THE GIPSI-TRAC PROJECT

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ABSTRACT

Inertial positioning has the property of very smooth and continuous tracking, but wanders with regard to absolute positioning. Dynamic Differential GPS (DGPS), conversely, is good at absolute positioning but suffers badly from "noisy" positioning and gaps (caused by obscuration from satellites in tree-lined and built up areas). These two complementary technologies are brought together in GIPSI-TRAC - Global and Inertial Positioning Systems Integration for Tracking Route Alignment and Crossfall. This paper outlines the development from concept to testing of this Australian made, compact, vehicle-based, hybrid positioning system.

Background

The Australian Road Research Board (ARRB) - representing State Road Authorities - in conjunction with the Roads and Traffic Authority of NSW, VicRoads and The University of Melbourne (Geomatics Department) developed GIPSI-TRAC to meet a need for accurately mapping road data on the fly.

The aim of the project was to amalgamate DGPS with ARRB's quasi-inertial Road Geometry Data Acquisition System (RGDAS) to produce continuous 3-D mapping of vehicle trajectories (and recording of crossfalls) in tree-lined and urban and rural canyon environments.

RGDAS alone records horizontal and vertical curvature and alignment and cross-slopes, related to chainage along the road. It basically comprises two orthogonal accelerometers, a yaw-rate gyro and an electronic odometer linked to a common synchronising /processing /recording computer. Two RGDAS systems have been in frequent use in Australia since 1984, while several systems have been sold off-shore.

The University of Melbourne (Dept of Geomatics) had recently developed a system for the Victorian Public Transport Commission to integrate DGPS with dead-reckoning (DR) - based on rate-gyro, odometer and transverse inclinometer - for rail alignment and superelevation capture. They developed a post-processing software approach for combining DGPS and DR sensor inputs based on a full least squares adjustment of all sensor observations and DGPS positions accurately synchronised to GPS time. "Piggy-backing" onto this development seemed the way to go. Melbourne University was contracted to adapt their adjustment program for GIPSI-TRAC.

VicRoads contributed to the project with their developments (by research students at RMIT) in DGPS capture and processing using low-cost Motorola GPS receivers. ARRB linked a Motorola GPS receiver board to their RGDAS to record GPS data and to synchronise the whole system to precise GPS time.

GIPSI-TRAC has been a little slow in coming into this world: after an interesting conception in February 1993, it went through a prolonged gestation period, considerable labour pains, a very difficult birth and extensive tests and consequent post-natal surgery. The project team is still suffering post-natal depression.

The Concept

Inertial tracking provides relatively smooth and continuous alignment but is not accurate in absolute position. A significant problem with yaw-rate gyros is the drift of about 1 to 3 degrees per minute of time, ie a straight line may plot as a circular curve if speed were constant. DGPS provides the ideal solution to solve for this drift, and to give absolute position to the trajectory. Vertical alignment in RGDAS is measured using odometer, time and longitudinal accelerometer observations, which give vertical accuracies in the order of 2-3 metres per kilometre.

GPS, however, tends to be "noisy" and spasmodic because of intermittent obscurations of the satellites by trees, hills and buildings, and because of reflected signals (multipath). Obscuration may be as little as 1% in open rural areas but may exceed 60% in built-up, forested and hilly areas. Melding inertial tracking and DGPS seems to be a mutually beneficial exercise - as indicated in Figure 1 below.

