UNIVERSITY OF CALIFORNIA

SANTA CRUZ

FASTPAS - FAST PREDICTIVE ARIEL SCANNING

A dissertation submitted in partial satisfaction of the
requirements for the degree of

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in

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ROBOTICS AND CONTROL

by

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Abstract

FASTPas - Fast Predictive Ariel Scanning

by

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Unmanned Aerial Vehicles (UAVs) have become more prevalent in fields of work and study that benefit from having a birds eye view on a given situation. Firefighter teams have been using UAVs to find the origin of fires, and where fires are spreading to. Scientific researchers have been using aerial thermal imaging to determine rates of change in ice growth and melting, and thermal exchange between the ocean and atmosphere.

The use of autonomous UAVs could benefit rescue teams, firefighters, scientific researchers, and private sector industries in the interest of time and data discovery. Using a single or multiple UAVs in a flying network, an area with fields of interest can be scanned efficiently completely autonomously. By simply drawing on a map the general area wished to be scanned by the autonomous fleet, a deployed pod of these UAVs can stream back, to a ground station, live aerial information. This mapping time can be greatly reduced with the use of statistical interpolation techniques that help the pod or single UAV avoid having to scan an entire region, but rather, have the UAVs scan the areas with the lowest level of confidence in prediction.

The Kriging Method, a popular interpolation tool offers a prediction and a variance of prediction, but is computationally expensive because of constant fitting procedures. We can exploit the Kriging variances generated by our prediction to motivate the UAVs to

autonomously steer in the areas of least confidence until a minimum confidence in prediction is achieved for an entire unknown field. By designing a computational efficient algorithm based on a Universal Kriging Method, the system is feasible and could benefit a large group of potential users.

To all those who think flying robots are cool, and to my mother, Marina.

Acknowledgments

I want to thank Sharon Rabinovich, who helped me make sense of everything, as well as the rest of the Autonomous Systems Lab at UC Santa Cruz for the support and motivation to continue this project everyday.

Part I

Efficient Interpolation

Chapter 1

Introduction

There currently exists no consumer-level UAV system that can autonomously scan a perimeter of area to quickly map an unknown field. Due to the benefits of the solution to the problem, in terms of scientific research and benefit to fire fighting, I believe that designing a modified mathematical statistical interpolation method could make this system possible. Using a modified Kriging Method and a custom autonomous pod-UAV simulation, I would like to demonstrate that the system is possible, and could also benefit a variety of civil servants and scientists. We will, in this chapter, develop the tools and understanding of a method for interpolating data autonomously from just a few measured positions.
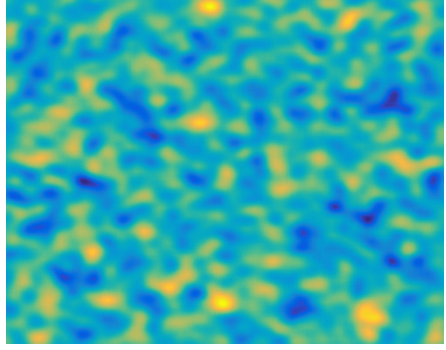
1.1 Kriging Prediction

It can be impossible to scan every square unit of area in a field, even with UAVs. Depending on the size of the map, it can often be most beneficial, in the interest of time flying above an area, to get a good enough prediction of the status of a field based off of a
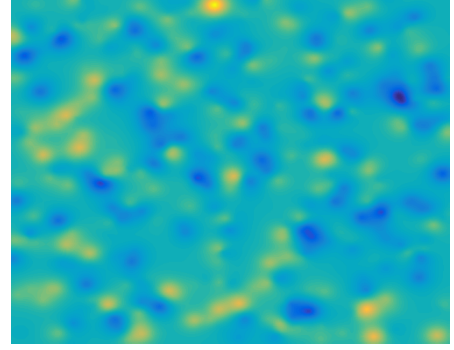
limited number of samples.

The Universal Kriging Method, also known as the WienerKolmogorov prediction, is a geostatistical Gaussian process historically used to interpolate data in fields varying from natural resource location prediction for mining to real estate value appraisals.

Using the Kriging method, the unknown probability of interest at point s_0 is achieved via:

$$\widetilde{Z}(s_0) = w_1 Z(s_1) + w_2 Z(s_2) + ... + w_n Z(s_n) \tag{1.1}$$

Randomly Generated Field   Kriging Method Predicted Field

Figure 1.1: A comparison of a random field generated using 500 random autocorrelated points, and a prediction of the field using the Kriging Method at randomly sampled points. *figures generated using MATLAB.*

The Kriging method also provides a variogram, with its prediction. The variogram provides a confidence score for each probability it computes via the computation of a discrete semi-variogram:

$$\hat{\gamma}(\mathbf{h}) = \frac{1}{2N(\mathbf{h})} \sum_{i=1}^{N(\mathbf{h})} \left[Z(s_i) - Z(s_i + \mathbf{h}) \right]^2 \tag{1.2}$$

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Where $N(\mathbf{h})$ is the number of pairs of data locations that are vector $\mathbf{h}$ apart.

The semi-variogram is then fit by a least squares to a continuous variogram that can be sampled for each point at question.
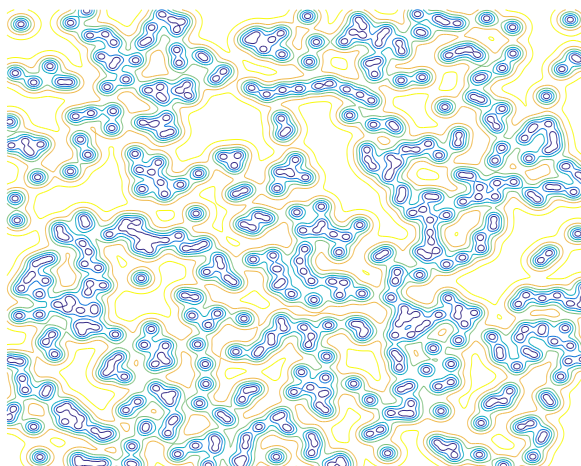

Figure 1.2: The variance of each prediction point from Figure 1. Larger spacing between the contours indicate greater variance. *figure generated using MATLAB.*

Although the method is optimal for data with no trends or drift, the use of the unmodified Kriging Method technique has the drawback of being computationally intensive and slow to compute in a live and timely manner. This is due to the multiple matrix inversions and least squares fittings to calculate the weights of the interpolation and the continuous variograms. It would be desired, in the case of autonomous UAVs that must constantly steer themselves in the best direction, to quickly calculate probabilities and covariances.

1.2 Kriging Variance

1.2.1 Semivariogram

1.2.2 Variogram

1.3 Autonmous Waypoint Selection

1.3.1 Searching for low confidence

1.3.2 Selecting points of low confidence

1.4 Natural Neighbor Selection

1.4.1 Voronoi Tesselations

Chapter 2

Previous Work

Some other research was once performed.

Part II

Can it fly?

Chapter 3

Introduction

3.1 Custom Simulation

3.1.1 Flying Engine

Plot Drawing

Waypoint Selection

3.2 FastPAS

3.2.1 The Algorithm

3.2.2 Simulating It

Chapter 4

Results

Chapter 5

Conclusion

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Appendix A

Ancillary Material

kriging formula least squares semi-v to v procedure calcuylating weights