Dr. Hsu First Name SURNAME: Chan Wei
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Paper id: 00066
Nationality: Taiwan
Position: Subsection Manager Specialist
Department: Research & Development Division
Organization: Automotive Research & Testing Center
Tel: 886-4-7811222ext2351 E-mail: winsonhsu@artc.org.tw
Fax: 886-4-7811333
Address: No. 6, Lugong S. 7th Rd., Lugang Town, Changhua Country, 50544, Taiwan (R.O.C)

## DEVELOPMENT OF THE CONTRIBUTION

This paper presents an autonomous GPS/INS design method for inter-vehicle application using data fusion. To achieve widely application, this system integrated with DSRC communication to apply cooperative driving.

# A DSRC-Based Collision Warning and Autonomous System for Cooperative Driving

**C. W. Hsu, C. N. Liang, L. Y. Ke, M. H. Shih, M. K. Ko, S. C. Huang**

*Automotive Research & Testing Center, Changhua, Taiwan*

## Abstract

Inertia Navigation System is capable to backup GPS unavailability. An autonomous system integrated different sensors to offer robots or remotely operated systems a reliable navigation means. This paper addresses an autonomous design method to accomplish collision avoidance and continuously position positioning based on GPS positioning, gear-box speed, odometry, IMU and DSRC in cooperative driving or deck reckoning. Besides, the availability of autonomous system is also verified using vehicles.

## Introduction

Traffic safety, in terms of infrastructure or injuries, has been continuously discussed and improved by government's policy in the world. However, the numbers of deaths or injuries have remained relatively flat due to the increasing number of vehicles or fatigued driving with low attention. Every year in Taiwan, about two thousands deaths within 24 hours in traffic accidents, there are about 2539 deaths per hundred thousands of people and the statistical number is very serious in the world [1]. While many different factors contribute to vehicle incidents or accidents, such as rainy day or blind spot area, driver behaviour is considered as the main cause of more than 95 percent. In the recent years, more and more people like to have a team travel in the weekend. People like to take a portable navigation device with them. It provides high accuracy position, any weather condition and has the advantage in faster positioning. Although it is easier to know own location mapped onto GIS, groups of team trip cannot be aware of others position. A vehicle operation may be located on the road or inside the buildings. Under such conditions, GPS loses its superiority of positioning and navigation. The Inertial navigation system (INS) can overcome this shortcoming by inertia sensors. The acceleration and spatial information can be obtained from accelerometers and gyroscopes of any moving platform.

An INS is an all-weather autonomous navigation system that can provide continuous position, velocity and attitude information in real-time operation [2]. The main defect of the INS is that its mean-square navigation error increases with time and needs frequent calibration with reference signals. INS error accumulates due to inertial sensor’s performance with time that long period performance of INS becomes less accurate.

A vehicular unit (VU) could sense vehicle speed and heading by calculating odometry. Although lower accuracy inertial sensors might cause the integration error with time in speed and vehicle spatial motion, a VU could provide continuous speed and heading with movement through controller area network (CAN). As a result, an idea of GPS/INS and VU integrated system tries to adopt commercial GPS and inertial sensors to construct a higher reliable and better accurate navigation in lower cost platform. In order to limit INS navigation errors, the INS position information could be updated in accordance with GPS, and vehicular data information is update and enforced by VU data acquisition and computation.

This paper adopted an embedded system to construct an independent navigation platform using data fusion integration for driving navigation. Combining with the GPS/IMU integration, the vehicular signals (VU) may play a potential auxiliary support to derive another package of position and moving information to enhance the autonomous capability. The hardware has been implemented on microcontrollers and carried out verification tests. The DSRC application and collision design has been presented in ARTC [3,4,5]. The collision algorithm is designed and separated as eight spaces to handle every kind of cases. Besides, the packet and data geocasting method are also designed in the proposed system [6]. The following content will be focused on autonomous design and its verification.

