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Search Strategy using Multidirectional Search Optimization

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Abstract
In this paper we concern ourselves on proposing a communication strategy so that the AUVs can exchange position to get the new optimized waypoints with the help of hexagonal grid sensor based network for the hierarchical control architecture. A Leader is defined by the multidirectional search followed by a Follower controller of nonlinear model of an AUV allowing higher levels of sensors and low field noise. The proposed optimization is simulated through MATLAB, the coordination and trajectory between team controller and vehicle controller are observed at different iteration of the optimization technique.

Keywords— AUV**,** optimization, MDS**,** hexagonal sensor based grid

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) are remarkable machines that revolutionized the process of gathering ocean data. Their major breakthroughs resulted from successful developments of complementary technologies to overcome the challenges associated with autonomous operation in harsh environments. During the last decades, AUVs have gone through notable developments. Control of parameters like heave, sway, serge, yaw, pitch, roll and so on are challenging in field of control system [1, 2]. Equipped with appropriate sensing devices, AUVs can measure underwater fields produced by submarines such as scalar temperature, salinity, or pollutant concentration fields, or vector magnetic fields [1, 2, 3].

The control objectives of AUV are navigation, path tracking and formation Control. Deployment of underwater AUV formation Control is challenging due to the issues concerning motion control as well as the development and use of a communication infrastructure [4, 5, 6]. Optimization algorithms have been used as the inspiration for other multi-vehicle search strategies [7]. A non linear optimization method include such classical search algorithms as coordinate search, proposed by M. J Box and D. Davies [8]. A brief example is the multidirectional search algorithm of Dennis and Torczon [9]. An informal description of a multi-vehicle search strategy based on the simplex algorithm is proposed in [10] A pure gradient-based method for scenarios where a vehicle platoon searches the minimum of a convex and smooth scalar fields by Bachmayer et al. Burian et al. in report results with mixed strategies and present illustrative examples using real data, such as depth profiles of a lake [11]. The proposed work addresses the leader–follower formation control of multiple non-holonomic AUVs where an AUV is designated as a leader and the other participating AUVs are treated as followers [12, 13]. In this scenario, the leader is time-varying and operates according to its optimized path, while each follower is required to follow the leader accurately with its desired separations and orientation with respect to the leader. Wireless underwater communications are usually established using acoustic waves although both radio and optical techniques may be used for applications that specialize to very short distances [14, 15]. The coordination strategy is inspired by a class of optimization algorithms with communication constraint such as hexagonal grid based sensor methods [16, 17]. The present study is motivated due to limited communications in heterogeneous scalar field design space of the team search of AUVs. This difficulty is avoided by ensuring that their controllers produce exact positions and can exchange them through proper communication topology.

This paper is structured as follows. Section II gives the concept of the problem formulation. Section III provides design concept of Leader as MDS optimization techniques. Section IV introduces the design concept of Follower controller as nonlinear model of AUV. Section V provides concept of communication issue. Section V verifies its performance through MATLAB simulation at different iteration. Section VI concludes the paper.

II. PROBLEM FORMULATION

Motion coordination strategy for the AUVs performing the search and rescue operation using the communications issue based on hexagonal grid sensor based topology of the MDS algorithm.

III. MULTI-DIRECTIONAL SEARCH AS LEADER

The control hierarchical search strategy is discussed in this paper is based on the search and rescue algorithm are discussed in details. The design of a team controller, modelled as a discrete-event system that executes the different search algorithm. An implementation of communicating team controllers is then designed with different sensor grid techniques. The discrete layer is modelled by a discrete-event system as discussed [5]. The Leader is defined by

$$D = (Z, E, W, \xi, z_0) \tag{1}$$

with $z(0) = z_0$

Let $Z = \{z(0), z(1), ... z(N)\}$ are the sequence of optimized waypoints generated by different optimization algorithm, such that $(z(N-1), z(N))$ is a fixed point. Multidirectional search is basically known as in the class of direct search optimization and ideally suited for parallel computation. The algorithm is based upon the principle of performing concurrent searches in multiple directions by neither computing nor approximating any derivative of the objective function. These searches are free of any interdependencies, so the information required can be computed in parallel. The major steps of the multidirectional search are reflection, expansion and contraction. The reflection step is used to rotate the old waypoints through the best vertex to provide new waypoints. If the new point does not satisfy the criteria of the search then by expanding the waypoints, new waypoints can be generated. Then the search distance can be shortened by using the contraction technique.

