iGPS - AN INITIAL ASSESSMENT OF TECHNICAL AND DEPLOYMENT CAPABILITY

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ABSTRACT

The indoor Global Positioning System (iGPS) is an innovative measurement system consisting of a network of Rotary-laser automatic theodolites (R-LATs) which provide a factory wide coordinate measurement system. The primary benefits of the system are that a theoretically unlimited number of sensors are able to simulatiously detect position using signals from a common network of transmitters and that the sensors are able to automatically regain connection to the network following a disruption of the line of sight. The basic functionality of this system is described together with a brief overview of work to verify its performance.

KEYWORDS: iGPS, Indoor GPS, Infrared GPS, Constellation 3Di, Metrology

1. INTRODUCTION

iGPS essentially consists of a network of automatic theodolites employing triangulation to automatically generate positional measurements at a single receiver. In this way a highly adaptable large scale coordinate measurement machine is created able to provide factory wide measurement. The system is best understood by first considering the function of an individual transmitter-sensor pair which constitutes a Rotary-laser automatic theodolite (R-LAT).

An R-LAT transmitter mounts a rotating head on a stationary body as shown in Figure 1. The rotating head sweeps two fanned laser beams through the working volume, while the stationary body delivers a strobe with a single pulse for every other revolution of the head. The fanned laser beams are inclined at 30 degrees to the horizontal and offset by 90 degrees to one another /1/ as shown in Figure 1. The receiving sensor detects the pulse of light from the strobe and both of the fanned laser beams as they sweep past. These optical signals are the only form of communication between the transmitter and sensor. The timing differences between pulses of light reaching the sensor are used to calculate the azimuth and elevation angles, this is explained in detail in Section 2.

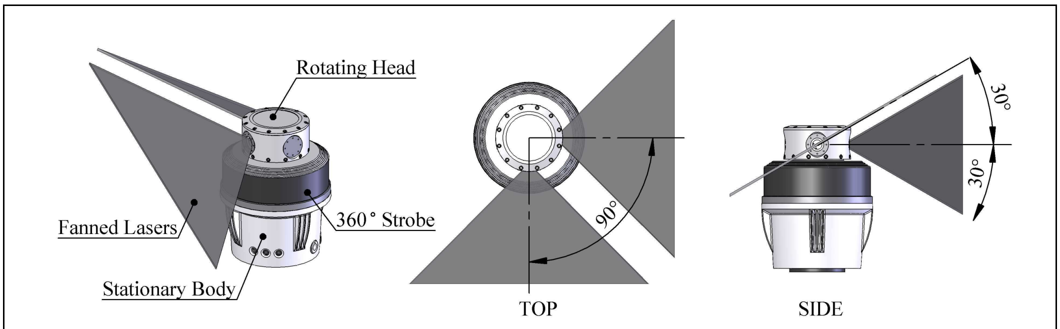


Figure 1: R-LAT Transmitter

The novel functionality of R-LATs provides a number of advantages to a coordinate measurement network. Since all communication is one-way, a very large number of sensors are able to simultaneously detect signals from a single network of transmitters. This massive scalability through one-way broadcasting is similar to the Global Positioning System in which satellites broadcast timing signals to receiver units. Transmitters are continuously scanning the entire measurement volume and therefore they do not have to track a target as is the case with theodolites and Laser Trackers. Therefore there is no requirement to re-aim the transmitter following a disruption in the line of sight. The sensor component of an R-LAT is able to detect signals coming from a wide range of angles, typically 360 degrees in azimuth and at least plus/minus 30 degrees in elevation. This is in contrast to the corner cube reflectors used with Laser Trackers which have an acceptance angle of less than ±45 degrees in all directions.

The cumulative effect is that a sensor can move around various line of sight obstructions losing and regaining connection to transmitters with relative ease. A point can be located by a single sensor as long as the sensor receives optical signals from at least two different transmitters. Each transmitter is configured to rotate at a slightly different speed; typically approximately 3,000 rev/min. It is this difference in speed which allows the system to differentiate between the signals from different transmitters /1/. If more than two transmitters are visible it is possible to apply some form of least squares fitting to the redundant data in order to reduce the uncertainty of the coordinate measurements. The network setup must include a procedure to determine the relative transmitter positions. The standard way of achieving this for any measurement system employing triangulation is by using bundle adjustment /2/.

The flexibility of operation facilitated by the system has considerable potential for use within the aerospace sector and other large scale manufacturing sectors. R-LAT networks have been demonstrated in industrial applications including positioning robots, the alignment of laser projection /3/ and the jigless assembly of aircraft structures /4/.

