry needs long time before it can reach it and observe it (i.e. the farthest position from the sentry's observation), which is our chosen strategy for hiding in this approach.

In this approach, the aim is to allow a mobile robot in a known environment to use the information it has about the sentries' locations to stay hidden as long as possible (assuming that the covert mission fails once the robot is observed). In order to choose the best place to hide, at least the initial location or subset of free space where each sentry might stand are assumed to be known by the robot or can be predicted. This assumption is practical as the robot may predict a sentry's location depending on the last time it was seen, or track its location using suitable equipped sensors. The robot's hiding plan can be changed dynamically as it gets new information about changes in the sentries' positions.

Our hiding strategy depends on a new technique that we have called: *Time-to-Exposure algorithm* (TTE). This algorithm gives each possible location in the tessellated environment a value that represents the maximum guaranteed time before possible observation by one or more sentries, given the sentries' initial locations and their speeds are known. These values are stored in a TTE map. Fig 5 shows an example of a TTE map for the case of one sentry.

Figure 5. The Time-to-Exposure map of an environment. Obstacles are represented in white, free cells values are represented in grayscale. The sentry (triangle) needs a longer time to observe the dark areas than the brighter ones.

The TTE map is used to create what we have called the *covert zone*. The covert zone is a connected set of free cells within which the robot can navigate to any destination cell without being observed, at least until reaching that destination. The hiding strategy is based on the way a human can think when no information about the moving sentries' next destination is known. Having the covert zone, the best place to hide there is the location of the cell with the highest TTE value (i.e. the last place the sentry can see in the zone). The robot is allowed to navigate to its hidden spot only through the covert zone. The following figures, Fig. 6 and 7, show two examples of a path generated for the robot to navigate to the best hidden spot given known initial sentries' locations. The TTE map is shown at the upper left side of each figure for clarity.

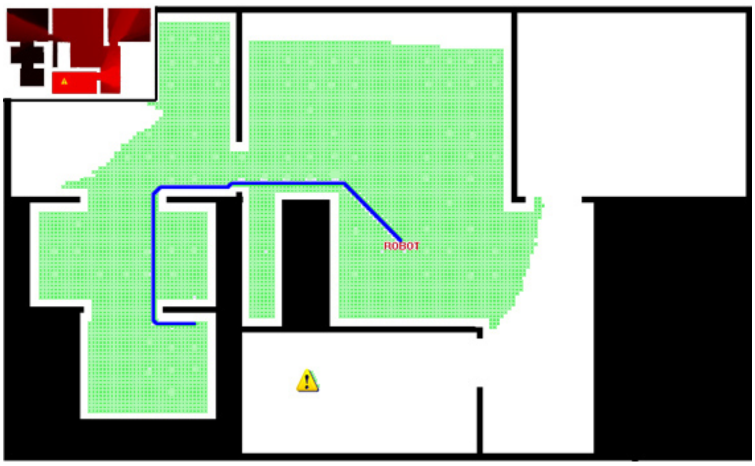


Figure 6. The generated path for the robot (labeled by 'ROBOT') is leading it to hide in a room that can guarantee a maximum time of covertness given the initial sentry's location. The path is generated within the covert zone which is the area represented by light gray color.

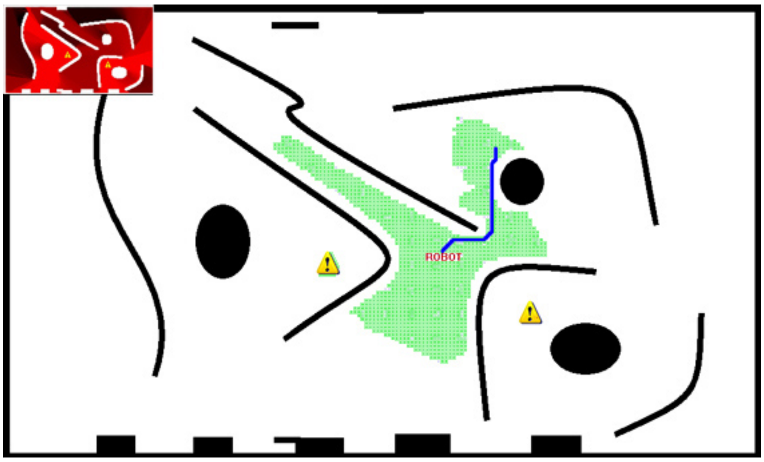


Figure 7. A similar case to fig 6 but with two sentries, the covert zone is much smaller due to the structure of the environment and the sentries' locations.

The carried experiment using this approach has shown the success of creating efficient covert paths to the hiding spots that insure a maximum time of covertness. Moreover, the approach has the ability to deal with continuous information, where re-planning for new hiding place can be processed in real time as the robot's information is updated about the sentries' current locations. More details and results of this approach are presented in [Marzouqi and Jarvis, 2004a].

