THE DEVELOPMENT OF AIRBORNE THREE LINE SCANNER WITH HIGH ACCURACY INS AND GPS FOR ANALYSING CAR VELOCITY DISTRIBUTION

Shunji MURAI*, Yoshitaka MATSUMOTO**
*University of Tokyo, Japan
Institute of Industrial Science
Murai@rs.iis.u-tokyo.ac.jp
** Core incorporated, Japan
y-matsu@msd.biglobe.ne.jp

Working Group II/1

KEY WORDS: Motion Recording and Analysis, CCD, INS, Mobile Mapping

ABSTRACT

The authors have developed a prototype of three line scanner (TLS) system with INS and GPS. A TLS and INS are installed onboard a stabilizer that will provide with smooth and continuous original images with the grayscale of 12 bits and 10,000 elements per line. INS is designed to have the accuracy of 10 arc second for roll and pitch and 20 arc second for yaw, while the stabilizer of fiber optic gyro will have pointing stability of 0.3 arc degree in an hour. Because of temporal difference between those acquisition times of three linear CCD arrays along the flight course, car velocity on a highway will be able to be measured from two or three sequential images. According to the experimental results, the velocity measurement proved to be useful for traffic jam analysis.

1 INTRODUCTION

There are three types of digital photogrammetry in terms of data acquisition;
1) digitizing aerial film to obtain digital imagery
2) photographing with 2D CCD camera
3) photographing with TLS

First two types have an advantage to be able to use the established technology that is aerial photogrammetry. However the first method that is a conversion from analog to digital has a weak point of time consuming for developing films and digitizing them. The second method with 2D CCD camera has two weak points, one is lower resolution, though 4,000 x 4,000 pixels are now available and another is lower dynamic range of up to 8 bits. TLS on the other hand has higher resolution (10,000 to 20,000 pixels per line) and higher dynamic range (10 to 12 bits). However the biggest problem of TLS is the unstability of aircraft with the variation of positioning and attitude as well as vibration between scan lines. If TLS and INS are onboard a stabilizer, smooth images will be obtained, that will help the interpolation of position and attitude of TLS during the flight. If the accuracy of positioning with a GPS and attitude with an INS are equivalent to the orientation parameters determined by analytical photogrammetry, the absolute orientation will be possible without the use of control points on the ground. The authors have been awarded American patent (No.5765044, 1998.6.9, Australian patent (No. 679599, 1997.10.23) and Japanese patent (No.280622, 1998.7.24) to the proposed TLS system.

2 DESIGN OF TLS SYSTEM

The following specifications are proposed to the design of a TLS system.

2.1 Camera

A 70 mm camera with the focal length of 60 mm with F=3.5 (Zeiss Distagon CD) will be installed three linear CCD arrays as follows;

- 10,200 elements per line with the interval of 7 μm
- vertical angle : R, G, B with 12 bits
- forward oblique angle : R, G, B with 12 bits
- backward oblique angle : R, G, B with 12 bits
- stereo angle between vertical and forward/backward ; 21°
- cycle time: 2 ms per line (maximum)

2.2 Stabilizer

A stabilizer of fiber optic gyro has pointing stability of 0.3 arc degree in an hour.

2.3 INS

The accuracy of attitude measurement is targeted in the final stage as follows;

- roll angle : 0.00275° or 10 arc seconds
- pitch angle : 0.00275° or 10 arc seconds
- yaw angle : 0.0055° or 20 arc seconds

2.4 Accelerometer

Acceleration of three axes; roll, pitch, yaw will be also measured.

2.5 GPS

A real time kinematics (RTK) GPS will be installed with the positioning accuracy of about 30 to 50 centimeters.

2.6 Data recorder

The prototype recorder had a rate of 11.25 MB per second, while the proposed one will have 50 MB per second with direct writing in a magnetic disc drive. Image, INS and accelerometer data will be recorded at the rate of 500 Hz, while GPS data, 5 Hz. Figure 1 shows TLS and GPS onboard a helicopter. Figure 2 shows an example of triplet images taken by the TLS in Sinjuku Area, Tokyo, Japan with many tall buildings.

