MULTISENSOR FUSION

A Minimal Representation Framework

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A Minimal Representation Framework

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To my father Sri. Liladhar Joshi
and
To the memory of my grandparents
Sri. Laxmidutt Joshi and Smt. Ganga Joshi
- Rajive

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Preface

Multisensor fusion has emerged as a central problem in the development of robotic systems where interaction with the environment is critical to the achievement of a given task. As applications become more complex, the selection of model, parameters, and data subsamples is more difficult to determine a priori, and therefore the availability of a consistent framework across a wide variety of problem domains is important.

The primary focus of this book is to describe a methodology for addressing model selection and multisensor data fusion issues, originally developed as part of the first author's doctoral thesis work under the guidance of the second author. This book is divided into three parts. In Part 1, we present a broad survey of the literature on multisensor integration, multisensor fusion techniques, and applications in object recognition using multiple sensors. In Part 2 of the book, we describe the minimal representation size framework for multisensor fusion and model selection, and develop generic environment and sensor models, minimal representation encodings and their properties, and templates for generic multisensor fusion algorithms. In Part 3, we apply the abstract framework to multisensor object recognition problems, and describe laboratory experiments and practical experiences using the minimal representation size fusion methodology.

The general framework for multisensor fusion and model selection uses representation size (description length) as a *universal sensor independent yardstick* to choose **(a)** the model class and number of parameters from a library of environment models, **(b)** the model parameter resolution and data scaling based on the sensor resolution and accuracy, **(c)** the subset of observed data features which are modeled (and are therefore used in

the environment model parameter estimation) based on sensor precision, and (d) the correspondence which maps data features to model features. The sensor precision, controls the balance between the number of modeled and unmodeled data features, and determines the data subsampling. Error residuals of subsampled data features from different sensors, “scaled” on the basis of sensor accuracy, and “weighted” on the basis of sensor resolution, are used to define the environment model parameters according to the sensor constraint equations.

The minimal representation size criterion may be used for the environment model parameter estimation itself, or alternatively a more traditional statistical estimation method may be used. The search for the best interpretation may be conducted using (1) polynomial time algorithms using constraining data feature sets to instantiate environment models, or (2) evolution programs which use principles of natural selection to reproduce a population of interpretations.

The application of the framework to object recognition focuses on solving the object identification, localization, and matching problems in two and three dimensional workspaces, using vision, touch, and grasp sensors. In the laboratory experiments, tactile data obtained from the finger-tips of a robot hand, while it is holding an object in front of a camera, is fused with the vision data from the camera, to determine the object identity, pose, and the touch and vision data correspondences. The touch data is incomplete due to required hand configurations, while nearly half of the vision data is spurious due to the presence of the hand in the image. Using either sensor alone results in ambiguous or incorrect interpretations, and multisensor fusion is necessary to consistently find the correct interpretation.

The experiments use a *differential evolution* program to search for the best interpretation. As developed in this work, the search problem is difficult because we have posed it as a broad search over many general pose configurations (local minima), and have chosen not to impose heuristic constraints to simplify the search. In practice, there are many such heuristics which may be imposed for specific problems, and they would often improve the execution time of the search. However, in this study the focus has been on the nature of the representation itself and the associated search algorithms, rather than on building a practical system. The understanding and performance of these measures and algorithms provides the basis for further improvement in practical systems.

The laboratory experiments demonstrate the automatic selection of environment model class (object identity), the environment parameter values (object pose), and the sensor data correspondences (touch and vision correspondences), in the minimal representation size framework for multisensor fusion and model selection.

In practice, robotic manipulation using multisensor data must be done in real-time, and it became clear that the general evolutionary algorithms are too slow to estimate pose at sampling speeds for continuous motion. In a real-time system, one would use the generalized algorithm described here to initialize and occasionally update the pose estimate, while a much faster real-time update algorithm based, for example, on a Kalman filter would provide real-time feedback.

The methodology presented in this book is a general approach to fusion which is not restricted to geometric pose estimation, and in fact may be applied to a variety of problems in model identification from a wide perspective, including model-based identification of parameters from noisy data and prioritization in noisy data sets. The extension of this approach to many different types of models and estimation problems is an important element of this methodology and its use for general parametric model estimation with noisy data is open for further research.

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