JMMC MODEL FITTING SOFTWARE FOR OPTICAL INTERFEROMETRY

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Abstract. A working group of the Jean-Marie Mariotti Center is in charge of developing software for fitting models on data obtained from various optical interferometers. Concerned interferometers are mainly VLTI instruments (AMBER, MIDI), but also other existing instruments. The software is built around a specific non-linear fitting engine currently under test. The model includes a model of the observed object as well as the instrument itself in order to correct for possible instrumental artifacts. The software will provide an expandable set of geometrical models of the object, and we will attempt to allow the fit of a few physical parameters from a set of maps computed with astrophysical numerical models.

1 Introduction

The Jean-Marie Mariotti Center (JMMC) is currently working on software developments for processing interferometric data. The aim is to enable astronomers to fully exploit the scientific potential of existing and planned facilities, particularly those of the VLTI. The data processing software has been divided in two parts: image reconstruction and model fitting.

Image reconstruction is applicable when interferometric measurements come from many different baselines, typically more than one hundred (Lawson et al. 2004; Thiébaut et al. 2003) This process relies on constraints (positivity, smoothness, etc.), but the reconstructed image is "objective", *i.e.* no assumption is made on a specific shape of the object.

A so large number of measurements is not yet easily accessible in optical interferometry. Progress is fast, but the number of telescopes that can be recombined

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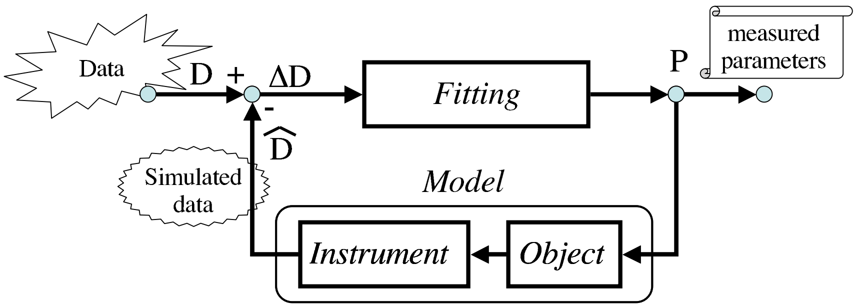

Fig. 1. Representation of the Model Fitting. Parameters (e.g. λ, $\Delta\lambda$, (u,v) config., etc.) are provided to a model describing the astrophysical object and a given interferometer. The "Fitting engine" minimizes the distance between simulated and real data, and provides adjusted parameters with error bars, matrix correlation and confidence level.

at the same time is currently low. In the case of the VLTI with AMBER, able to combine 3 telescopes only, collecting several hundreds of measurements with an even coverage of the (u,v) plane implies a huge observing time with different baseline configurations. When the number of measurements is sparse, we need to rely on assumptions on the shape of the object, with a limited number of free parameters: model fitting is currently the main road for processing interferometric data.

On the other hand, when image reconstruction is possible, it may be still necessary to rely on model fitting for getting measurements and error bars on a few specific parameters of the object. The reconstructed image is the key step for selecting a relevant model of the object and for knowing exactly what to measure. But the last step can be just model fitting.

Model fitting is an inverse problem. We suppose that we know a "direct" model to compute simulated data from parameters of the object and from a description of the interferometer during observations. Inverting means seeking a set of free parameters that allows us to fit the real data with the simulated ones. In our case, the model is complex and non-linear. A modified Levenberg-Marquardt algorithm is used, performing an iterative process, which can be seen as a control-loop working by trial and error (Fig. 1).

2 The model fitting software

The work is driven by several general requirements. Firstly, the software must be accessible to astronomers with no particular expertise in optical interferometry, which is essential for making the most of the available facilities. Then, the software architecture must allow us to merge the expertise already accumulated in this field. This implies an overall simple structure, with interfaces accurately defined. The software is organized around the three following parts (Fig. 1).

2.1 Object models

This part contains a library of geometric objects with basic elements (disc, ring, gaussian, limb darkening profiles, etc.) that can be combined to build up more complex shapes. We should offer the ability to apply simple geometric distortions (rotation, scaling, anamorphosis, etc.) to the object as a whole. The structure of the software allows us to easily implement any model.

Coupling the fitting software with astrophysical numerical models of the objects is a major requirement. We foresee two different means to fulfill this requirement: 1) From a set of maps pre-computed on a sparse grid of astrophysical parameters, we can fit across the maps using an interpolating algorithm between them. 2) The fitting algorithm could drive directly an astrophysical numerical model to get the required object map from a given set of free parameters.

2.2 Instrument models

The relationship between the observed object and the interferometric measurements must be taken into account. The current available data processing generally considers an idealized interferometer giving measurements from localized point in the (u,v) map. However, on monomode interferometers, the finite diameter of the telescopes induces an apodization of the field of view (Longueteau et al. 2002). The effect of this "antenna diagram" is not easy to model when taking into account partial correction with adaptive optics, and it depends on the kind of measurements done by the interferometer. On multimode interferometers, the Michelson arrangement produces a frequency conversion (Tallon & Tallon-Bosc 1992) that has complex effects with a finite spectral window (Tallon & Tallon-Bosc 1993). Furthermore, effects as simple as the sliding of the projected baselines during the exposure time or field apodization from a finite spectral window must also be considered.

2.3 Fitting engine

The fitting "engine" must be as reliable as possible and able to give understandable hints upon the fitting process and its quality. We have to solve a non-linear, non-convex inverse problem that may have several local optima (Bates & Watts 1988). Thanks to the limited number of free parameters, we foresee to provide the user with different means to overcome this problem. The fitting engine is based on a modified Levenberg-Marquardt algorithm (Dennis & Schnabel 1983), combined with the trust regions method (Powell 1970). The algorithm needs to use the gradient of the global model, including object and instrument models. The fitting engine estimates this gradient from finite differences (backward or forward according to parameter proximity to its bounds). Close to the Orthogonal Distance Regression algorithm ODRPACK (Boggs et al. 1987, 1989), the stability and hardiness of the fitting process is improved by a distinct normalization of the problem and a subtle use of bounds information on parameters values. The engine also enables to fit heterogeneous data, such as amplitudes or phases of complex visibilities or triple products, in the same process. At the end of the procedure, final reduced chi-squares, covariance matrices, standard deviations, and confidence level intervals allow the user to evaluate his model reliability.

3 Implementation

We have chosen to proceed progressively, insuring a reliable model fitting at each step: a demonstrator, consisting in the competitive fit of a simple direct model (simple object and ideal instrument) is firstly made (until October 2004). Then, it will be expanded with the implementation of more complex models of objects and instruments. Furthermore, it is developed through software rules to guarantee a long and large use. The JMMC Model Fitting group indeed is also a part of the European Joint Research Activity 4 (JRA4) "Integrating interferometry into mainstream astronomy", in OPTICON framework. In this context, we have to furnish during the first semester of 2005 several basic documents, essential for the writing of public software, deliverable in 2008.

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