Map Based Navigation for Autonomous Underwater Vehicles

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Abstract - **In this work, a map based navigation algorithm is developed wherein measured geophysical properties are matched to a priori maps. The objective is a complete algorithm applicable to a small, power-limited AUV which performs in real time to a required resolution with bounded position error. Interval B-splines are introduced for the non-linear representation of two-dimensional geophysical parameters that have measurement uncertainty. Fine-scale position determination involves the solution of a system of nonlinear polynomial equations with interval coefficients. This system represents the complete set of possible vehicle locations and is formulated as the intersection of contours established on each map from the simultaneous measurement of associated geophysical parameters. A standard filter mechanism, based on a bounded interval error model, predicts the position of the vehicle and, therefore, screens extraneous solutions. When multiple solutions are found, a tracking mechanism is applied until a unique vehicle location is determined.**

Keywords: *Underwater Navigation, Geophysical Maps*

I. INTRODUCTION

Autonomous underwater vehicles (AUVs) offer the potential for an efficient and cost effective means of measuring physical properties and performing surveys of the hostile and largely unknown ocean environment. Particular applications that are currently envisioned include surveys of the deep ocean, contaminated coastal waters, and the ice-covered seas of the Arctic and Antarctic. As AUVs become more intelligent and cost effective, large groups, acting alone or in concert, might one day be able to provide sufficient measurement resolution to permit accurate initialization of climate simulation models. An outstanding problem in permitting such applications of AUV technologies is *navigation*, the ability of the AUV to determine its global position at any time.

This paper is structured as follows. In Section II., we provide a motivation for map based navigation systems as applied to AUVs. In Section III. we give a brief survey of current map based navigation systems. In Section IV. and V., we formulate and outline our navigation algorithm and in Sections VI. to IX. discuss in detail various aspects of our approach. In Section X. an example of geophysical navigation is given. Finally, Section XI. offers some closing remarks.

II. MOTIVATION

Motivation for a map based approach is found in Table I. Various AUV navigation systems are listed, and the remaining columns refer to[1]:

A - ERROR BOUNDED - if the position error is bounded as time or distance traveled increases.

B - AUTONOMOUS - only data and sensors on board the vehicle are needed to perform navigation.

C - SPATIAL RESTRICTION - whether the use of the navigation system is restricted to a certain spatial region.

D - COST RESTRICTION - whether cost is prohibitive as compared to a platform cost of $50,000 *US*.

E - EXTRA COST/UNIT - whether the mission cost of navigation for multiple AUVs is a direct multiple of the number of vehicles.

Of particular interest is that an unlimited number of vehicles can use the same maps making the use of multiple platforms more cost effective.

III. SURVEY OF MAP BASED NAVIGATION

Perhaps the most well-known example of geophysical navigation is the terrain contour matching guidance system used by cruise missiles operating over land [11]. In this system, vehicle

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[1] Y and N refer to yes and no, respectively.

magnitude or direction over smaller spatial scales, then a chart of water current measurements could be consulted to establish the correct navigation sampling rate.

Finally, estimated bounds for the current velocity for track #1 are: $V_x = [-0.8466, 0.7810]$ m/s with $\overline{V_x} = 0.2083$ m/s, and $V_y = [-0.4308, 0.4408]$ m/s with $\overline{V_y} = -0.0013$ which demonstrate a conservative bound for a current velocity of $0.2 m/s$ in the x-direction.

XI. CONCLUSION

We have presented an algorithm for autonomous navigation using a consistent interval model to represent uncertainty. A position error bound is obtained directly from the interrogation of maps represented by interval B-spline surfaces. In this manner, a conservative position estimate provides for a robust solution to the localization problem.

Simple numerical tests demonstrate an alternative to current AUV navigation practices. However, in order to test the practicality of this approach, we are implementing the navigation model into a complete simulator that is currently being developed. Any implementation, however, will be limited by the availability of data at a significant resolution for realistic applications. This would motivate interest in a concurrent map building and navigation capability, a more ambitious topic which is recommended for further research.

