CQSSP: A NEW TECHNIQUE FOR ESTABLISHING THE TIE BETWEEN THE STELLAR AND QUASAR CELESTIAL REFERENCE FRAMES

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ABSTRACT. Using artificial satellites as transfer objects the project "Coupled Quasar-Satellite-Star Positioning" represents an independent method for linking quasar and stellar reference frames. Optical observations of close approaches between reference stars and satellites yield satellite positions in the stellar reference frame. On the other hand high precision satellite orbits in the International Earth Rotation Service (IERS) terrestrial reference frame are obtained from laser or radiometric observations. Using IERS earth rotation parameters and adopted transformation models the satellite and eventually the star positions can be expressed in the IERS quasar celestial reference frame. In this paper we describe the CQSSP project and assess its capability for providing an accurate tie between tho two metioned celestial reference frames.

1. Introduction

In recent years techniques have been proposed to tie the conventional inertial coordinate reference frames defined by the very long baseline (radio) interferometry (VLBI) positions of selected extragalactic radio sources, primarily quasars, to the reference frames established through optical observations of stars. The need to tie these two types of frames stems from the high accuracy but limited accessibility of the quasar frames on the one hand and the less accurate but more readily accessible stellar frames on the other. If the relationship between the radio source and stellar frames can be accurately established optical positions could be readily expressed in the radio source frame. The procedure of relating the two types of frames should reveal the errors in position of individual stars and zonal errors in the optical catalogues as well as giving the global orientation of one frame with respect to the other.

The classical techniques used to tie the radio to the optical frames all make use of radio-emitting object which are observable by VLBI as well as in the visible part of the electromagnetic spectrum. Several ongoing projects observe either extragalactic objects (EGOs) or radio stars in the optical using astrograph cameras or CCD sensors on large telescopes. The priciple of these methods is outlined in Figure 1. Unfortunately there are some limitations of this technique. The first is that there are relatively few compact EGOs which are strong enough to be accurately positioned by VLBI and sufficiently bright in the visible to provide good optical images. The second is that for most EGOs there will not be a nearby FK5 star in the image. Hence the positions of secondary and tertiary reference stars must be established with attendant positional uncertainty. Third one must assume that the radio centres and optical photocentres of the objects coincide. Many radio-emitting EGOs show an elaborate structure on the scale of a few mas or more that is both time and frequency dependent. For example, Charlot et al. [1988] found for 3C273B that at 1985.37 the 90 % of peak brightness contour spanned over 28 mas at 2.3 GHz but only about 5 m as at 8.4 GHz.

2. The CQSSP Technique

The key idea of the "Coupled Quasar-Satellite-Star Positioning" project is to use artificial earth satellites as transfer objects (see Figure 2). The positions of these satellites can be observed very accurately in the International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) by Satellite Laser Ranging (SLR) or radiometric observations (e.g GPS). On the other hand VLBI observations of quasars define the International Celestial Reference Frame (ICRF) and a series of earth orientation parameters as determined by the International Earth Rotation Service (IERS). Therefore we can assume the transformation from the IERS Terrestrial Reference Frame (ITRF) to the quasar frame to be given by VLBI at any epoch. This enables us to express the coordinates of the transfer objects (the satellites) in the quasar frame although they are measured by Satellite Laser Ranging (SLR) or GPS in the ITRF. The optical observations of the satellites with respect to the reference stars will finally result in coordinates of these stars in the quasar reference frame (ICRF).