## INS-VU integration

INS provides autonomous independent means for 3D positioning with high short-term accuracy and degrades over a short period of time when GPS suffers poor availability, e.g., due to indoor and underground uses, multi-path, EMI, or blocked satellite signals. Integration of GPS with an INS improves the quality and integrity of each navigation system. Integration of VU with GPS is usually applied to keep GPS position error to a minimum [7]. VU could assist system to correct the integration error of vehicle speed with time and plays secondary equipment.

### *A. The proposed system architecture*

An autonomous platform is built of the basic four parts of processing core; Inertial Measurement Unit (IMU) sensors with accelerometer and gyroscope; GPS Receiver and vehicular information unit. The system architecture is shown in Figure 1. The dsPIC30F6014 [dsPIC30F6014 Datasheet, Microchip Products Inc., web: http://www.microchip.com/] is chosen as the core controller to handle real time message. Time slots are used to process and measure the inertial sensors data and GPS data through Universal Asynchronous Receiver and Transmitter (UART) port.

### *B. INS core*

The dsPIC30F6014 is Microchip product for signal processing. This chip are designed to perform as supervisor core, where GPS message and inertial analog signals are on-lined captured, sampled and processed, back to the DSRC application; while the vehicular data is determined as the calibrated information. This INS core has the communication interface to a personal computer/IXP to downlink messages and broadcast to adjacent vehicles in real time. As the needs for the system, the specification and requirement of dsPIC30F6014 are listed in the following Table 1.

### *C.IMU*

An IMU is a closed system that is used to detect altitude, location, and motion. It normally uses a combination of accelerometers and gyroscopes to track the vehicle motion in attitude and location. The IMU is capable to transmit inertia data from core to IXP, where the interface is full duplex UART2. In order to output vehicle spatial states, it is accomplished by integrating an output set of sensors, such as gyros and accelerometers. Gyros measure angular rate with reference to inertial space, and accelerometers measure linear acceleration with respect to vehicle's frame. The IMU utilizes a tri-axis accelerometer and three one-axis gyroscopes as inertial measurement components. The accelerometer is measured for X-Y-Z axis; while the gyros are assigned to X-Y-Z axis correspondingly. The IMU plays a full inertial function for vehicle in real time.

The ADXRS614 operates on the principle of a resonator gyroscope. The output signal of ADXRS614 is a voltage proportional to angular rate about the axis normal to the top surface of the package. With the increase of the rotation rate, the output voltage leaves the neutral point [ADXRS614 Datasheet, Analog Devices Products Inc., UK, web: http://www.analog.com/]. An external capacitor is used to set the bandwidth. Use external capacitors in combination with on-chip resistors to create two low-pass filters to limit the bandwidth of the ADXRS614's rate response. ADXL330 is made by the principle of resonant accelerometers. It can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity). The outputs are analog voltages proportional to acceleration [ADXL330 Datasheet, Analog Devices Products Inc., UK, Rev. A., 2003. Available on web: http://www.analog.com/]. This sensor is capable of measuring both positive and negative accelerations to at least ±3 g. Because the signal measure from the accelerometer is analog, it may be disturbed by external noise. According to specifications, the external capacitor can be chosen to determine the bandwidth of the accelerometer, e.g., 0.47μF capacitor for 20 Hz is used in this paper.

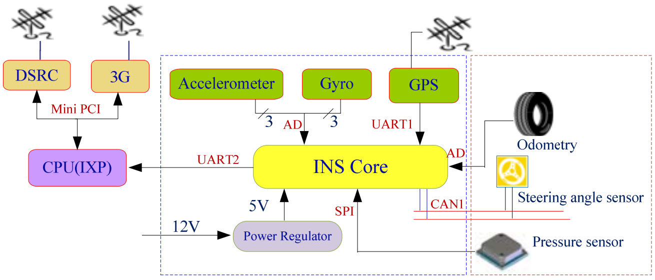

Figure 1: The architecture of autonomous system.

