Chapter 1

Introduction

1.1 Applications of Unmanned Surface Vehicles (USV)

USV can be integrated for remotely controlled combat system ideally suited to meet force protection requirements in all maritime settings. By providing long range stand-off surveillance, identification and engagement capability, USV can be quickly deployed to defend high value assets including naval vessels, port operations, oil rigs and coastal power plants.

Protector is a name of an USV developed by Israel's Rafael Armament Development Authority in response to emerging terrorist threats against maritime assets [27]. That USV is stealthy, highly autonomous and can operate with general guidance from a commander in port, harbor and coastal waterways in a variety of roles, thanks to the plug-and-play design of its various mission modules, such as force protection, anti-terror, surveillance and reconnaissance, mine warfare and electronic warfare.

With integrated navigational sensors including GPS, navigation radar and video cameras, the USV can conduct harbor surveillance even in busy waterways. Highly autonomous and remotely controlled, USV can successfully monitor waterways with general guidance from a commander and operator at sea or from shore - no matter how hazardous the condition [38]. The USV having an on-mount camera allowing for day and night operation and has a forward-looking infrared laser range finder capability to detect and track targets in the near vicinity. The Boat Control unit's navigation sensors are used to obtain location, speed, heading and course data.

1.2 Obstacle Avoidance of Unmanned Ground Vehicles

An intelligent vehicular system which is a subtopic that comes under "Intelligent autonomous systems" is an important research topic today, due to its importance in the field of "Autonomous surface vehicles and intelligent transportation systems". These systems can be classified according to the technology based on them and their method of implementation. This lies from basic vehicular management systems such as traffic lighting systems, container management systems and simple navigation systems to more advanced systems such as the systems getting feedback from the other compatible external systems, and external sources such as live feedback, whether information and so on. Predictive techniques have been developed to implement better inference systems.These methods allow some advanced modeling and comparison with historical baseline data and real-time data hence to provide an intelligent inference system which can deduct the best option at a time to control the system [31]. Collision avoidance techniques should be implemented within the platform or within an external system and a proper communication scheme should be maintained in order to prevent any life or material hazards, for these intelligent vehicular systems. In most of the times these inter platform communication scheme for short ranges (less than 400 meters) is accomplished by using IEEE 802.11 protocols or the Dedicated Short Range Communications standard being promoted by the Intelligent Transportation Society of America and the United States Department of Transportation [31]. In the case of long range communication schemes, this is accomplished by using infrastructure networks such as WiMAX (IEEE 802.16) or Global System for Mobile Communications (GSM).

Obstacle avoiding algorithms play major role in the overall process of navigation. Waypoint navigation without obstacle avoidance is given only limited capabilities to the USVs in a real-world mission. In order to provide more functionality and reduce the reliance on operator oversight, a robust obstacle avoidance capability must be added. More advanced behaviors can be added, such as autonomous recovery in the case of lost communications, target tracking and interception, etc., after adding a obstacle avoidance controller with algorithms.

In this research, a typical intelligent vehicle prototype was implemented and tested under laboratory conditions for its mobility, controllability and communication capabilities between the vehicle and a personal computer. Then another identical prototype was implemented to test, the communication capabilities between the two prototypes (inter vehicular communication capabilities) and communication between the vehicles and a personal computer. A dead reckoning algorithm is used as the tracking algorithm for the vehicles.

The novel interactive control paradigms in here have been testified as effective solutions for reliable collision avoidance of autonomous vehicular systems via computer simulations will be experimentally validated. The so-called interactive controller negotiates collision scenarios between two vehicular systems leading to cooperative maneuvers. The key point is that in order to avoid a probable collision situation, both the vehicular systems interactively carry out maneuvers. The hierarchical differentiation of the participatory vehicular subsystems is done by using a mater-slave concept. In the experimental validation using the prototypes, the advanced collision avoidance algorithms are implemented in the personal computer due to the limitations of memory and computational speed in the prototype. RS 232 serial communication standard is used for the wireless communication between three nodes (the computer and two prototypes) based on a suitable communication protocol that is developed specially for this scenario [32].

The developed prototypes were fully equipped with required hardware such as sensors and actuators. This has the motion control and position tracking abilities. The communication scheme was implemented via the RF broadcasting. The obstacle detection was done by ultrasonic sensors. Detection of the other prototype (as an obstacle, in collision conditions) was done by the relative distance, relative angle and relative velocity information, that are exchanged between vehicles via an inter-vehicular communication scheme that was implemented. Micro controller board was programmed in order to act as the central information processing unit [8].