3 MEASUREMENT OF CAR VELOCITY

3.1 Theory of Velocity measurement

Car velocity (v) can be measured as follows; $v = L1/\delta t$

Where L1 : distance that a car moved from the acquired time by forward looking sensor to the one by vertical looking sensor (see Figure 3)

δt : time difference during the movement of the car along L1

Car velocity can be rewritten with the velocity of helicopter or air craft (V) and looking distance on the ground between forward and vertical sensors (L2) as shown in Figure 4.

$v = V*L1/(L1+L2)$

The accuracy of car velocity depends on the accuracy of V, L1 and L2.

The velocity of helicopter or aircraft can be measured by RTK GPS with the accuracy of about 1 meter per second. The velocity of helicopter used in a test ranged 100 to 140 kilometer per hour or 30 to 40 meters per second. Therefore the relative velocity error will be about 3 per cent. The accuracy of L1 and L2 depends on the ground resolution and image identification or pointing accuracy. The altitude of helicopter was 500 to 600 meters high, which gives the photo scale of 1:8,300 to 1:10,000. Therefore the ground resolution ranged 6 to 7 centimeters per pixel. In the case of stereo angle of 21° . L2 is about 200 to 230 meters, that will be about 6 seconds travel by the helicopter. L1 depends on car velocity ranging 0-30 km/hour for traffic jam and 80-120 km/hour for normal condition. L1 can be measured using some fixed points such as an over bridge as shown in Figure 6 and lane marks on highway. As compared with the distance of L1 or (L1+L2), the ground resolution is relatively less than 0.1 per cent. Therefore the overall error of car velocity will be less than 5 per cent.

3.2 Experimental measurement

In order to analyze the velocity distribution of cars on a highway, the following site was selected.

Site: Near Fukushima (about 250 km to the northeast of Tokyo) Highway: Tohoku Highway

Platform: helicopter Altitude: 1,500 feet (500 meters)

Traffic condition: traffic jam to Tokyo direction ranging from 10 to 40 km/hour

Car type: big cars (truck and bus), small trucks, ordinary cars

The items of analysis:

- car velocity distribution of two lanes
- car distance distribution of two lanes
- density of cars per 500 meters
- relation between velocity and car distance
- relation between velocity and car distance