Table 1: Requirements and specifications.

| *Criterion* | *Required* | *Desirable* | *dsPIC30F6014* |
|---|---|---|---|
| On chip nonvolatile memory | Enough to eliminate need | for data storage and use to buffer the data | 144kB Flash, 8kB RAM |
| ADC | 6 channels, at least 12-bit resolution, with 100SPS | Simultaneous sampling, ADC buffer memory | 16 channels, 12-bit resolution, simultaneous S/H, up to 500k SPS |
| I/O pins | Enough I/O pins to support transmission | I/O pins available for more buttons | Over 48 I/O pins |
| Timers | At least one 16-bit timer | More timers | 5*16-bit timers available |
| Controller Area Network interface | Data Acquisition from CAN | Vehicular data available | 2 channel CAN, up to 500 kbits |

### *D. GPS Receiver and Calibrated information*

In this development, a commercial GPS module as Skytraq FGPMMOPA5 is chosen for its high performance, low power consumption, small size, based on the well-verified technology by 51 channel GPS receivers and MediaTek chipset solution. GPS adopts the NMEA-0183 standards as a format for interfacing marine electronic devices. The default communication parameters for NMEA output are set as 115200 baud, 8 data bits, stop bit, and no parity. In the proposed system, NMEA message format GPRMC and GPGGA are employed to provide the precise positioning.

In system operation, the system needs to have speed calibration function in order to correct speed integration error. This processing technique utilizes wheel speed sensor to provide raw signal, and it is measured by hall sensor. Using charge-pump chip (LM2907) to convert signal's frequency to voltage varying from 0 to 5 volt, the sensing technology used AD interrupts to calculate average voltage. In low-speed, wheel speed from odometry whose response is very slow is not available to get on-line information. Gear-box speed is used as assistant secondary device.

## Principle of system algorithm

In the inertial navigation data, the output states include latitude, longitude and altitude that require coordinate transform by adopting proper algorithms. These measurement data from IMU are three orthogonal components of body rotation rates and three accelerations in body frame [8,98]. Figure 2 describes how to achieve inertial navigation via measurement and frame transform. The navigation algorithm contains several steps to compute vehicle attitude, earth rate, transport rate and Coriolis. The procedure to integrate acceleration, angular rates and calculate vehicle states in hardware is operated with software which is built in the microprocessor following the theoretical formulation below.

*A. Attitude calculation - Quaternion method*

Euler angles are the values which present the attitude of the vehicle. The attitudes of the vehicle mean the angles between body axes with navigation axes. There are three Euler angles φ, θ and ψ used to show the relative angles along x, y and z axis. The definition of Euler angles is shown in Figure3. The Direct Cosine Metrics (DCM) is used to transfer information from one coordinate system into another coordinate system. It is carried out as a sequence of three successive rotations about different axes. The DCM mentioned earlier is limited since the solution become indeterminate when $q = 90^{o}$. The quaternion is the method to overcome this problem. The concept of the quaternion is based on the idea that a transformation from one coordinate frame to another can be effected by a single rotation angle δ and an orientation unit λ defined with respect to the reference frame in Figure 4.

In the quaternion transformation, the orientation is written as a vector which contains four elements with the magnitude of the rotation. The preceding about body-to-navigation DCM can be expressed through quaternion elements as Equation 1. The $q_i$ (i=0, 1-3) are calculated from kinematic equation in Equation (2), and it can be substituted with the quaternion elements which is shown in Equation (3). From Equation (3), vehicle attitude can be integrated and updated to get Euler angles.

$$C_b^n = \begin{bmatrix} q_0^2+q_1^2+q_2^2+q_3^2 & 2(q_1q_2-q_0q_3) & 2(q_1q_3-q_0q_2) \\ 2(q_1q_2+q_0q_3) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_2q_3-q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} 1 & S\phi T\theta & C\phi T\theta \\ 0 & C\phi & -S\phi \\ 0 & S\phi/C\theta & C\phi/C\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \tag{2}$$

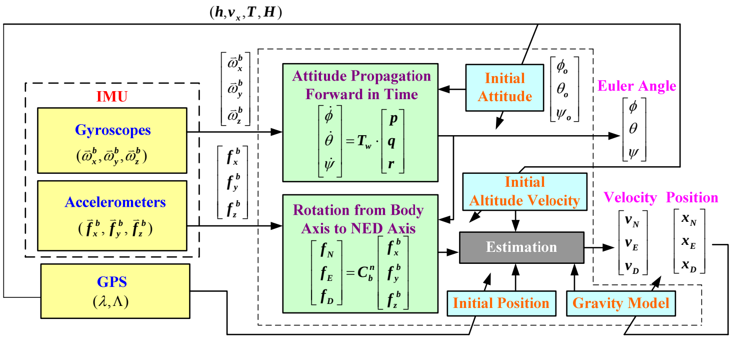

Figure 2: The block diagram of algorithm in navigation.