The R-LAT network can be compared to other multi-station metrology networks. Automatic theodolites /5/ have been used to demonstrate the concept of automatic triangulation while considerable work has been carried out to demonstrate the advantages of multilateration using specially constructed tracking interferometers /6/ and industrial laser trackers in applications such as the assembly of spacecraft structures /7/. Multilateration generates positions based on distance or displacement measurements from multiple stations to a single measurement sensor. The *Anglescan* positioning system /8/ probably has the most in common with R-LATs. In the *Anglescan* system a fixed laser is swept across the horizon by a rotating mirror, the laser is returned to the instrument by a retroreflector allowing a pulse of light to be detected at the transmitter. This is a two dimensional navigation system. None of these systems are able to offer the flexibility of operation provided by an R-LAT network.

2. MATHEMATICAL MODEL

The equations relating the azimuth and elevation angle to the timing signals received by the sensor can be derived by consideration of the two fanned lasers sweeping past the sensor and the strobe illuminating the sensor. If a vector is located so that it is normal to the first fan when that fan crosses the sensor (at t_1) and a second vector is similarly located so that it is normal to the second fan at t_2 then a third vector which is orthogonal to the first two will give the direction from the transmitter to the target sensor.

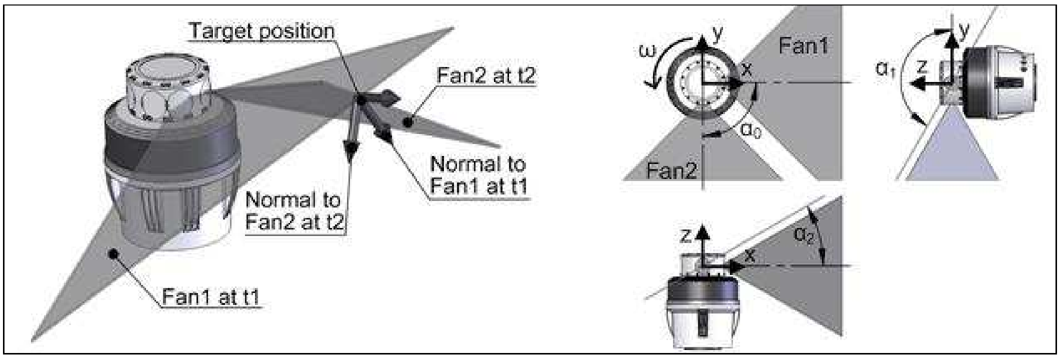


Figure 2: Parameters used in Construction of Vector Describing Target Direction

Constructing the vectors normal to the fans when these fans are aligned with the x-axis and then rotating the vectors around the z-axis will give the vectors at t_1 and t_2 (n_1 and n_2 respectively). The rotation around the z-axis is simply calculated from the time difference between the strobe and the fan illuminating the sensor, multiplied by the angular velocity (ω). The vectors to fan 1 at t_1 and to fan 2 at t_2 are therefore given by;

$$n_1 = \begin{bmatrix} \cos a_1 & \sin a_1 & 0 \\ -\sin a_1 & \cos a_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ -\sin \alpha_1 \\ \cos \alpha_1 \end{bmatrix} \tag{1}$$

$$n_2 = \begin{bmatrix} \cos a_2 & \sin a_2 & 0 \\ -\sin a_2 & \cos a_2 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \sin \alpha_2 \\ -\cos \alpha_2 \end{bmatrix} \tag{2}$$

where a_1 is the rotation of fan 1 about the z-axis from the time of the strobe illuminating the sensor (t_0) to the time of the fan passing the sensor (t_1) and a_2 is the rotation of fan 2 from t_0 to t_2 and α_1 and α_2 as defined in Figure 2.

$$a_1 = (t_1 - t_0) \cdot \omega \tag{3}$$

$$a_2 = (t_2 - t_0) \cdot \omega - \alpha_0 \tag{4}$$

The vector giving the direction from the sensor to the origin is then simply the cross product of n_1 and n_2 and from this vector it is straightforward to calculate the azimuth and elevation angles. The azimuth angle is the angle about the z-axis to the sensor target while the elevation angle is the angle from the x-y plane to the target.

An interesting implication of this model is that measurements of the azimuth angle taken using an R-LAT will always be considerably more accurate than measurements of elevation.

3. VERIFICATION STRATEGY

The accuracy of the R-LAT system is difficult to quantify since despite reports of accuracies better than those for a laser tracker /4/ there has been little work published to independently verify this performance. Since uncertainties in the coordinate measurements provided by a triangulation network propagate from the uncertainties in the individual angular measurements, the first step in assessing the accuracy of the system is to determine the uncertainties of an individual R-LAT.

Standards in existence for the verification of coordinate measurements include the ISO 10360 standard for coordinate measuring machines /9/ and the ASME B89 standard for Laser

Trackers /10/. These standards have in common low level tests designed to isolate sub-systems followed by high level tests using the complete system in a more realistic manner. Initial testing of the individual R-LAT is in keeping with this principle of isolating sub-systems. Unfortunately the only available standards for testing theodolites are somewhat vague and *"are not proposed as tests for acceptance or performance evaluations…"*/11/. A test procedure was therefore designed to ensure the comparison of the measured angles with a calibrated reference angle.