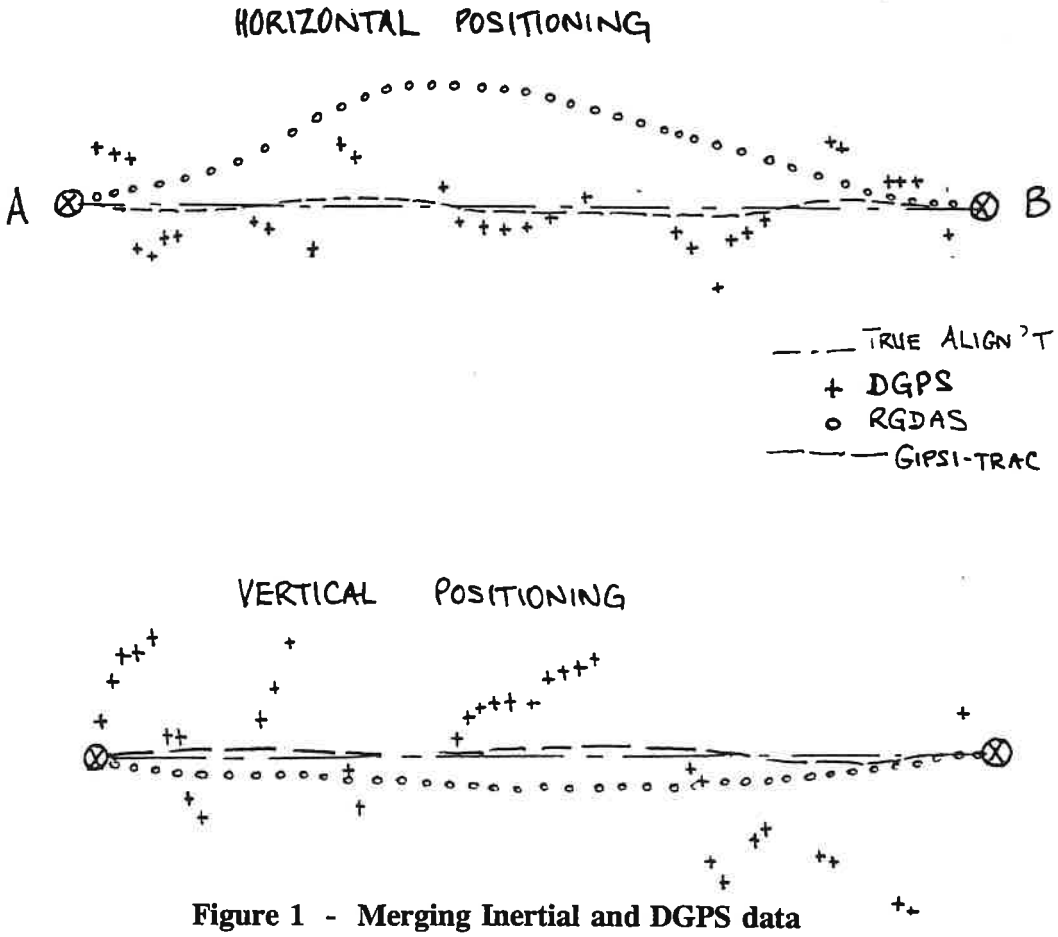
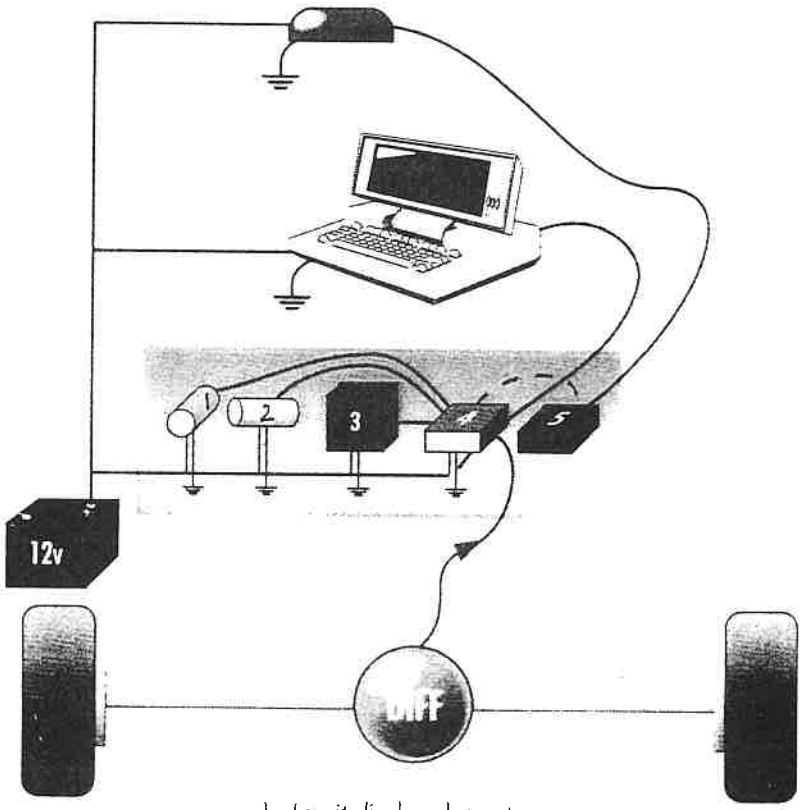


Figure 1 - Merging Inertial and DGPS data

Justification for GIPSI-TRAC

Current digital road centreline maps for GIS/LIS are fairly coarse - and are often up to 100 metres in error, and they are only 2D. With more and more road-related data being captured by DGPS, that data (5 to 10m accuracy - 95% of the time) will be located much better than the centreline base to which it is supposed to refer. It is obvious that end-users will soon become dissatisfied with the inaccuracy of the base to which they are trying to match. A more accurate base will inevitably need to be captured. GIPSI-TRAC provides the solution: a horizontal accuracy of approximately 2 metres is expected.