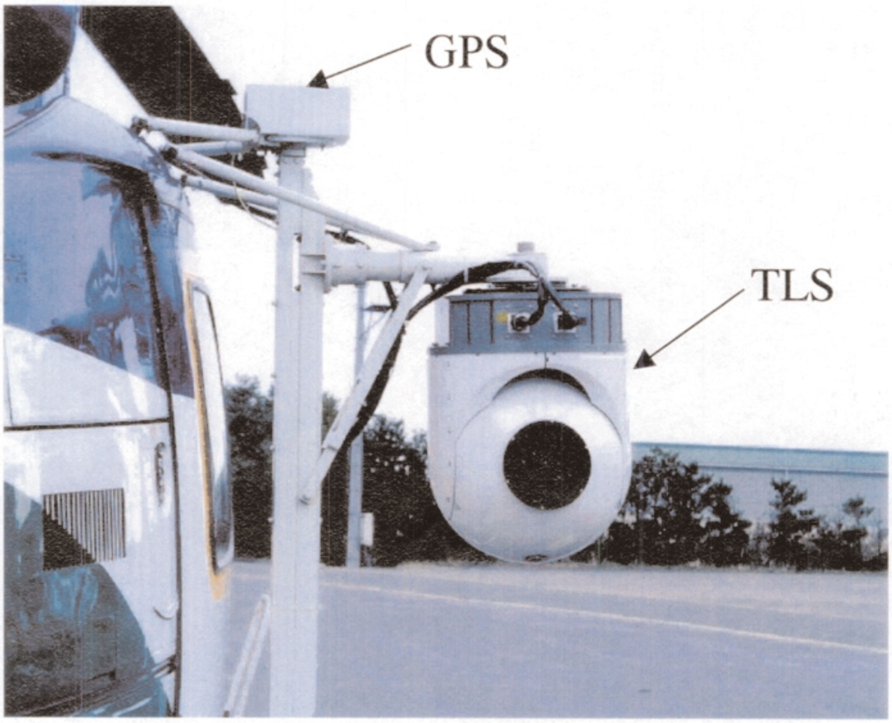
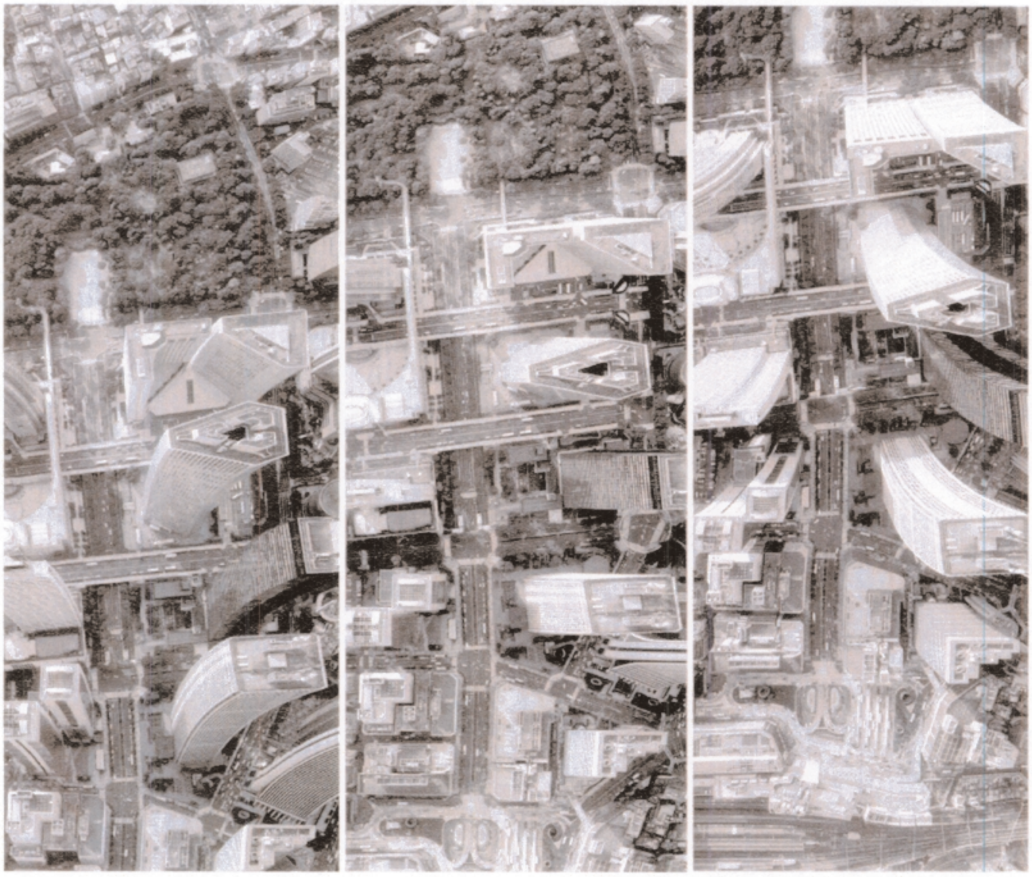


Figure 1 TLS and GPS onboard a helicopter



Forward Looking Vertical Looking Backward Looking

Figure 2 Triplet Image taken by TLS in Shinjuku Area, Tokyo, Japan(10/31 1999)