Assumed that the contraction factor θ is equal to one half while expansion and factor μ is equal to two. The choice of θ and μ are used for initial waypoints and provides stopping criteria of the algorithm and is given by [7].

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Given an Initial Simplex $S_0$ with
$< v_0^0, v_1^0, ......., v_n^0 >, \mu \in (1, +\infty)$ and $\theta \in (0,1)$
        $\min \leftarrow \arg_i \min\{f(v_i^0), i = 0,1,......,n\}$
    Swap $v_{\min}^0$ and $v_0^0$
For k=0, 1, ….

STEP-1. Reflection: Checking the stopping criterion
For i=1, 2 ……n,
            $v_i^{k+1} \leftarrow v_0^k - v_i^k$   Calculate $f(v_i^{k+1})$
 $if (\min\{f(v_i^{k+1}), i = 1,.....,n\} < f(v_0^k)) then$

STEP-2. Expansion:   for i=1, 2 ……n
    $v_{e_i}^k \leftarrow (1-\mu) v_0^k + \mu v_i^{k+1}$   Calculate $f(v_{e_i}^k)$
 for i=1, 2 ……n

 $if (\min\{f(v_{e_i}^k), i = 1,.....,n\} < \min\{f(v_i^{k+1}), i = 1,.....,n\})$
            $v_i^{k+1} \leftarrow v_{e_i}^k$  for i=1, 2 ……n
Else