The test procedure involves mounting the transmitter on a high precision rotary table (Figure 3) with the sensor mounted in a fixed position at an appropriate distance which was known approximately. The initial azimuth angle of the sensor is measured and the transmitter is then rotated through a known reference angle using the rotary table. A second angle is measured and this provides the difference between the two measured angles which can then be compared with the rotary table reference.

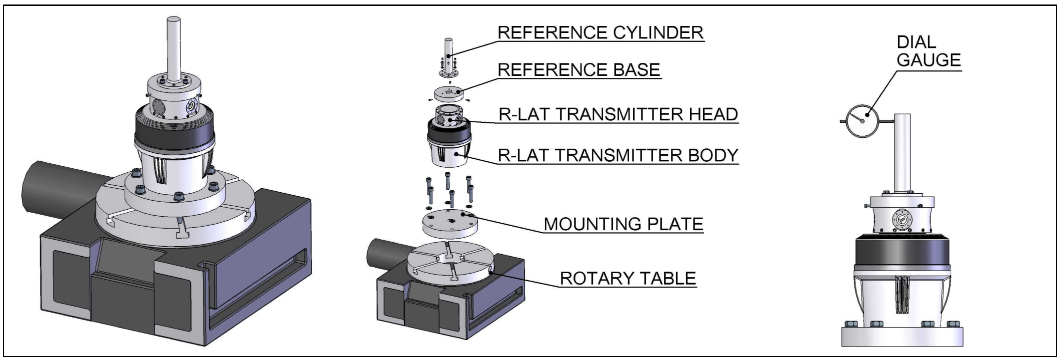
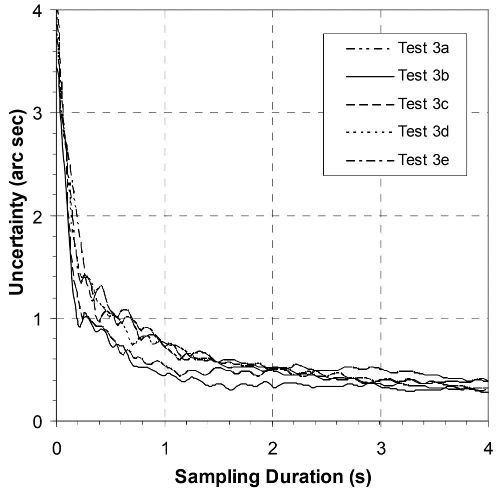


Figure 3: Experimental Setup

In order to ensure the validity of the reference angle the transmitter must be mounted coaxial to the rotary table. A calibration procedure was designed to reduce deviation from the coaxial. This involved mounting a reference cylinder to the rotating head of the transmitter, the reference cylinder was moved radially on the centering base to adjust the concentricity and jacked-off the centering base to adjust the parallelism of the axes. A dial gauge was used to measure the radial deflection of the reference cylinder as the transmitter head was rotated in order to adjust the position of the reference cylinder until it was coaxial within the measurement limits of the dial gauge. The rotating head was then fixed and the rotary table was rotated to adjust the position of the transmitter until the transmitter was coaxial with the rotary table. Combining the uncertainties arising from this procedure with the uncertainty inherent to the rotary table the expanded uncertainty at a 95% confidence level for the uncertainty in the reference azimuth angle is approximately 0.5 arc seconds.

4. INITIAL RESULTS AND FURTHER WORK

Initial results indicate that measurements of azimuth can be made with an expanded uncertainty of approximately 0.5 arc seconds at a 95% confidence level. This level of accuracy is only obtained when measurements are averaged over at least 2 seconds as shown in figure 4. This angular uncertainty relates to an uncertainty in coordinate measurements of approximately 25 µm at a range of 10 m. Since this is at the same level as the experimental calibration it is likely that the actual performance of the R-LAT is better than this, all we can say with any confidence is that the R-LAT is at least as accurate as indicated by these tests.



<u>Figure 4:</u> Uncertainty in Azimuth at 95% Confidence against Sampling Duration

There are a number of possible directions for further work. Improved accuracy of the current experimental design would provide interesting results on the actual azimuth performance of the system. Investigation of the accuracy throughout the working volume at different ranges and elevation would also be interesting.

Similar tests for the accuracy of elevation angle would be desirable but also difficult to realize. The mathematical model combined with the existing results show that the expanded uncertainty in elevation must be lower than 0.5 arc seconds. In order to provide any new information the tests would therefore have to have a calibration uncertainty of considerably less than this.

The third area suggested for further work is testing to verify the coordinate measurement capability of the complete system.

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Comment [11]: The NPL “JIT grant” number can also be added here if Alistair and Ben wish to include it. But this can be added later after the review.

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