1.3 Appling Ground Vehicle Technologies for Surface Vehicles

Current unmanned vehicles adhere to different levels of autonomy as defined by existing technology limitations and used sensors. Important operational characteristics related to unmanned vehicle functionality (aerial, surface and ground), include perception, intelligence and action. Here, the acquiring and use knowledge about the environment and itself is called the perception [17]. This is done by taking measurements using various sensing devices and then extracting meaningful information that should be used in all later tasks such as localization, planning, collision free motion control. The meaning of the Intelligence relevant to unmanned vehicles, is operating for a considerable time period without human intervention. This is associated with the learning and inference capabilities, which of the vehicle should be able to adapt to the environment. The action is the way that unmanned vehicle should travel from one point to another. The vehicle should utilize predefined and acquired knowledge to move in dynamic environments without involving humans in the navigation loop. So, the algorithms and technologies developed for unmanned ground vehicles can apply for the surface vehicles as well due to those similarities.

1.4 Potential Field Method for Obstacle Avoidance

During the past few years, potential field methods (PFM) for obstacle avoidance have gained increased popularity among researchers in the field of robots and mobile robots [34]. The idea of imaginary forces acting on a robot has been suggested by Khatib in 1985 [18]. In these approaches obstacles exert repulsive forces onto the robot, while the target applies an attractive force to the robot [41]. The sum of all forces, the resultant force, determines the subsequent direction and speed of travel. One of the reasons for the popularity of this method is its simplicity. Simple PFMs can be implemented quickly and initially provide acceptable results without requiring many refinements.

PFM cannot be applied for dynamic obstacles directly. An ongoing unpublished research work is there to apply potential field method for dynamic obstacle avoidance. The velocity dipole is used for that. The velocity dipole field is presented for real-time collision avoidance of mobile robots. The direction of motion of the obstacle is used as the axis of the dipole field, and the speed of the obstacle is used to proportionally strengthen the dipole field. The elliptical field lines of the dipole field are useful to skillfully guide the robot around obstacles, quite similar to the way humans avoid moving obstacles. That system seems to have the capability of a new real-time collision avoidance strategy and it will overcome the weaknesses in the conventional potential field method.

The Software developed by Lee Feng [20] for potential field applications was utilized in this research to compare the proposed methods with the potential field method .

1.5 Morphin algorithm for path planning

Morphin is an area-based algorithm and it analyzes obstacles in the area which can disturb its navigation. It projects all the possible paths to the front initially. To select from among multiple paths, path evaluations are assigned to all possible candidate paths according to how effectively each path would drive the rover toward its goal point. The path that would lead directly toward the goal with less obstacles is given the highest evaluation; other paths are assigned lesser values according a predefine function [21]. These evaluations are then combined with the user's preferences to determine the overall best command, which is then sent to the rover to be executed. The cycle time for this process is about 1-2 seconds, with the stereo computations taking up about 75% of the total time.

This algorithm is novel but the approach has a long history of applications in real-world systems (including the Mars Rovers) and has its lineage back to the Carnegie Mellon University Morphin algorithm and Distributed Architecture for Mobile Navigation (DAMN) [29].

In the practical applications, the problems which are mainly attributable to an abundance of noise, particularly in the stereo-produced obstacle maps and Global Position Systems (GPS) are jammed or the Inertial Navigation Unit (INU) drifts can create problems to the previous algorithms since they are heavily depend on Obstacle positions. So another approach had to be chosen to develop new algorithms to overcome above particulars for smooth and safe navigation of the USV.

An applying ground vehicles algorithm for surface vehicles and PFM were done previously. So Morphin approach was chosen due to it's proven capabilities for ground robots like famous Mars Rovers and Lunar Rovers [21]. The algorithm is novel, but the approach has a long history of applications in real-world systems and has its lineage back to the DAMN of Carnegie Mellon University .

1.6 Defining safety distance for path planning

Safety distances need to be defined for different obstacles considering their geometrical shapes. They might change around obstacles center of gravity. That was not considered in this study. Therefore circular safety distance is defined for the safety of the USV. The ways of defining safety distance is shown in Figure 1.1.

