GLOBAL FRINGE FITTING FOR SPACE INTERFEROMETRY

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The technique of global fringe fitting has proven to be very valuable for very-long-baseline interferometry (VLBI). It allows weaker fringes to be detected than is possible with conventional single-baseline fringe fitting algorithms, and thus improves the sensitivity of present VLBI arrays. Global fitting was developed for VLBI by Schwab and Cotton (1983, *Astron. J.* **88**, 688), and has been incorporated into the NRAO Astronomical Image Processing System as program VBFIT. As Schwab and Cotton point out, this is a generalized from of self-calibration in which closure relations for residual fringe delay and rate (frequency) are satisfied in addition to those for fringe phase and amplitude. These additional closure relations allow station-dependent delays and rates to be solved for, using data from all baselines with sufficiently strong fringes. Then it is possible to calculate where fringes will be on any less sensitive baselines between these telescopes, so that very narrow search windows in delay and rate can be used.

A generalized version of VBFIT has been developed for use with VLBI arrays that include orbiting radio telescopes. This program, VBGFF, can accomodate the rapidly-changing geometric delays and fringe rates on baselines to orbiting telescopes. It requires at least one ground-space baseline with enough sensitivity to produce strong fringes in integration times which are shorter than the time it takes the actual baseline motion to differ from a smoothly-varying model of its motion through the (u, v) plane.

Let $\phi(i,j)$ be the source phase on the baseline between antennas i and j, which is initially unknown. To get around this problem, we require a model of the source brightness distribution from which the $\phi(i,j)$ can be calculated. As in normal hybrid mapping, a more accurate source model will improve convergence of the fringe search, although in practice a point source model is often sufficient.

The observed visibility phase is $P(i) - P(j) + \phi(i,j)$, where $P(i)$ is the phase error associated with antenna i. The partial derivative of the visibility phase with respect to frequency is the baseline delay $D(i,j)$ and the partial derivative with respect to time is the baseline fringe rate $R(i,j)$. The location of the maximum amplitude of the Fourier transform of the observed visibility function in delay-rate space gives the values of $D(i,j)$ and $R(i,j)$. Standard fringe fitting uses this method to find $D(i,j)$ and $R(i,j)$ for all i and j during each integration interval. The values of D and R for a given baseline

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are then used to correct the observed baseline phases for the effects of $P(i) - P(j)$ and hence allow coherent integrations of the visibility function for periods during which $\phi(i,j)$ remains nearly constant. This can be as long as several minutes.

The problem with this approach is that it only works on baselines where the Fourier transform of the observed visibility function has a large enough maximum amplitude. There is no way to use the $D(i,j)$ and $R(i,j)$ for other baselines to calculate D and R for a baseline on which fringes are very weak, since the D and R nave not been separated into antenna-dependent $D(i), D(j), R(i)$, and $R(j)$. Global fringe searching solves for antenna based $P(i), D(i)$, and $R(i)$ using a set of $\phi(i,j)$ calculated from the source model. Once the antenna-based quantities have been determined (by least-squares, for example), they can be used to find fringes on all baselines.

The VBGFF program allows searching for fringes which vary over much wider ranges in delay and rate for some antennas than for others. This is done by setting different widths for the delay and rate search windows for the various antennas. This is useful when an array includes both ground and space based antennas, or when equipment problems or bad weather cause some ground based antennas to have less stable delay and rate solutions than others. The delay and rate search windows are defined by adding a "penalty function" to the quantity being minimized to estimate the antenna-based parameters. The penalty increases with increasing absolute value of the residual $R(i)$ and $D(i)$. VBGFF uses a more steeply-rising function than VBFIT does.

An additional modification to VBFIT allows different solution intervals to be used for the initial Fourier transform fringe search and the final least-squares search. Now one can use a relatively long time interval to determine initial values for the least squares part of the program, but use a shorter interval for the least squares fit so it can more accurately follow changes in the delays and rates. This avoids the need to run VBFIT twice – once to detect fringes using a very long solution interval and a second time to get more accurate telescope solutions with a shorter solution interval. Using a short solution interval can be particularly helpful for high frequency experiments, where bad weather can cause rapidly changing telescope solutions.

A final modification to VBFIT concerns the way in which the delay and rate solutions are edited or smoothed prior to being applied to the input data. The initial solutions found by the FFT search can be boxcar smoothed over an arbitrary time interval before being used to "center" the visibility data for a second fringe fit. The final solutions can still be edited and smoothed in the same way as in VBFIT before being applied.

Several limitations remain, including a requirement that search windows be centered at zero. This requirement will eventually be removed. In addition, it is assumed that antenna amplitude errors will remain constant during the period of the fringe search (up to several minutes), and that the amplitude of the source visibility will also remain constant during this period. These assumptions are not always valid.

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