***4.3 Map understanding tools for covert robotics*** [Marzouqi and Jarvis, 2004b]:

Environment map understanding is an important aspect towards a successful covert mission. The previously described *visibility map* was one way which allows understanding the environment in term of exposure of each non-obstacle location to the entire environment.

Another map understanding tool which has been developed in this research is the Map Segmentation algorithm [Marzouqi and Jarvis, 2004b]. This algorithm divides free spaces in a known environment map into natural (i.e. realistic or logically divided), convex regions. This representation of the environment can be helpful for future work in covert robotics as the convexity and the connectivity of the regions can help extracting some useful information about the environment. One usage of the Map Segmentation algorithm is to identify environment traps. An environment trap can be defined as a room or a space in the environment with has only one doorway. In a covert mission, a trap can lead to mission fail by minimizing the robot chances to escape a certain situation. With map segmentation, the connectivity of the regions can be used to identify trap regions which usually have low connectivity comparing to other regions (see Fig 8). However, there is still more work to be done in this part of the research.

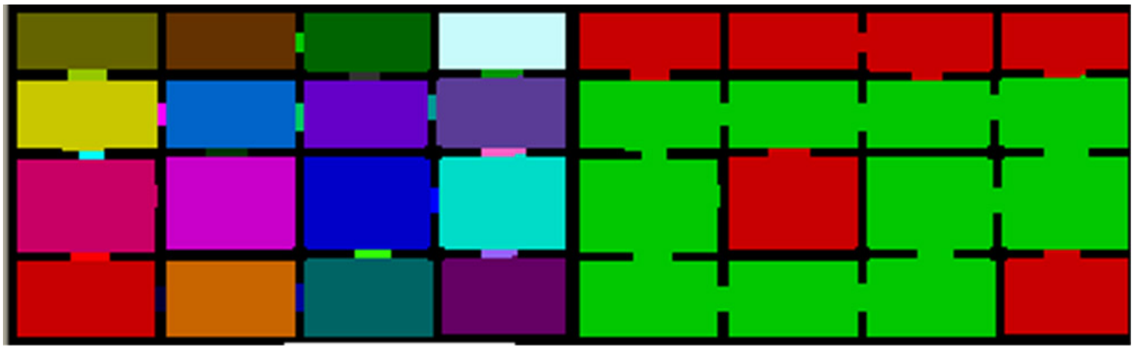

Figure 8. The left map represent a segmented map of an environment (obstacles are in black) where each room and doorway has been efficiently recognized as a separated region. The connectivity of the regions in the segmented map is analyzed to find the trap rooms (the dark rooms) which are represented in the right map.

Another way to understand traps in an environment is to find loop paths around obstacles, the following figure fig9 show an example of a know environment where a number of loop paths obstacles was identified . these paths for example a robot can hide using them in case of one sentry , as moving along these paths is leading to infinite loop with no trap.

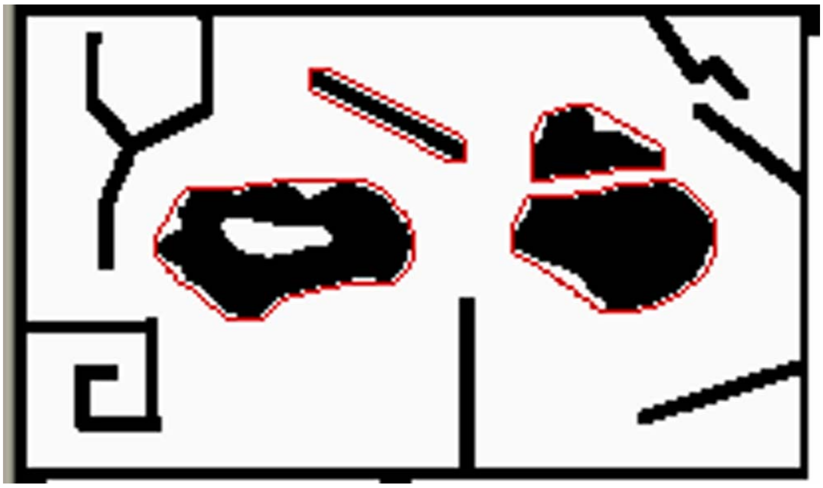

fig 9 . loop paths in red

## 5.0 Current and Future Work:

Our strategy in this research is to move from lower to higher layers of complexity and to investigate different dimensions and aspects of the general problem. Currently, the research concentrates on three main problems in covert robotics:

a- Working with unknown environments: developing strategies that allow a covert robot to achieve its mission in unknown environment.

b- Covert team of robots is another extension that we need to explore extensively (with known and unknown environments). The aim is to develop a communication strategy between the team members by exchanging the necessary information to achieve the required covertness in different type of team based missions.

c- Moving to real covert robots: the results we have found so far depend on a computer-based simulated environment. Moving to real robots is an important step in this research as we expect more difficulties to arise that need to be considered when dealing with physical covert robots.