GIPSI-TRAC will also provide an accurate positioning base for road and near-road data video capture (including stereo capture).



1 Longitudinal accelerometer
2 Transverse accelerometer
3 Piezo-Electric Gyroscope
4 DAS Card
5 GPS receiver

Figure 2 - GIPSI-TRAC Components

Yaw-Rate Gyroscope Technology

The Road Geometry vehicle previously used a conventional spinning mass rate-gyro costing about $15,000. Piezo-Electric Vibrating rate gyros (very recent technology) promised a very cheap alternative -and may be purchased for about $700 each. Preliminary tests by ARRB showed the use of P-E/V rate-gyros to be quite feasible.

It was recommended that GIPSITRAC use the PE/V gyro rather than the conventional type. However some very disappointing results occurred with this type of Gyro. After many trials and tests it was found that the gyros produced unpredictable gross errors (of the order of 10-15 degrees !) in deflection angles on very sharp turns at high angular velocity, and at very slow speeds (ie under 10 kph). At first it was thought to be a systematic non-linearity that could be actually calibrated. A lot of time and resource went into trying to model or eliminate that behaviour - to no avail. Intermittent gross errors persisted. The PE/V gyros may be abandoned!

At the time of writing (1 March 95), we have just received two new Fibre Optic Gyros (FOGs). These new hi-tech American units cost around $2300 each, and on paper should be much better that the PE/V gyros. Our fingers (and toes) are crossed. If they do not succeed then it is back to a spinning mass rate gyro.

Differential GPS

As mentioned earlier, GIPSI-TRAC has a low-cost Motorola Coarse/Acquisition code receiver built in. This is an inexpensive unit with a one-pulse-per-second output, costing around $2,000, and is primarily used to synchronise all transducers to GPS time at the millisecond level. Navigation position solutions and Smoothed C/A pseudoranges are recorded on the GIPSI-TRAC computer. A post-process differential program written by RMIT is used to get DGPS positions at the 5-10 metre level of accuracy.

For accurate mapping the RTA also uses one of its Wild 200 dual-frequency receivers in the vehicle. As all inertial and GPS observations are synchronised, these additional DGPS fixes are easily introduced to the adjustment program (which allows up to two DGPS data sets). The use of dual-frequency machines means that very long ranges from base can be tolerated (up to 400 km) as the ionospheric effects are virtually eliminated.

Computation Concept

DGPS is used to dynamically and statically determine the vehicle's location with respect to a chosen mapping datum. These positions may be fixed as frequently as every half second. This sequence of position fixes is often jittery (within a certain range) and often has gaps caused by obscuration from satellites. Inertial tracking can be used to smooth the irregular tracking and fill in the gaps (in 3D) respectively.

Pre-processing of the inertial data against good stretches of DGPS fixes enables the systematic drifts of the gyro(s) to be modelled over the full length of a run. A low order polynomial least square fit is applied. This systematic bias is then removed before entering the data into the final adjustment.

Horizontal and vertical curvature, grade and crossfall can be deduced from inertial sensor measurements, ie longitudinal and transverse acceleration forces, yaw gyro angular velocity, and linear velocity (from odometer and time). Once crossfall and grade are deduced, yaw angular change can be resolved into horizontal angular deflections.

The ultimate 3D trajectory is determined by amalgamating all "observations" into a 'Least Squares' adjustment. DGPS positions, which are determined from third-party post-processing differential software, are input into the 'Least Squares' adjustment as position "observations" equations. Other "observation" equations for incremental height differences, and for incremental horizontal component differences, are similarly input into the adjustment. Approximate coordinates (for input) are deduced from DGPS and simple dead-reckoning. Many other observations can be eliminated by pre-adjustment filter algorithms. "Weighting" is deduced from the estimated a-priori standard deviations. These need to be empirically fine-tuned over known test alignments to ensure a good relative balance of weights.
On the completion of the Least Squares solution, and rejection of outliers, the resultant 3D alignment can be further filtered to minimise the number of points digitised by the Douglas-Peucker algorithms.