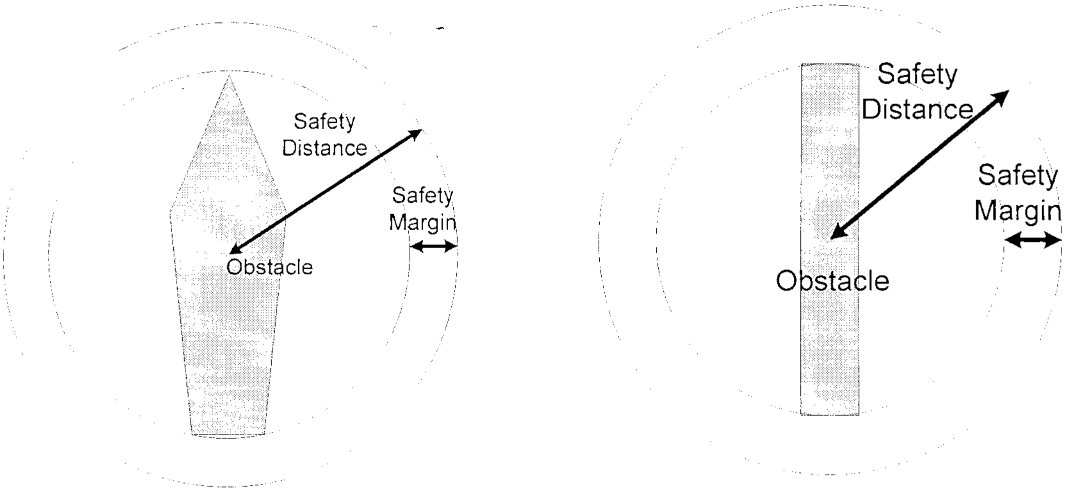

Figure 1.1 – Safety Distance for Obstacles

For an example the length of the USV named Protector used by IIsraeli Sea Corps is 9 meters.

1.7 Dynamic obstacle avoidance

A lot of researches has been carrying out to avoid dynamic objects and unable to find a best solution for that although comparatively good approaches has been presented. Canny and Reif [13] showed that motion planning for a point in a plane with bounded velocity in the presence of moving obstacles is Non-deterministic Polynomial-time hard. Aggarwal and Fujimura [22] show that a more optimal solution can be found by adding a third dimension of time and plotting the location of the moving obstacles along that three-dimensional (3D) structure. Fujimura and Samet [15] provide yet another solution, but even they admit the solution is best with few moving obstacles.

A solution for dynamic obstacle avoidance is presented by Space and Naval Warfare Systems Center, San Diego for the requirement of robust USV operation in a real world environment, primarily focusing on autonomous navigation, obstacle avoidance, and path planning. Velocity Obstacle method (VOM) is one of the good methods for dynamic obstacle avoidance is utilized mainly for those developments. To avoid moving obstacles and maintain the desired path set by the user, the safe velocity ranges using the Velocity Obstacle method [25] have to be determined by the controller. This algorithm transforms a moving obstacle into a stationary one by considering the relative velocity and trajectory of the USV with respect to the obstacle. After producing a collision area called the Velocity Obstacle, defined using the relative velocity vector, the algorithm returns a set of USV velocity vectors which are guaranty the collision avoidance. This transformation and collision area detection reduces the complexity of the path planning among moving obstacles with respect to time. This is used as a first pass to avoid moving obstacles. In the case that changing velocity the controller has to change the path by creating projected obstacle areas for each obstacle and determining a safe alternative route.

1.8 Sensor considerations

As with any unmanned vehicle attempting to navigate in a complex environment, good sensor data is critical, and getting good data is often the most difficult part of the project of developing a USV. The oceanic environment poses many challenges including waves, spray, and a disordered obstacle setting. There are some advantages to the marine environment including well charted operating areas, absence of negative obstacles (holes or cliffs), a mostly planar surface (except for the waves), no vegetation, etc. It’s important that the sensors are selected to make the most of the environmental advantages and to provide the best data possible in the challenging territories.

The sensors for the obstacle avoidance need to provide data about obstacles in the far-field (e.g., >200-300 yards) and provide state information (position, course, and speed) for the moving obstacles.

High-resolution and at a much higher rate data is needed about the obstacles in close proximity to the USV (e.g., <200-300 yards). Some of these sensors are typically not found in the commercial marine industry but many have been used extensively in UGV programs.

1.8.1 Radar Contacts

Standard marine radar (Furuno) with a third-party PC controller can be used for USVs. The controller, developed by Xenex Innovations Ltd., provides a digital networked interface for the radar. The Xenex system provides an API to access the radar data and controls as well as an Advanced Radar Plotting Aid (ARPA) Software Development Kit, which provides algorithms to automatically acquire and track up to 100 contacts [23].

One significant problem with the radar is that it tends to classify noise from the shoreline return as contacts which are often shown to be moving at a significant velocity and in the direction of the USV. These false contacts are obviously detrimental to the successful operation of the path planner. To mitigate this problem, the on-board nautical chart server can be used to calculated polygons that follow the shoreline and structures along the shoreline. The radar contacts are compared with these polygons and those that fall inside a polygon are rejected and deleted from the radar's list [28].

Laboratory (JPL) for a number of years to transition technology to its UGV programs. That work is now being extended to the USV domain [14]. The stereo vision system provides high-resolution 3D data about the near-field environment, which can be converted into a 2D obstacle map and fused with data from the other sensors.

Stereo vision is capable of providing very high quality 3D data but also has the disadvantage of requiring precise calibration every time the cameras are mounted. There is also the risk that the cameras may move relative to one another slightly which will affect the calibration and result in erroneous data. So the monocular vision with sophisticated algorithms can be utilized for that as well.