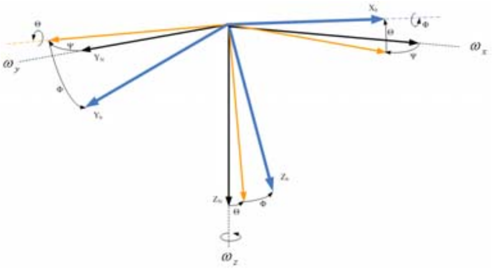

Figure 3: Definition of Euler angles.

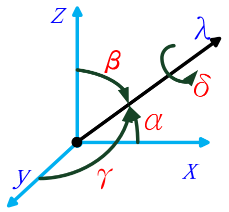

Figure 4: Quaternion coordinate

$$\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_0 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & r & -q & p \\ -r & 0 & p & q \\ q & -p & 0 & r \\ -p & -q & -r & 0 \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_0 \end{bmatrix} \tag{3}$$

*B. Velocity and position integral equations*

The variations of velocities are integrated from the accelerations in the local geodetic frame. However, the measurements derived from sensors are in body frame. Therefore, the DCM mentioned earlier is used to transform the measurements from body frame into the local geodetic frame. The transformation is shown in Equation (4).

$$\dot{v}^n = f^n - (w^n_{e/n} + 2w^n_{i/e}) \times v^n + g^n \tag{4}$$

Owing to the Earth's rotation ($2w^n_{i/e} \times v^n$) and gravitation ($g^n$), the effect of the Coriolis force ($w^n_{e/n} \times v^n$)and gravity need to be corrected in the middle term of Equation (4). The position of vehicle is always described with longitude, latitude, and altitude $(\Lambda, \lambda, h)$ in local geodetic frame. The navigation systems using on earth surface are mechanized or implemented such that the local geodetic frame is maintained while the vehicle is moving. The ellipsoidal model of the Earth is used to orientate the navigation frame with the variation position of the vehicle. The equations of the ellipsoidal are $R_{\text{meridian}}$ and $R_{\text{normal}}$. Motion over the surface of the Earth is along the arc of the ellipsoidal surface. The changing rate of latitude and longitude are expressed in terms of $R_{\text{meridian}}$ and $R_{\text{normal}}$ in Equation (5). The variation of altitude is equal to negative down velocity.

$$\begin{bmatrix} \dot{\Lambda} \\ \dot{\lambda} \\ \dot{h} \end{bmatrix} = \begin{bmatrix} \dfrac{1}{R_{meridian} + h} & 0 & 0 \\ 0 & \dfrac{1}{(R_{normal} + h)C\Lambda} & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} v_{north} \\ v_{east} \\ v_{down} \end{bmatrix} \tag{5}$$

## Implementation and tests

The developed system is integrated and fabricated modular units based on the circuit configuration as Figure 5. All the modules are available and ready to use. The implementation work needs to design suitable power supply; data interface and control circuit with accurate strategy to carry out the expected function capability. System software on data bus is programmed with appropriate protocol. Under the integrated concept, the proposed system will operate GPS data acquisition and INS correction to enhance the navigation performance. To accomplish the capability of VU, the odometry and gear-box speed are test and compared with GPS velocity in ARTC campus.

### *A. Odometry and gear-box speed test*

The odometry hardware used frequency to voltage chip to convert signals into voltage. The dynamic test is compared with GPS velocity. The odometry speed test is implemented in the ARTC campus, and operator drove to the road terminal and turn left/right. Figure 6 showed the variation and difference contrast to GPS speed. The frequency of odometry signal was varying from 0 Hz to 600 Hz, and then converted to voltage (0.0~5.0V). In low speed operation, the odometry signal has large variation because of disturbance in Figure 6(a) and 6(b). However, the mostly result is very similar to GPS velocity and this test is accomplished in calm weather. The Figure 6(b) is special used to test availability and know how the available speed is. The odometry sensor has high feasibility and could be used in vehicle test when the speed is larger than 10kph.