STEP-3. Contraction:   for i=1, 2 ……n

            $v_i^{k+1} \leftarrow (1+\theta) v_0^k - \theta v_i^{k+1}$
Calculate $f(v_i^{k+1})$ for i=1, 2 ……n
Endif
        $\min \leftarrow \arg_i \min\{f(v_i^{k+1}), i = 1.....,n\}$
If
```

IV. VEHICLE CONTROLLER

A complete nonlinear model of a Autonomous Underwater Vehicles is described in detail [2]. In this work we consider the problem of controlling the AUV's on a scalar field. The nonlinear model of the system is

$$\dot{x} = V \cos \psi_i \tag{2}$$

$$\dot{y} = V \sin \psi_i \tag{3}$$

$$\dot{\psi} = r_i \tag{4}$$

where $(x_i, y_i)^T$ is the position of the i^{th} AUV with respect to a global coordinate frame, ψ_i is the yaw angle and r_i is the yaw rate. The dynamic behaviour of Follower controller AUV as a continuous system is by [12]

$$r_i(x_i, \eta_i) = k_p \varepsilon_i + k_i \int_0^t \varepsilon_i(\tau) d\tau - k_d \frac{d\psi_i}{dt} \tag{5}$$

The velocity V is constant and the guidance in the horizontal plane is achieved using a LOS control law, at each time step the vehicle is commanded to head towards the reference waypoints z_i [12]. The event *e* is generated when the vehicles reach the assigned waypoints. Due to the vehicles control limitations, in practice, it is not possible to assure that the vehicles will reach the exact waypoint. To overcome this difficulty, when a vehicle reaches a neighbourhood of radius of the assigned vertex of the MDS, a new measurement is taken and the event e is triggered. Therefore, the values are not always sampled at the exact grid intersections [11].

V. COMMUNICATION ISSUES

Acoustic communications are governed by three factors: limited bandwidth, time-varying multipath propagation, and low data rate in underwater. Together, these factors result in a communication channel of poor quality and high latency, and pose challenges very different from terrestrial wireless networking [14]. This is driving the design of new communication algorithms and network protocols across all layers of the system architecture. Underwater communication is very costly in terms of energy since the SNR is generally very low [15, 17]. If the communicated data are not available then the discrete event systems are non-deterministic.

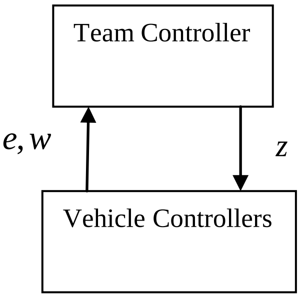

Fig. 1 Hierarchical control structure for *n* vehicles

In this paper transmitting measurements using underwater acoustic modems is the major issue by considering that full communication is present within the acoustic modems. A communication protocol is presented in which measurements and low data rates are used.

In underwater communication, network coverage is the fundamental issue of wireless sensor network and played a vital role in the coverage performance. Coverage problem is generally divided into two classes such as static sensor network and mobile sensor network coverage [17]. To remove the discrepancy in triangular grid search techniques a Hexagonal Grid method is used to get the next waypoint. This method is commonly used in area lay out and grid plot. According to this method, minimum sensor nodes are used to achieve maximum coverage degree. The least sensor node N is decided by the following formula [14]

