Proceedings of the 8th IFAC International Conference on
Manoeuvring and Control of Marine Craft
September 16-18, 2009, Guarujá (SP), Brazil

AUV Guidance and Navigation using Intelligent Control

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Abstract: The design and implementation of a control layer architecture used to control the motions of a Semi Autonomous Underwater Vehicle (SAUV) is focused and presented. At first, the main functionalities required for navigation, guidance and collision avoidance during missions of marine robots are drafted to facilitate the understanding of the whole design process. After that, a set of rules are created, seeking to guarantee the consistency and correctness of the control system operation. A modular topology is employed to establish this set of rules, i.e. input-output relationships are clearly defined at each execution level, ruled through constraints established through an algorithm based on fuzzy logic. The control system itself is subdivided into three layers. Extensive simulation studies are then performed using the configuration of a vehicle under construction. The main advantages of the proposed navigation control architecture lies in its simplicity, modularity and flexibility, leading to a high performance of the control system.

Keywords: Intelligent control, fuzzy logic, collision avoidance, motion control, modular control architecture, guidance, navigation, AUV.

1. INTRODUCTION

In recent years, the use of Underwater Vehicles (UV) by the offshore industry and the navies all over the world have increased steadily and consistently. The design of UVs involves a very large number of practical and theoretical problems, ranging from the choice of appropriate control laws to navigation and guidance issues and to the construction of prototypes, leading to a very intricate process. The development of a control system for a Semi Autonomous Underwater Vehicle (SAUV) is further investigated here.

A number of control approaches and artificial intelligence techniques have already been applied to the autopilot design problem of UVs. However, dynamic features of UVs impose control design problems, which many design methodologies cannot accommodate easily. Craven and Sutton (1998) showed how UV dynamics are non-linear in nature and subjected to a variety of disturbances such as varying drag forces, vortices effects and currents, hindering the control task. Many control systems are not quite adequate when the system to be controlled presents characteristics of nonlinearity, time dependence and extreme complexity, Lea and Allen (1999). Still, human operators manage to control most of these vehicles very well. The idea is to use a controller which emulates the behavior of a human operator during the control task. The emergence of fuzzy logic enabled the vagueness of the human way of thinking to be mathematically represented, so that control decisions of an experienced plant operator could be formulated into an algorithm to control a desired plant. Such an approach may therefore be able to control an UV successfully; Craven and Sutton (1998) and Garus and Kitowski (2006).

Using similar procedures, Xu and Smith (1994) and DiBitetto (1995) managed to design depth control systems of UVs. Good results from simulations using this approach are also reported in the papers of Lea and Allen (1999), Smith and Rae (1994), Khanmohammadi and Alizadeh (2007), Doitsidis and Nelson (2005), Jantapremjit and Wilson (2008) and Wallace and Bessaa (2008). Kanakakis and Valavanis (2004) and Kanakakis and Tsourveloudis (2007) designed autonomous navigation systems and collision avoidance also using fuzzy logic.

The development of a full intelligent and adaptive controller is presented here, to be used in the guidance, navigation and collision avoidance of a SAUV. The main advantage of the proposed navigation control architecture is its simplicity, modularity, expansibility and applicability to any type of autonomous or semi-autonomous underwater vehicles, independently of its particular configuration. To achieve a controller using this procedure, it is necessary to define and treat a vast set of complex commands. To facilitate this, the control action is subdivided into three

⋆ corresponding author. The first author is grateful to the financial support by the Brazilian agency CAPES.

stages, in which a first stage deals with the control action during the initial positioning of the vehicle, a second stage deals with the navigation itself and a final stage deals with the control action when the vehicle is close to the objective-position. The controller operation was also subdivided into two modules. The first module is responsible for managing environmental disturbances and important data such as the vehicle initial position, depth and attitude. The second module is in charge of the detection of obstacles in different directions and the optimal evasion action to avoid collisions. The control action during a mission is established using concepts of the fuzzy theory, by means of linguistic variables and rules of inference defined on the basis of the knowledge of specialists, involving the characteristic imprecision of human behavior, but at the end of the day a univoque control action is produced, allowing a practical implementation. A traditional application of fuzzy control is when no plant model is available, but a human operator can control the process satisfactorily. The controller action is constructed based on a set of rules tailored by the designer according to the expertise of an experienced process operator. By "fuzzyfying" crisp input data into linguistic sets, it is possible to set-up an automatic control strategy, based on linguistic control; Lea and Allen (1999).