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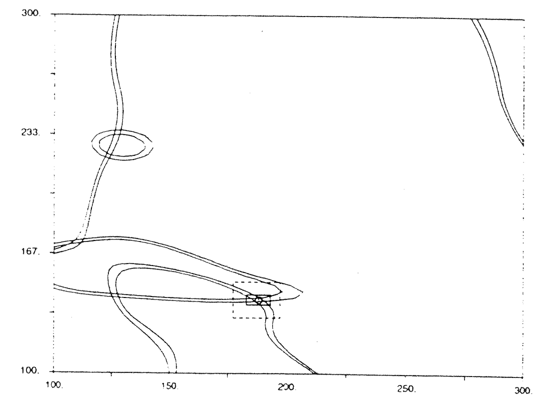

Figure 10. Plot for T = 0. Initiate track #1.

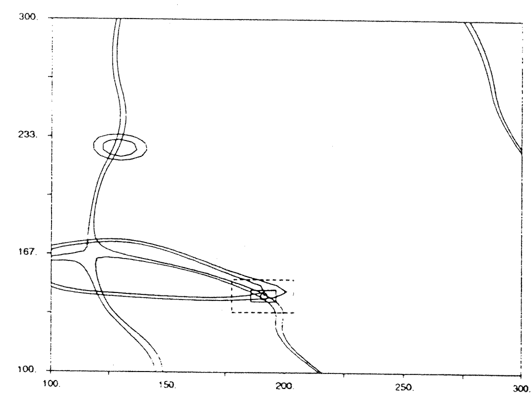

Figure 11. Plot for T = 1.

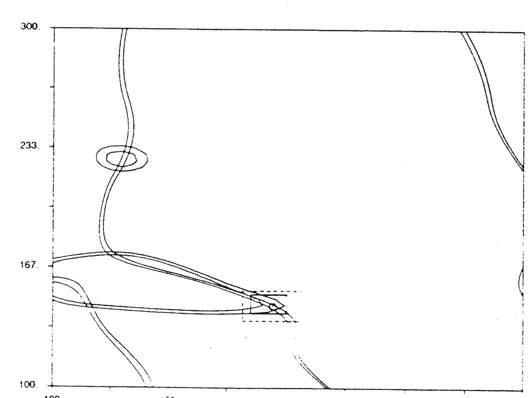

Figure 12. Plot for T = 2.

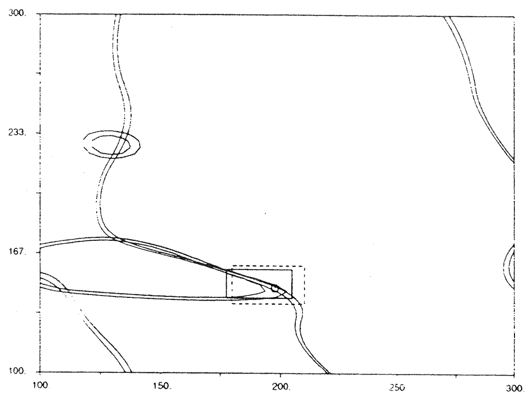

Figure 13. Plot for T = 3.

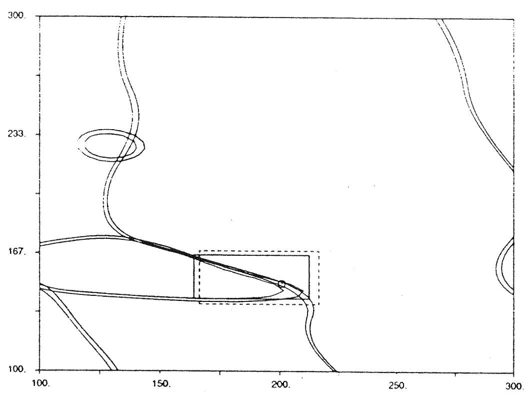

Figure 14. Plot for T = 4. Note that the contours at the vehicle location are nearly tangent and that navigation is losing positioning accuracy.