2.1 OPTICAL OBSERVATIONS OF STARS AND SATELLITES

Close encounters between satellites and stars are recorded on

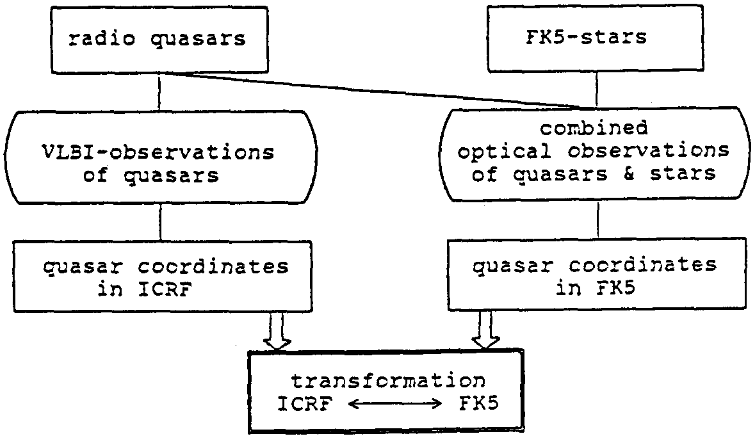

Figure 1: Classical Method

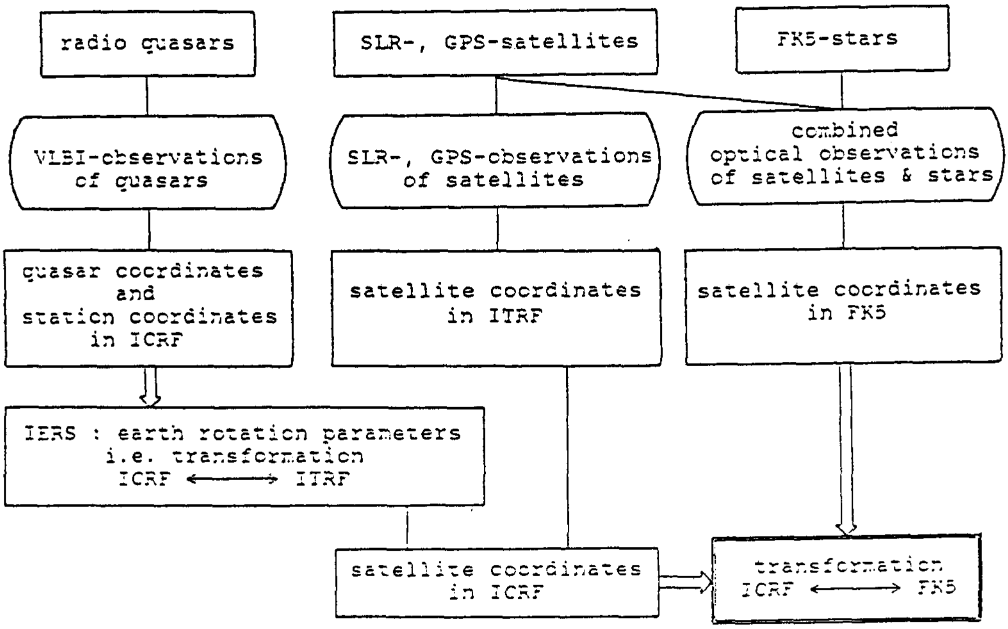

Figure 2: CQSSP

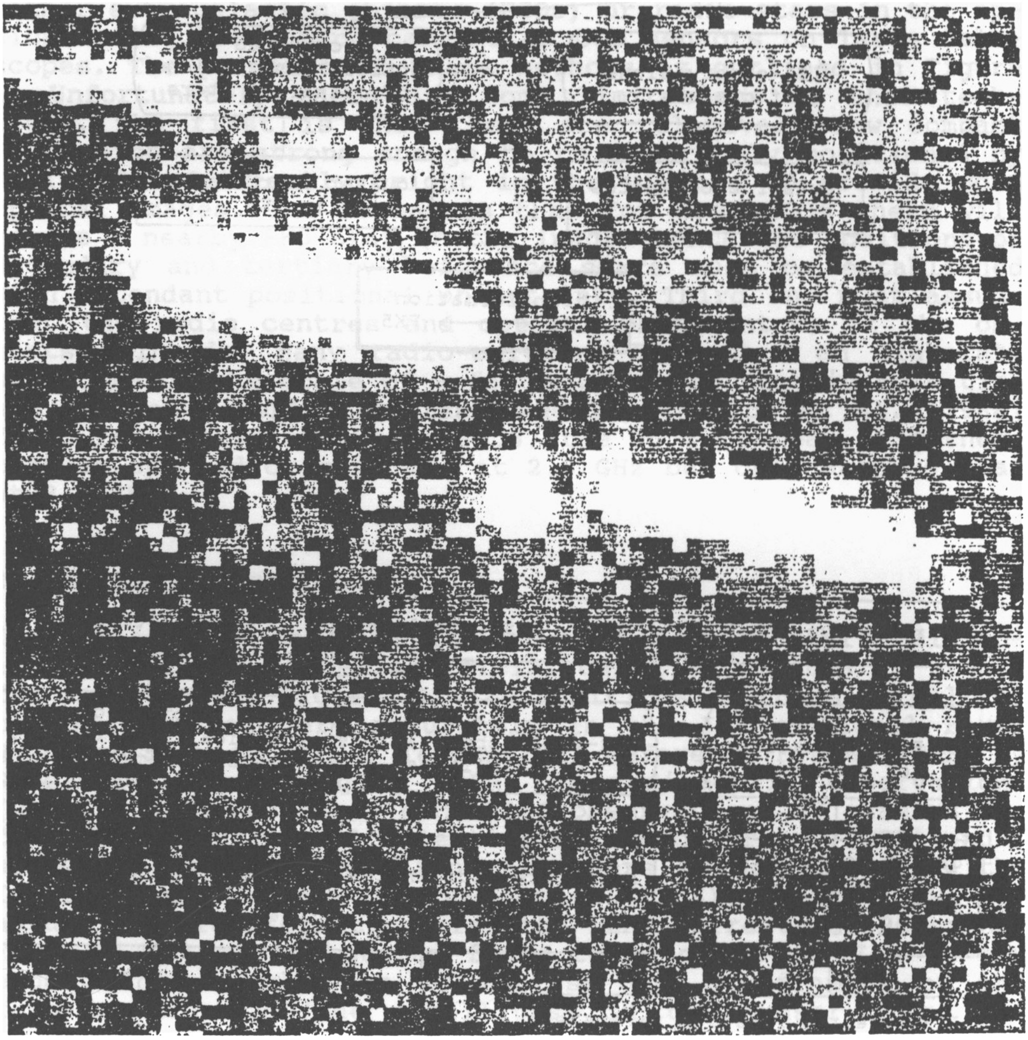

Figure 3. 0.5 second exposure of the geodynamics satellite LAGEOS and several star trails at the 0.5 m laser ranging telescope in Zimmerwald. The telescope was tracking the 13.5 mag. satellite moving with about 200"/sec relative to the stars. The image represents approximately a 7′ x 7′ area.