Testing

The RTA has a 40 kilometre loop around the Royal National Park, with 13 km of accurately surveyed centreline through hilly, winding, tree-covered road. Thus GIPSI-TRAC mapped centrelines can be overlaid on the true line in a CAD package.

The first test runs were absolutely awful, with horizontal errors up to 180 metres in the middle of a 3 km GPS-devoid stretch. We have been able to get this down to the 20 metre level over that stretch, but it is still not good enough, due to the erratic gross errors in the gyro records. We await the the Fibre Optic Gyro tests with bated breath.

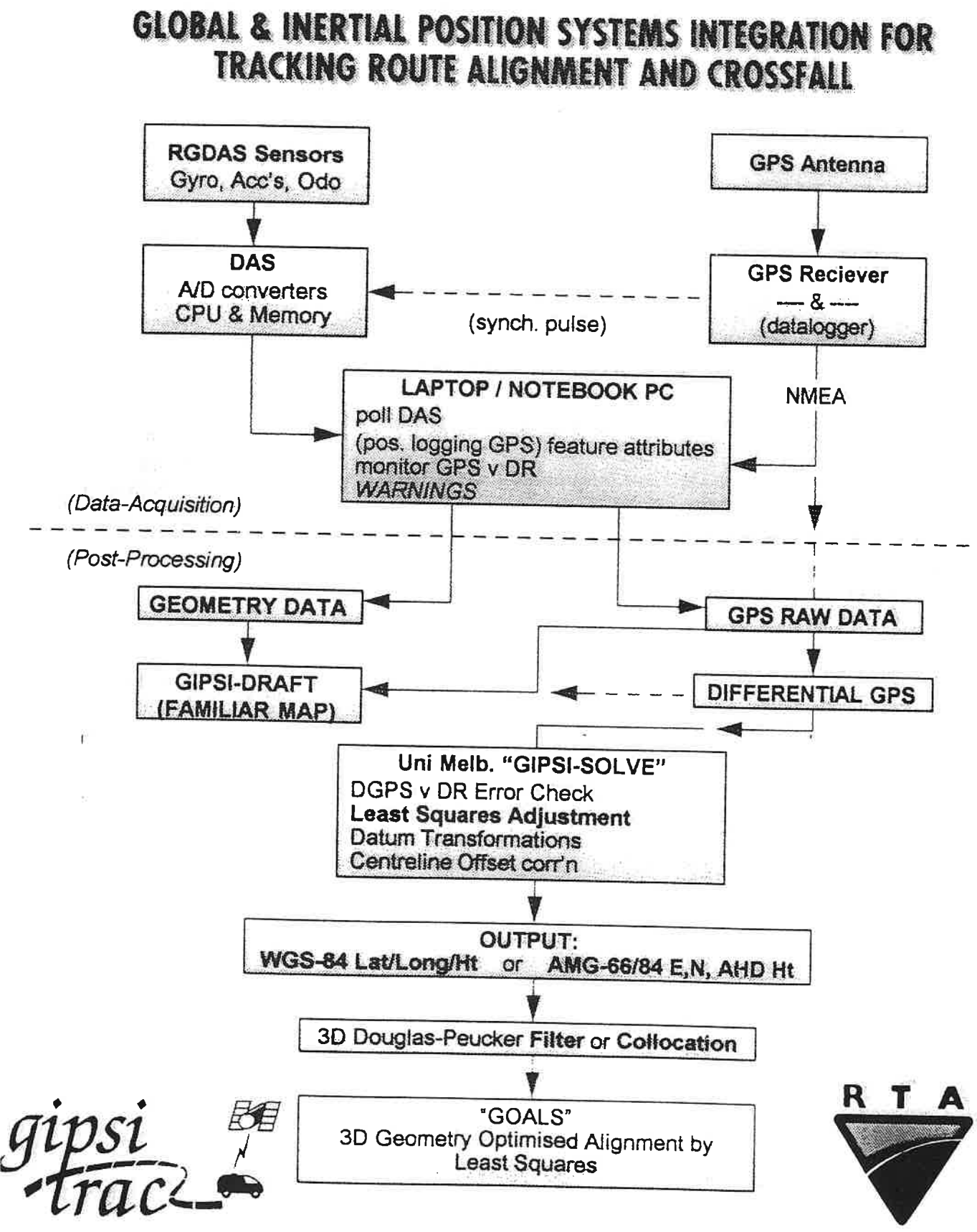


Figure 3 - Overall GIPSI-TRAC Schematic