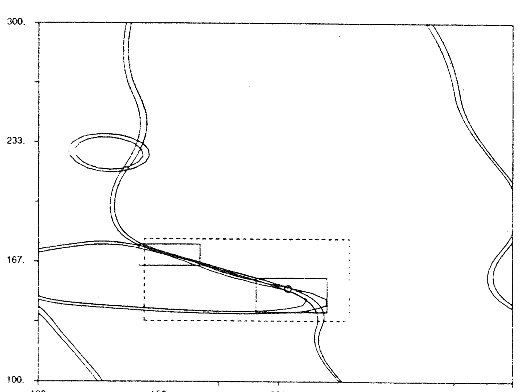

Figure 15. Plot for T = 5. Multiple solutions found from contour intersection and track #2 initiated.

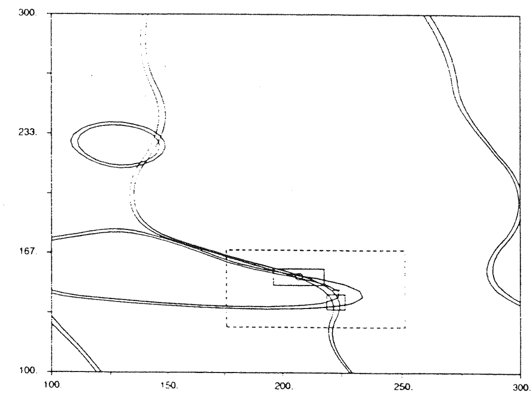

Figure 16. Plot for T = 6. No solution for track #2. Multiple solutions found from contour intersection for track #1 and tracks #3 and #4 initiated.

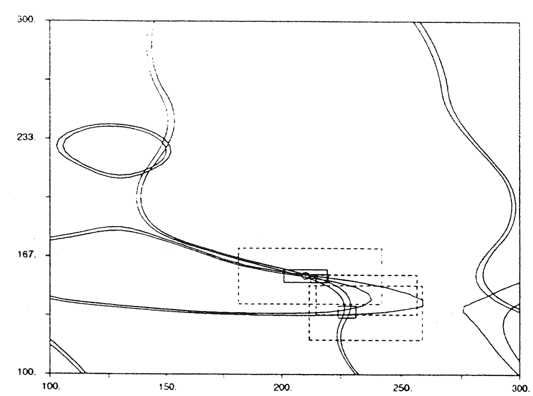

Figure 17. Plot for T = 7. No solution for track #2. Multiple solutions for track #4; track #5 initiated.

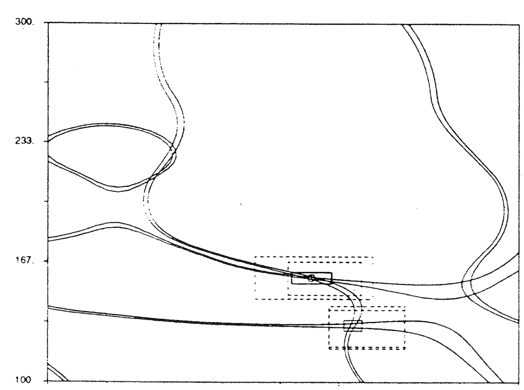

Figure 18. Plot for T = 8. No solution for track #2.

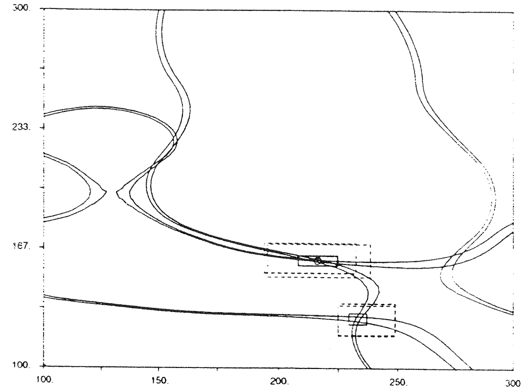

Figure 19. Plot for T = 9. Track #2 pruned through beam search after 3 misses.

