HIPPARCOS reductions for multiple stars, IVb.
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In a previous note (IVa, NDAC/LO/080), a study of triple components to known binaries was envisaged to follow rather soon. Since then, an important complication that touches on all "known" multiples has emerged: It is not possible to assume that the a priori position of the primary component is well known, only relative data are available.

The present note is therefore partly a discussion of this added complication, partly a discussion of the triple star problem as outlined before.

1. Grid-search for the primary

Before, the a priori positions for known doubles and multiples were assumed to be known within some 0.2 arcsec, enabling a direct LS-solution with only the standard iterations due to non-linearity. It appears now that this is an oversimplification. The relative positions of the components are almost always well known, but the position of the primary is not improved in the main-stream data reductions, and it may thus easily be in error by 1-2 arcseconds. It is thus necessary to search for a useable primary position, that is, one that gives a converging LS-solution.

A simple way to perform this search is to apply the double iteration method previously used when searching for an unknown secondary component. The difference is that we now iterate with the primary at different grid-points, keeping the secondary (or secondaries, for a multiple) at the a priori relative positions. An efficient way to do this search seems to be to keep only the primary position and magnitude as variables. The parallaxes and proper motions are set to their a priori values, as are the relative positions and magnitudes for the other components. (For numerical stability reasons, it is advantageous to include the normally excluded Fourier bi-components in this search-mode; they are not used in the "final" LS-solution).
With twelve grid-points as before, but with their "gridstep" increased from 0.25 to 0.35 arcsec, the correct primary position is almost always obtained when it is a priori in error by less than 1.5 arcsec. The relative positions are then usually assumed to be known to 0.3 arcsec, and the relative intensities to 0.5 magnitude. For multiples, the relative positions are more critical. From a number of runs for n=4-5 "trapezia" as studied in Paper IVa, it appears that the positions should be known to about 0.15 arcsec for 0.5 magnitude intensity-errors or 0.20 arcsec for 0.2 magnitude accuracy.

The above grid-search gives mainly an improved primary position, and one then performs the "full" LS-solution with up to 6n parameters. The convergence is rapid, and all results in previous reports apply. There is a possible time-problem, because we have to make some one hundred extra iterations to find the primary position. This part of the program may be written more efficiently, however, as it really uses only three variables. Beginning with the present tests, the Fourier components are also averaged over each FOV (8 frames), reducing the number of observations by a factor 8. This is a great improvement for the tests, but such averaging has been foreseen all the time for the real reductions.

For the non-negligible proportion of systems with larger a priori errors for the primary, one has to search in a larger grid. This will take more time, but it is otherwise no different from the "standard" case.

2. Triple components to known doubles

A (small) proportion of the known double stars will in reality be resolvable triples. This is indicated by a poor fit to the assumed binary model, and one may then try to find the extra component. From well-observed and presumably "non-triple" doubles, one obtains statistics for the $\chi^2$ fit to the observations, $S_b$, and any system with an apparently too high $S_b$ is subjected to the triple search. This is done exactly as the search for a secondary to a "single" star, assuming the third component to have any of the 12+12 grid-positions around the double components. The best-fitting solution is adopted, giving a "triple" $\chi^2$-value $S_c$. If this fit is markedly better ($S_b - S_c$ greater than some limit), and if the triple star parameters look reasonable, the triple model is accepted.
There are some complications. First, the a priori position of the double star primary is unknown, as described above for bona fide doubles. One has thus to start by searching for the primary, and this search will be difficult if the third component is too apparent. No exact limits may be given, but if one of the known components is really a binary with equal components, this "close" separation should not be much above 0.5 arcsec if one is to avoid problems. Fortunately, such a system is likely to be already discovered as triple, as it has been scrutinized closely by double star observers. Also, one always has to make the grid-search around both the known components. It is generally impossible to select \( \chi^2 \)-limits such that a solution may be accepted without actually trying all 2x12 grid-positions. A large number of iterations has thus to be done, but for a relatively small number of systems.

An exhaustive study of the large number of possible triples is beyond the scope of the present investigation, but a sufficient number of test cases has been accumulated in order that some preliminary conclusions may be given. In these tests, the primary of the known double has been magnitude 8.5, the secondary mag 8.5 or 10.0, and the wide separation was 15 (sometimes 5) arcsec. In all cases, an area in the (close) sep/\( \Delta m \)-plane may be defined where the third component is normally discovered. Very roughly, we get a \( \Delta m \)-limit around 2.5, and a separation-limit around 0.15 arcsec for the equal-magnitude case (known double 8.5+8.5). For the unequal system (8.5+10.0), the detection is (as expected) easier/more difficult than in the equal case when the primary/secondary is double. However, the \( \Delta m \)-limit does not seem to vary by more than 0.5 magnitude and the sep-limit by more than 0.05 arcsec either way.

The above results are probably typical for a large number of triples, but they should not be taken as final. The 12+12+12 (primary-search, triple search around two different stars) individual LS-solutions make for problems in special cases, and from the present experience, the border between triple/double solutions is not as well-defined as the double/single-border investigated in NDAC/LO/085. Certainly, however, this method for finding unknown triples will be applicable and useful in many cases.