2. CONTROL SYSTEM

The vehicle used in the case study is presented in Fig. 1. This SAUV is at a test stage in the Dynamic and Control Laboratory (LDC) of the Polytechnic School of University of São Paulo. It has a tubular structure made of stainless steel, and it is propelled by 8 thrusters; four of them are in charge of motions in the horizontal plane and the other four of motions in the vertical plane. The vehicle is equipped with an ultrasonic transducer to estimate its position. The vehicle electronics is packed in two steel cylindrical pressure vessels and includes boards (A/D, converters, etc) and sensors (gyros and inertial reference systems), and a $PC-104$. The power supply is installed in a third pressure vessel, involving two sets of 12 lead acid batteries of $24V$ connected in series to power the electronics and trusters, offering 3 hours of autonomous operation, when the SAUV is its light weight ($200kg$). Seven PVC tubes symmetrically distributed are by now working as buoyancy pontoons. In a near future, they will be replaced by steel vessels to enable the vehicle to reach deeper waters (600m depth).

2.1 Control Fundamentals

Considering that without any drive power the vehicle will drift upwards because of its positive buoyancy and possibly drift laterally because of water currents and also considering the non-linearity of the thrust of propellers and of drag forces, the controller was thought to compensate these problems. Unfortunately, many combinations are required to work in a regime in which the drag forces vary considerably with vehicle velocity. A further problem arises because of the vehicle shape. The vehicle is not streamlined and will have equipment mounted on its skeletal frame. Drag forces on the vehicle are therefore

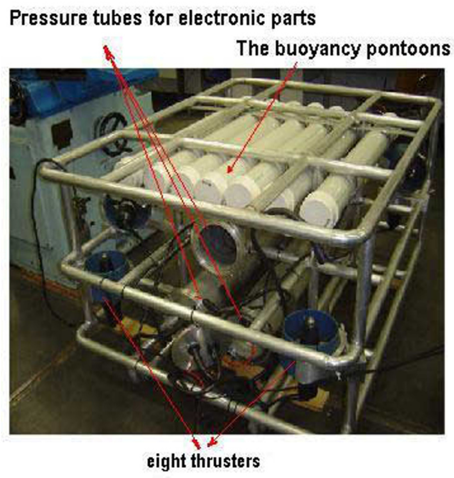

Fig. 1. Semi Autonomus Underwater Vehicle (SAUV)

complex to manage. Also significant coupling between the various degrees of freedom are expected due to the vehicle shape. Moreover, SAUVs are often required to operate with variable payload. Special tools may be attached to the vehicle for particular missions, or the vehicle may retrieve an object from the seabed. In view of the SAUV specific control problem operation, and the ability of skilled pilots to operate similar vehicles in real sub-sea environments, artificial intelligence techniques will be employed. As it will be shown, due to the problems related, a vast set of rules may be necessary to design a satisfactory fuzzy control system. Under such conditions, the control scheme must be very robust to remain stable and still perform satisfactorily. However, as the literature shows, if well designed intelligent control systems may face these problems; Wallace and Bessaa (2008), Khanmohammadi and Alizadeh (2007), Kleanthis and Costas (2006), Smith and Rae (1994), DiBitetto (1995), among others.

To emulate human knowledge and its way of thinking in fuzzy control, a task plan of the vehicle navigation is first established. To reach this end, parameters such as the actual position of the vehicle with respect to the origin of the inertial reference system, the position of the objective, the maximum reach range of sonar, the vehicle speed, the depth of operation, the radius R(m) of a cylindrical surface around the goal position where the SAUV should arrive, the depth range F(m) in which the SAUV should operate, e.g., must be known. Some of these parameters are illustrated in Fig. 2 and Fig. 3, which show the inertial reference frames used in this work and variables related to the vehicle dynamics, as shown in Table 1.

Table 1. Margin settings

D.F.	Var.	Inert. ref. Position	Speed	Move ref. Position	speed
1	Surge	x	$\dot{x}$	x_m	u
2	Sway	y	$\dot{y}$	y_m	v
3	Heave	z	$\dot{z}$	z_m	w
4	Roll	ϕ	$\dot{\phi}$	ϕ_m	p
5	Pitch	θ	$\dot{\phi}$	θ_m	q
6	Yaw	ψ	$\dot{\psi}$	ψ_m	r