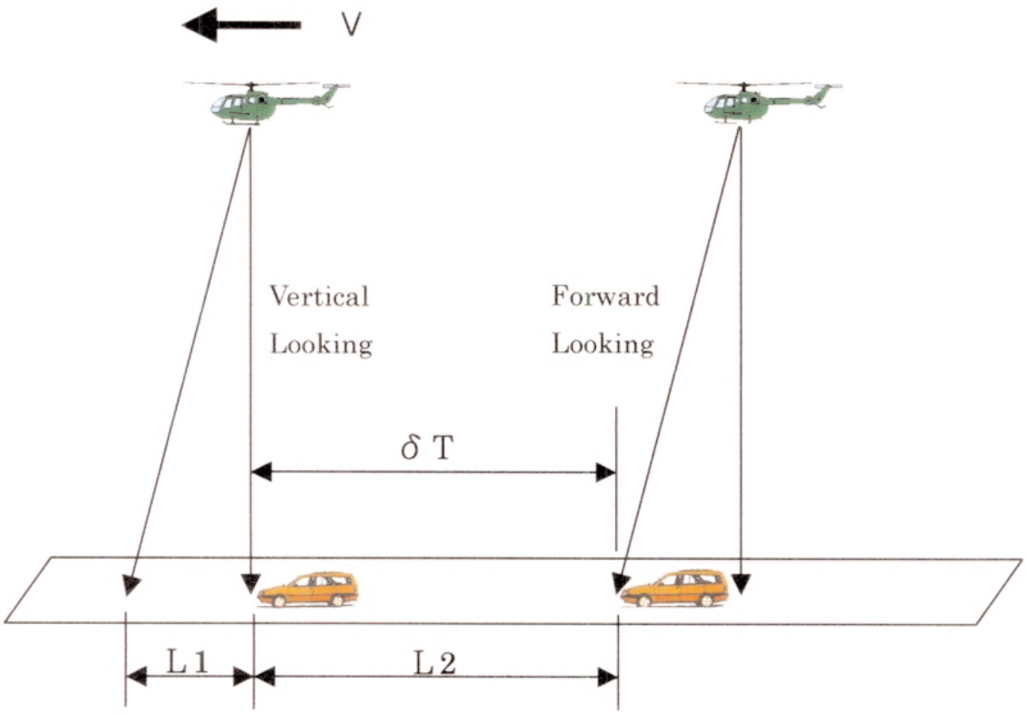


Figure 3 Theory of car velocity measurement

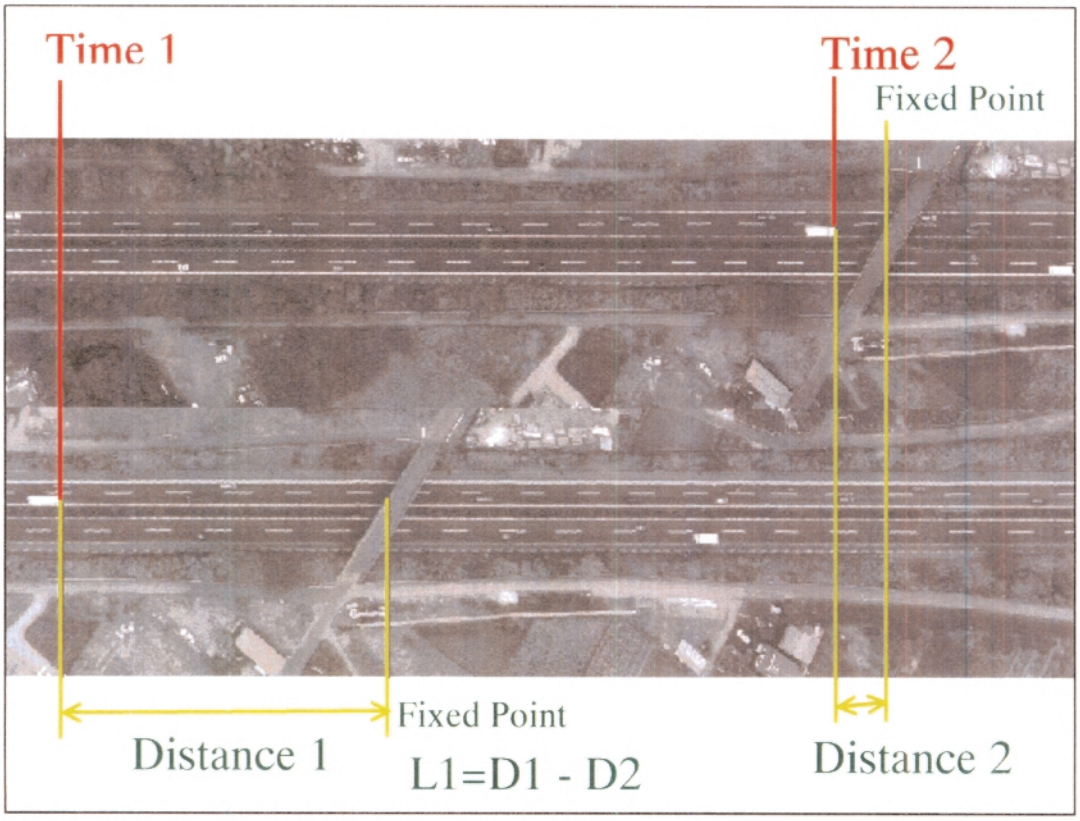


Figure 4 Measurement of