## References

[Cheng, 2003] Peng Cheng, “A Short Survey on Pursuit-Evasion Games”, Department of Computer Science, University of Illinois at Urbana-Champaign, 2003.

[Jarvis 1984] R. A. Jarvis, ”Collision-free path trajectory using distance transforms,” Proc. National Conference and Exhibition on Robotics – Melbourne, August 1984.

[Khatib, 1986] O. Khatib, "Real-Time Obstacle Avoidance for Manipulators and Mobile Robots", International Journal of Robotics Research, 5(1):90-98, 1986.

[Kratochvil, 2002]Brad Kratochvil, “Implementation of Scout Behaviors Using Analog Sensing Methods”, University of Minnesota, 2002.

[LaValle, 1998] S. M. LaValle, “Rapidly-exploring random trees: A new tool for path planning”, TR 98-11, Computer Science Dept., Iowa State University, Oct. 1998.

[LaValle and Hinrichsen, 1999] S. LaValle and J. Hinrichsen, “Visibility based pursuit-evasion: an extension to curved environments”. IEEE International Conference for Robotics and Automation, 1999.

[LaValle et al., 1997] S. M. LaValle, H. H. Gonz'alez-Ba nos, C. Becker, and J.-C. Latombe. “Motion strategies for maintaining visibility of a moving target”. In Proc. IEEE Int'l Conf. on Robotics and Automation, pages 731-736, 1997

[Mann, 2003] Katelyn Mann, “Evolving robot behavior to play hide and seek”, The Journal of Computing in Small Colleges archive, Volume 18 , Pages: 257 – 258, May 2003.

[Marzouqi and Jarvis, 2003] Mohamed Marzouqi and Ray A. Jarvis, “Covert path planning for autonomous robot navigation in known environments”, Proc. Australasian Conference on Robotics and Automation, Brisbane 2003.

[Marzouqi and Jarvis, 2004a] Mohamed Marzouqi and Ray A. Jarvis, Covert Robotics: “Hiding in Known Environments”, Proc. 2004 IEEE Conference on Robotics, Automation and Mechatronics (RAM), Singapore, December 2004.

[Marzouqi and Jarvis, 2004b] Mohamed Marzouqi and Ray A. Jarvis, “Efficient Robotic Pursuit of a Moving Target in a Known Environment Using a Novel Convex Region Segmentation”, Proc. The second International Conference on Autonomous Robots and Agents (ICARA), New Zealand, 13-15 December 2004.

[Moore, 1995] Moore, Michael B., Geib, Christopher, and Reich, Barry D. “Planning for Reactive Behaviors in Hide and Seek”, In Proceeding of 5th Conference on Computer Generated Forces and Behavioral Representation, Orlando, FL, May 1995.

[Nilsson, 1969] N.J. Nilsson, "A Mobile Automation: An Application of Artificial Techniques", Proceedings of the 1st International Joint Conference on Artificial Intelligence, pp.509-520, Washington, DC, 1969.

[Rybski et al.,2000] Paul E. Rybski, Sascha A. Stoeter, Michael D. Erickson, Maria Gini, Dean F. Hougen, Nikolaos Papanikolopoulos. “A Team of Robotic Agents for Surveillance”, Proceedings of the Fourth International Conference on Autonomous Agents. Publisher :ACM Press,2000.

[Spoerry and Wong, 1999] T. Spoerry, K.C. Wong “Design and Development of a Micro Air Vehicle (MAV) Concept: Project Bidule”, School of Aerospace, University of Sydney, 1999.

[Suzuki and Yamashita, 1992] I. Suzuki and M. Yamashita, “Searching for a mobile intruder in a polygonal region”, SIAM J. Comput., 21(5):863-888, October 1992.

[Vaughan et al., 2000] R. T. Vaughan, G. S. Sukhatme, F. J. Mesa-Martinez, and J. F. Montgomery. “Fly spy: Lightweight localization and target tracking for cooperating air and ground robots”. Distributed Autonomous Robotic Systems, 4:315-324, 2000.

[Vidal et al., 2002] R. Vidal, O. Shakernia, H. Kim, D.Shim, and S. Sastry. “Probabilistic pursuit-evasion games: Theory, implementation, and experimental evaluation”. IEEE Transactions on Robotics and *Automation*, pages 662-669, Oct. 2002.