$$P_{area} / N * \pi r^2 = 3\sqrt{3} / 2\pi$$

Where P_{area} is the whole monitoring area, N is the least sensor node number to cover the whole area, r is the radius of the sensor network. The target region is divided into small equivalent hexagonal shapes as shown in the Fig. 2 and the sensor nodes are located on the centre of the grids provided be '*'. The communication strategies for the hexagonal technique is that if the grid contains two or more sensor nodes, mark the node which is nearest to the executing hexagonal sensor nodes of the grid and then differentiate the nodes into two sets such as executing nodes and. non-executing node. Then MDS optimization will produce a new optimized way points [20].

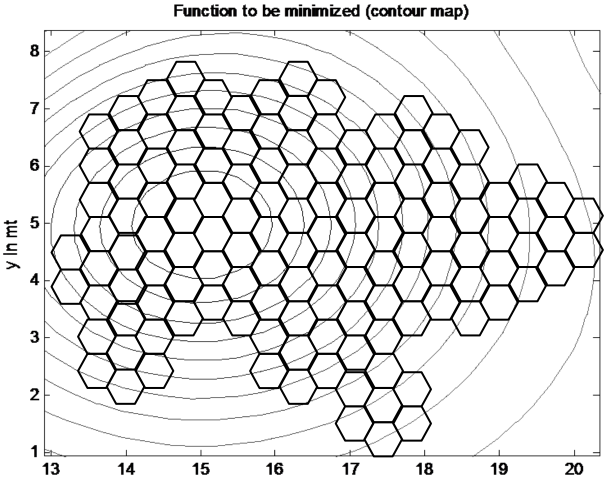

Fig. 2 Hexagonal grid sensor based technique on the simulated scalar field

VI. SIMULATION ENVIRONMENT

The AUV hydrodynamic parameter is presented in Table 1. Two identical autonomous underwater vehicles are used for both team controller and vehicle controller. The scalar field is given by $V(p_1, p_2) = p_1^2 + 2p_2^2$ with no noise. Applying MDS technique in presence of control communication constraint, the trajectories of AUVs are simulated at different iterations. L_1, L_2 and F_1 are the AUVs named as Leader 1, Leader 2 and Follower of Leader 1 respectively.

Table 1. INFANTE AUV HYDRODYNAMIC PARAMETER

$X_{\dot{u}}$ =-141.9 kg	X_{uu}=-35.4 kg/m
$Y_{\dot{v}}$ =-1715.4 kg	Y_{vv}=-667.5 kg/m
$N_{\dot{r}}$ =-1349 kg.m2/rad	N_{rr}=-310
N_{vv}=433.8 kg	X_{vr}=1715.4 kg/rad
Y_{ur}=103.4 kg/rad	N_{ur}=-1427 kg.m/rad
Y_{uv}=-346.76 kg/m	N_{uv}=-686.08 kg

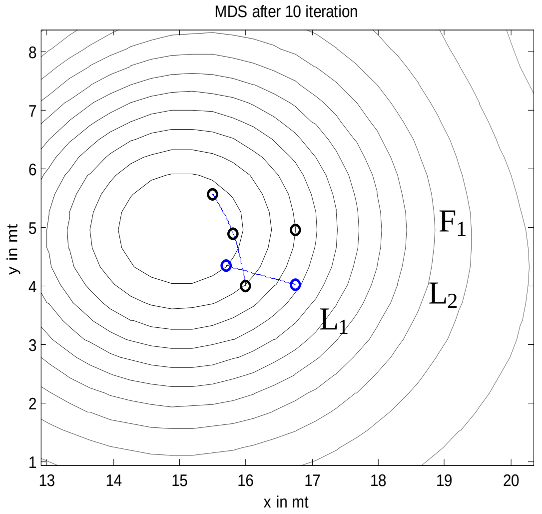

Fig. 3 Coordination control of AUVs after 10 iteration in search operation

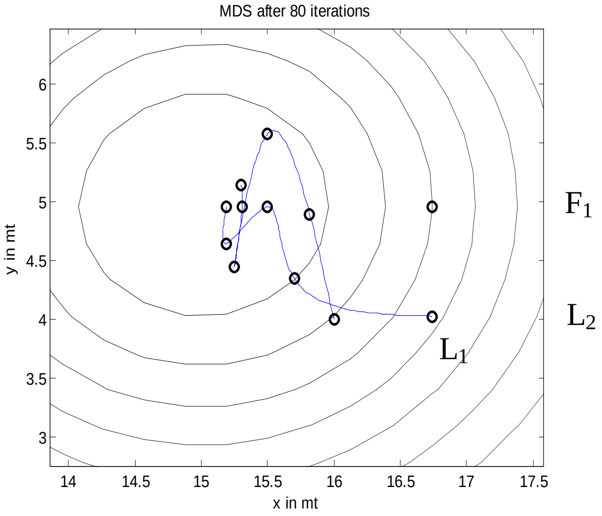

Fig. 4 Coordination control of AUVs after 80 iteration in search operation

Fig.3 represents the coordination control between Team controller and vehicle controller after 10 iterations using hexagonal sensor based techniques. Whereas, Fig. 4 provides the trajectories of AUVs and a moving scalar field at 80 iterations.

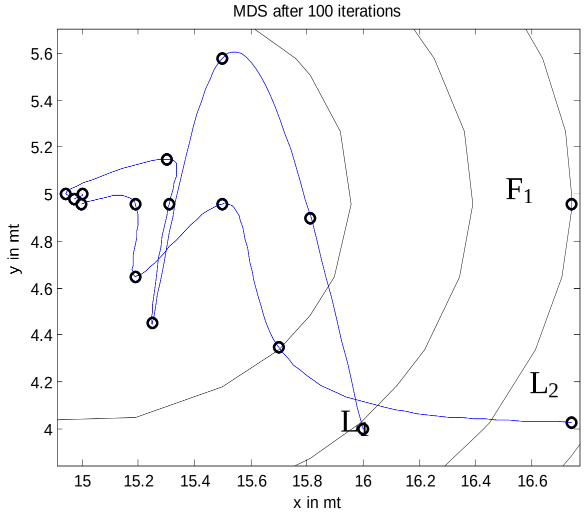

Fig. 5 Coordination control of AUVs after 100 iteration in search operation

The complete optimized trajectory of AUVs is represented in Fig. 5 having a scalar field that drifts a constant speed by allowing higher levels of sensors and low field noise. Simulations were stopped when the MDS reached a fixed optimized points.

VII. CONCLUSIONS

As seen from previous sections, this paper adapts a multidirectional search optimization technique for coordination and search mission of multiple AUVs. A hexagonal sensor based grid search technique successfully provides the best optimized waypoints to team controller for the coordination. The simulation results produce the trajectories at different iterations and the coordination in the search mission is verified. Not only this brief article is interesting in its own right, but considering an under actuated scenario, may give inside a new control and communication strategies for the AUVs.

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