car movement using a fixed point

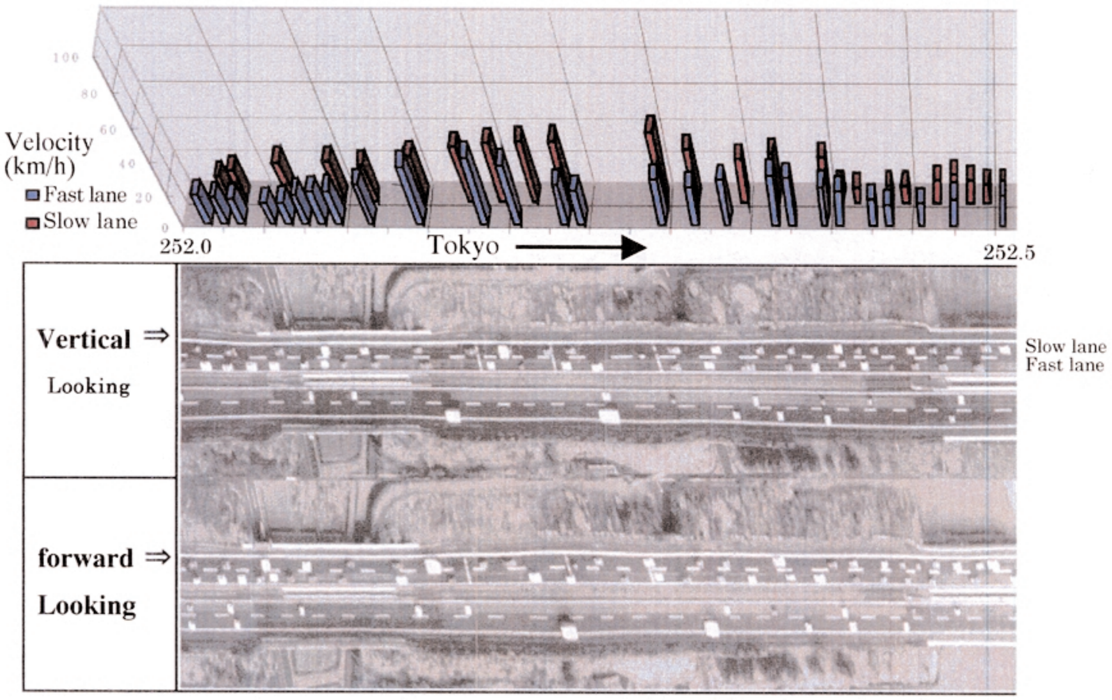
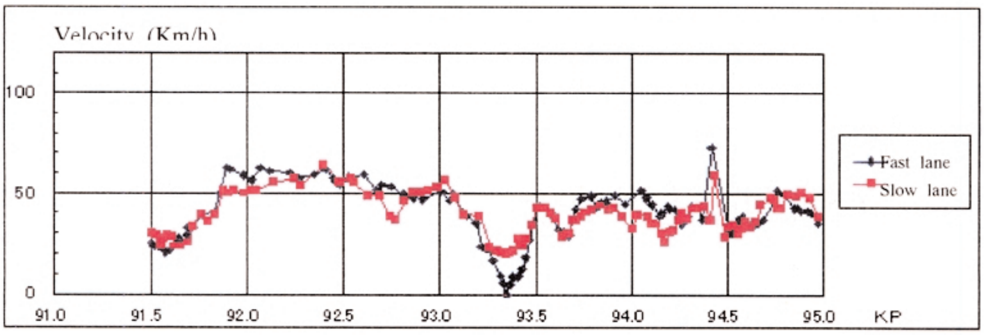
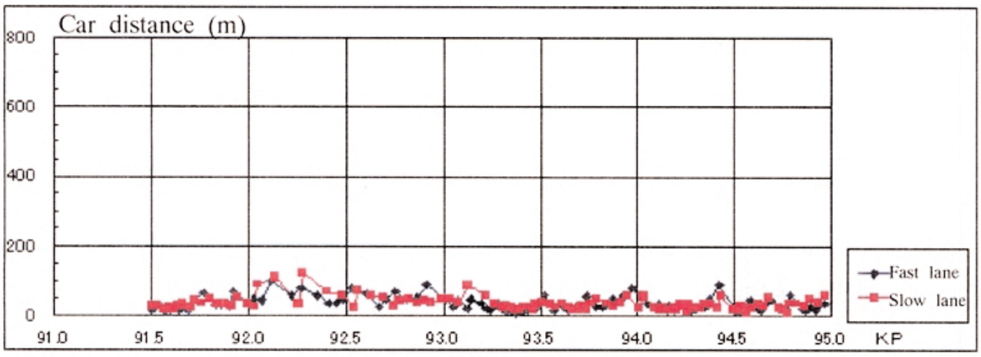