a CCD detector. The idea is to select such events with very small angular distances between the two objects thus minimizing the influence of differential refraction. Pushing the approach to the limit would mean that we allow for occultations only which however would restrict the number of events to much. Assuming a small field of view of 10 arcminutes and 200'000 reference stars homogeniously distributed over the entire celestial sphere (HIPPARCOS catalogue) we end up with about 50 observable encounters per satellite pass (from 30 deg elevation over zenith to 30 deg elevation). (See Bauersima, 1984).

First observations have been acquired with the 0.5 m f2 Cassegrain telescope at the Zimmerwald Laser Ranging observatory where the useful field of view is about 10 arcminutes. The detector is an 512 x 512 pixel front side illuminated CCD with 20 x 20 f pixel size resulting in a linear scale of 4.1 arcseconds per pixel.

Depending on the height of the used satellites (1000 to 6000 km for LASER, 20000 km for GPS satellites) an encounter may be observed for 10 to 50 seconds at maximum (determined by the fact that both objects have to be simultaneously in the small field of view of 10 arcminutes). Due to the movement of the satellites with respect to the stars we will obtain trailed images at least for one object (depending on the tracking mode).

Figure 3 shows the situation where the telescope was tracking a satellite and thus the stars moved with respect to the telescope. Thinking in terms of signal to noise ratios of the single images we prefer to concentrate the light of the fainter object on a few pixels of the detector which in most cases means that we have to track the satellite. The importance of this point is evident considering an optical brightness of 12 to 14 mag for the satellites in contrast to the brightness of the reference stars (< 10 mag). We should also point out, that a 0.5 m telescope equipped with a CCD will collect only about 4500 photons per second from an 14 mag object.

With exposure times < 1 sec we end up with a series of 10 to 50 single images of the type shown in Figure 3 per close encounter. Each image results in a pair of coordinates for the star and the satellite in a CCD coordinate frame. These coordinates can be transformed to give satellite positions in the reference star system (FK5) or vice versa to give in star positions in the satellite reference frame (ITRF).

3. Advantages of the Method / Error Estimation

There are several distinct advantages of a method using satellites as transfer objects over methods using some sort of triangulation techniques (e.g. secondary and tertiary reference stars):

- The large angular distances between the quasars and the reference stars are bridged by high precision satellite orbits.

- Satellites allow for a selection of a homogenious set of reference stars.

- Only differential quantities are observed optically which reduces the influence of refraction to a negligible amount.

Errors of the radiointerferometric observations of the quasars and the determination of the satellite orbits are not concerned because they are well below 0.01 arcs and thus of minor importance compared with the errors associated with the optical observations.

For the error budget of the optical part we considered the following contributions:

- Determination of the observation epoch (the satellites move with up to 250 arcs/s).
- Determination of the centroids.
- Estimation of the parameters of the transformation CCD coordinates <--> celestial reference frame (FK5).

Assuming a 1 m, f4 to f6 telescope with high quality (astrograph) optics we end up for a single close encounter between a reference star and a 14 mag satellite with an accuracy for the position of the satellite in the stellar reference frame of 0.06 arcs.

Using the Zimmerwald Laser Ranging telescope (see section 2) as a test instrument first results already indicate a accuracy of about 0.4 arcs. We have to point out in this context that the mentioned telescope gives a scale of 4.1 arcs/pixel and produces images of very poor quality! Nevertheless an accuracy of 0.4 arcs is in the range of what is achievable with small Schmidt cameras. Since the exposure times are up to 2000 times shorter with the CCD system this opens a variety of new applications.

However, we should always remember that the CQSSP goal is the determination of 3 Eulerian angles (and their first derivatives) of the transformation ICRF <--> stellar reference frame (FK5) (and not positions of individual sources!) using hundreds of single "close encounter" observations.

4. Conclusions

CQSSP gives a link between the quasar and stellar reference frames which is independent from the classical link using radio sources.

The technique has the advantage to depend on a comparatively homogeneous distribution of reference stars.

We expect an accuracy which is comparable with the classical approaches using astrographic techniques.

In view of the importance of the topic, the specific advantages and the expected accuracy of the technique, we expect CQSSP to make a valuable contribution to the establishment of transformation parameters between optical and quasar reference system.

5. References

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