Although the odometry had shortcoming in low speed driving, the proposed system adopts gear-box speed as alternative solution in low speed. The gear-box speed is used to instead of odometry in low-speed, but higher speed is also adopted from odometry information because of turning angles. The gear-box signal is digital level, and its frequency varies from 0.5 Hz to hundred Hz with speed variation. Figure 7 is the vehicle dynamic test comparing with GPS speed.

### *B. Inertial sensor calibration and test*

After INS had been set well in demonstrated vehicle, a driver drove in different speed to test straight moving and turn availability. The straight driving test is used to adjust accelerometer parameters refer to GPS speed. The output data would be processed using integration. Owing to integration error, the result should be calibrated and delicate processed well. Figure 8(a) used a one-axis acceleration to get speed and the result is compared with GPS speed. The parameters was learned and calibrated by parameters

Figure 5: The hardware of autonomous system in demonstrated vehicle.

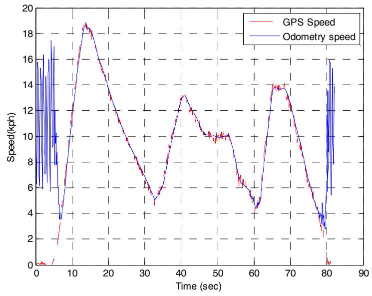

Figure 6(a):Driving test from 0~20kph.

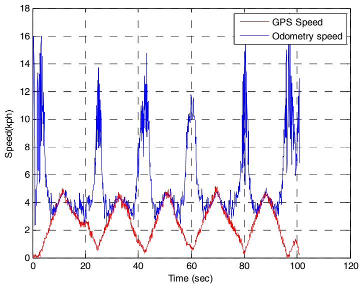

Figure 6(b): Driving test from 0~5kph.

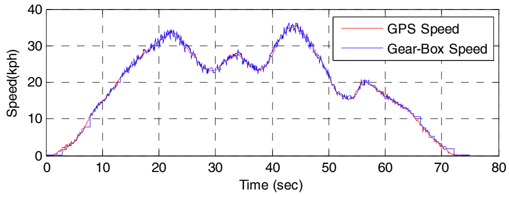

Figure 7(a): Gear-box speed vs GPS speed.

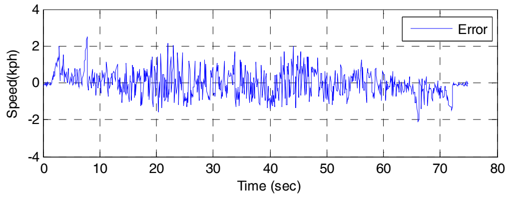

Figure 7(b): Speed error vs GPS speed.

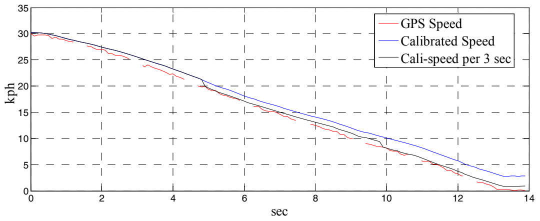

Figure 8(a): Acceleration integration test.

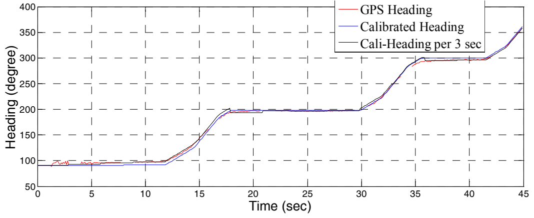

Figure 8(b): Gyro integration test.

learning and error cancelation. Hence, the speed error is under 5kph. In the similar way, the gyro integrated angular rate into heading comparing with GPS course w.r.t North direction in Figure 8(b).