Figure 5 Car velocity distribution in trafic jam condition

(near Fukushima, Tohoku HighWay ; 10:35, 16 August 1998)



a) velocity distribution



b) car distance distribution

Figure 6 Spatial distribution of velocity and car distance near Fukushima, 16 August 1998

Figure 5 shows a part of the measurement of cars in traffic jam condition to Tokyo direction on the two lanes (upper side) near Fukushima, Tohoku Highway, at 10:33, 16 August 1998. The car velocity ranges 10 to 40 kilometers per hour in this area in 500 meters. Reference fixed points were selected as kilometer post (KP) at the interval of a kilometer. Figure 6 shows spatial distribution in 5.5 kilometer span, near Fukushima, Tohoku Highway in traffic jam condition, on the 16^{th} August 1998. Such spatial distributions of car and velocity were useful for the traffic analysis on the mechanism of traffic jam.

4 FINDINGS

The following findings were obtained after several experimental flights.

1) Helicopter was easier than aircraft in tracing a targeting highway because the pilot can identify the curves and operate the helicopter properly.
2) Stabilizer did work very well in the case of helicopter to obtain smooth imagery in spite of curve flight, vibration and variation of attitude.
3) In the case of helicopter, the flight direction should be against the car flow direction because the velocity of helicopter is sometimes not enough to trace in the follow direction.
4) If TLS is installed outside of helicopter, a remote control of exposure or gain setting should be added.

5 CONCLUSIONS

1) A TLS system with a three linear CCD array camera, a stabilizer, INS, GPS and high speed data recorder has been designed and developed.
2) Several experimental flights were implemented to measure velocity of cars on a highway in a traffic jam condition.
3) Spatial distributions measured by TLS were very useful for understanding the mechanism of traffic jam.

6 FURTHER STUDIES

1) Three dimensional measurement of objects should be developed with GPS and INS data.
2) Automated measurement of cars in motion should be developed.
3) Validation should be promoted to other applications.

ACKNOWLEDGEMENTS

Great thanks should be given to Experiment and Research Institute of Japan Highway Corporation in providing a helicopter and an opportunity to measure car velocity on a highway. The author also thanks Sumitomo Electronic Co., Ltd. to sponsor a new company to develop higher level TLS in future. The authors also appreciate Professor Armin Gruen to have joined to develop software for 3D measurement of topography and possibly building height or city modeling.