Construction of an Obstacle Map and its Real-Time Implementation on an Unmanned Ground Vehicle

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This paper presents the development of an obstacle mapping system designed to support the generation of a Probabilistic Threat Exposure Map (PTEM). The paper also discusses the implementation of this obstacle mapping system on a small Unmanned Ground Vehicle (UGV) to support real-time embedded obstacle avoidance and mapping. These activities are a part of a larger effort to establish a theoretical foundation for autonomous and cooperative multi-UxV guidance solutions in adversarial environments [Zengin 2007], [Desai 2009]. Within the context of the larger multi-UxV guidance solution, the PTEM is used to identify areas of hazard within the operational area of one or more UxVs. In this approach, the environment is modeled as a continuous probabilistic map. In particular, the map models the obstacles by the sum of Gaussian probability density functions. Different types of obstacles and restricted areas are characterized using the same probabilistic framework. This particular probabilistic map or framework, where obstacles are represented by a single or multiple probability density functions, is referred to as a PTEM. This probabilistic map is not meant to provide a physical map of the area of operation, but rather to provide a means to plan the trajectory of an UxV to avoid obstacles and accomplish the given mission. A threat / obstacle may be characterized by a single Gaussian PDF (Probability Density Function) or multiple Gaussian PDFs. Multiple obstacles can also be represented by a single Gaussian PDF. There are two parameters needed to fully specify a Gaussian PDF; the mean value specifies the concentration point (location) and the variance specifies the area of influence of the PDF. There is not necessarily a one-to-one correspondence between the actual number of obstacles and the Gaussian PDFs used to construct the PTEM. Once constructed the PTEM can be used as an input to the rule-based guidance strategies designed to support path planning, target tracking, and rendezvous missions for one or more UxVs while reducing their risk/exposure level and avoiding threats and obstacles.

Although the original Multi-UxV guidance algorithms, developed by Zengin, were verified through computer simulation, they were not implemented or tested on physical vehicle systems. In addition, the obstacle maps, represented by the PTEM, were manually constructed and provided to the guidance algorithms in advance. This paper presents our attempts to address both issues by demonstrating that the PTEM can be automatically constructed from on-board sensor data and then used to feed the obstacle avoidance and vehicle guidance algorithms running on the vehicle. This paper discusses the extension of Zengin's work to include the real-time construction of the PTEM and its simultaneous use in embedded target tracking or way-point navigation guidance applications on a small UGV. This paper presents the practical application of guidance and obstacle avoidance strategies on physical autonomous vehicle platforms. The actual implementation of the obstacle mapping system within onboard microcontrollers responsible for the real-time control of the autonomous platform is discussed.

The paper describes the simulation environment that is employed for the development and evaluation of the algorithms for PTEM construction, guidance, and navigation. The tool chain used for the rapid prototyping of the algorithms is described. This includes the auto code generation from simulation and compilation of the code for a specific target micro processor. The paper also describes the vehicle's embedded control system and sensor suite to inform the reader of the class of hardware required to

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implement the obstacle mapping and vehicle guidance solution. The UGV control system consists of multiple microcontrollers integrated by a Controller Area Network (CAN). The heart of the distributed vehicle controller is a phyCORE®-MPC555 development system which utilizes a Freescale 32-bit 40 MHz PowerPC MPC555 microcontroller. This development system was selected because of its support by the MatLab / Simulink® software development tool chain that was also used in Zengin's original work. The MPC555 is responsible for hosting the obstacle mapping system as well as the vehicle's general guidance applications. The MPC555 development system also has connectivity to the dual quadrature encoder channels used to provide angular displacement feedback and is also responsible for generating the pulse width modulated output commands used to drive each of the independent drive motors on the skid-steer platform. A constellation of New Micros PlugAPod® microcontrollers are used as sensor interface subsystems that offload the real-time data parsing and filtering tasks from the core MPC555 microprocessor. The PlugAPod® is a 16-bit, 80 MHz Freescale DSP56F803-based microcontroller that has been optimized to support state-machine-based, real-time, virtually parallel embedded control applications. All the microcontrollers communicate through a series of CAN messages. This sensor integration strategy provides a flexible framework for connecting a wide variety of sensors using various physical interfaces and communications protocols to the central guidance and control processor. The rapid prototyping tool chain used to move the guidance system from a conventional desktop computing environment into the MPC555 embedded microcontroller is also discussed. The challenges we have encountered during this process are also presented. The vehicle control / obstacle mapping / platform navigation software architecture is provided. The paper presents the strategies used to construct a two dimensional obstacle map using LIDAR sensor data. Additional vehicle sensor data, specifically differential encoder data and digital compass information is used to transpose the body-fixed frame referenced laser range finding data into the vehicle's navigational frame or a corresponding global reference frame to construct the obstacle map. The techniques used to incorporate the obstacle map data into the target tracking or waypoint navigation vehicle guidance system is also briefly discussed. A series of experiments designed to test the vehicles mapping capabilities is described. The paper presents a comparison between simulated and actual vehicle performance.

References:

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