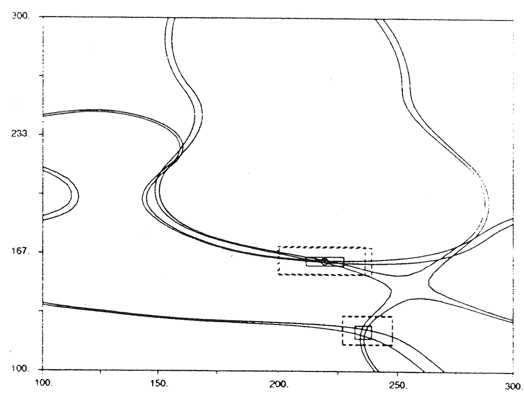

Figure 20. Plot for T = 10.

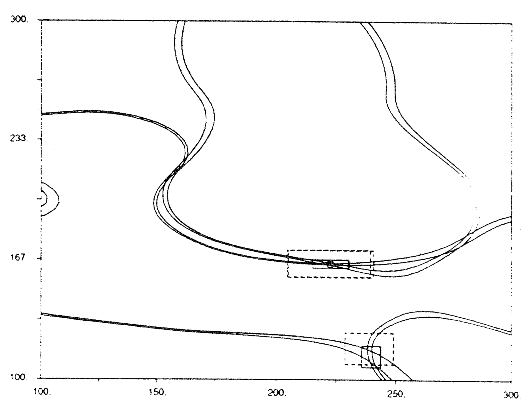

Figure 21. Plot for T = 11. Track #5 is pruned.

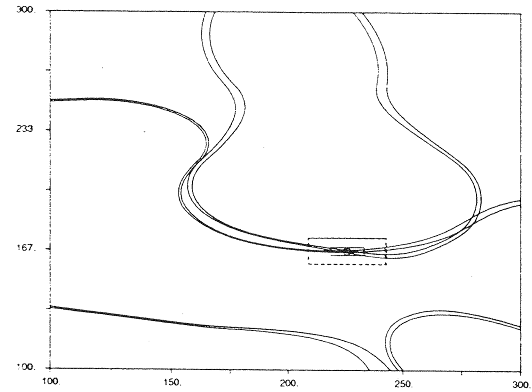

Figure 22. Plot for T = 12. Track #3 is pruned.

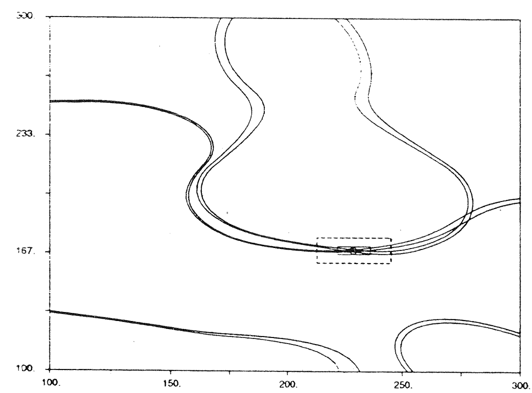

Figure 23. Plot for T = 13.

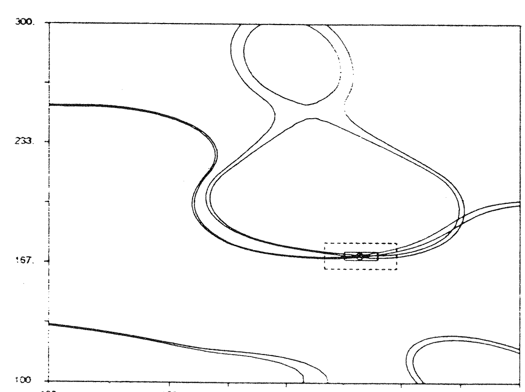

Figure 24. Plot for T = 14. Track #4 is pruned.