### System verification

From the algorithm, this paper adopted a realization test in a car. In the integration of GPS and INS, the GPS provide a good position and heading. The reliability for long period is well, but it might be affect by the environment. The characteristic of INS is autonomous and reliable in short period. But the

Figure 9: Test field in ARTC campus.

integration error is as larger as time. So the integration of GPS and INS has a good advantage in compensating each other. The GPS can be an error bound of INS. Figure 9 is the test area, and the related experiments are test in different driving procedures from reference points located in the terminal of the road. The test included static tests in Table 2 and dynamic result in Table 3.

## Discussion

In this paper, several hardware, software and firmware are implemented to realize the concept of autonomous navigation. Combining with the GPS/IMU integration, the vehicular signals could play a potential auxiliary support to derive moving information to enhance capability. The advantage of autonomous system has presented fewer than 4% position error, and the demonstration provides a higher availability solution for vehicle position to enhance cooperative driving.

Table 2: Static tests result.

| *Ref. Points* / *Error index* | *ARTC7* | *ARTC8* | *ARTC9* | *ARTC10* | *ARTC11* | *ARTC12* | *ARTC13* | *ARTC14* |
|---|---|---|---|---|---|---|---|---|
| RSS (m) | 10.097<br>10.097 | 7.062<br>7.062 | 7.592<br>7.666 | 6.487<br>6.486 | 5.351<br>5.350 | 4.904<br>7.998 | 8.856<br>8.320 | 4.200<br>4.200 |
| North Error(m) | -7.140<br>-7.139 | -4.994<br>-4.993 | -5.364<br>-5.420 | -4.587<br>-4.586 | -3.783<br>-3.783 | -3.468<br>3.952 | -6.257<br>-5.871 | -2.970<br>-2.970 |
| East Error(m) | 3.601<br>3.959 | 3.990<br>3.823 | 5.790<br>5.842 | 4.874<br>4.709 | 3.289<br>4.063 | 5.570<br>-1.981 | 3.950<br>3.950 | 5.458<br>5.458 |
| CEP50 (m) | 0.1718<br>0.158 | 0.144<br>0.1 | 0.295<br>0.126 | 0.145<br>0.1 | 0.341<br>0.158 | 0.115<br>6.952 | 0.338<br>0.451 | 0.1<br>0.1 |
| CEP90 (m) | 0.308<br>0.280 | 0.253<br>0.1 | 0.537<br>0.212 | 0.255<br>0.1 | 0.621<br>0.280 | 0.182<br>12.674 | 0.616<br>0.821 | 0.1<br>0.1 |

Table 3: Dynamic tests result.

| *Tests* / *Reference points* | *Test1* | *Test2* | *Test3* | *Test4* | *Average distance and its error rate* | *Max. error rate* |
|---|---|---|---|---|---|---|
| Ref.12→Ref.11(N to S) | 97.10 | 97.03 | 97.47 | 95.95 | 96.89 | 3.32%<br>3.22% |
| • RTK 97.8 m | 0.72% | 0.79% | 0.34% | 1.89% | 0.93% | |
| • RMS 96.4 m | 0.73% | 0.65% | 1.1% | 0.47% | 0.74% | |
| Ref.10→Ref.9(W to E) | 224.23 | 223.06 | 224.53 | 223.24 | 223.77 | |
| • RTK 221.9 m | 1.05% | 0.52% | 1.19% | 0.60% | 0.84% | |
| • RMS 221.2 m | 1.37% | 0.84% | 1.51% | 0.92% | 1.16% | |
| Ref.8→Ref.7(S to N) | 93.92 | 95.04 | 92.72 | 92.72 | 98.5 | |
| • RTK 95.9 m | 2.06% | 0.90% | 3.32% | 3.32% | 2.4% | |
| • RMS 95.8 m | 1.96% | 0.79% | 3.22% | 3.22% | 2.3% | |
| Ref.14→Ref.13(E to W) | 224.27 | 223.47 | 223.24 | | 223.66 | |
| • RTK 222.7 m | 0.70% | 0.35% | 0.24% | | 0.43% | |
| • RMS 225.8 m | 0.68% | 1.03% | 1.13% | | 0.95% | |

## Acknowledgements

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