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Study on the compensation algorithm for inertial navigation system

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ABSTRACT : *This paper describes how a relatively compensate the error of position by using low cost Inertial Measurement Unit (IMU) has been evaluated and compared with the well established method based on a Kalman Filter(KF). The compensation algorithm by using IMU have been applied to the problem of integrating information from an Inertial Navigation System (INS). The KF is to estimate and compensate the errors of an INS by using the integrated INS velocity and position. We verify the proposed algorithm by simulation results.*

KEY WORDS : *INS, IMU, compensation, Kalman Filter.*

1. Introduction

Over the years, there has been a major upsurge of interest in the integrated global positioning system (GPS)inertial navigation system (INS) as a cost-effective way of providing accurate and reliable navigation aid for civil and military vehicles (ships, aircrafts, land vehicles, and etc)(Britting 1971, Chui and Chen 1987, Farrell and Barth 1998, Loebis et.al. 2004). For auto sailing system in the sea, generally a GPS is very useful for measuring the exact position, because of no obstacle between ship and satellite. But, there suffers a large bound of position error. Also, when the ship is passed through in the sea-pollution area, there requires a precise auto sailing system. However, for measuring precise position, also there need a high resolution and high price of GPS module.

Generally, the INS includes two modules; alignment module and navigation module. From these modules, any errors in either the alignment module or the navigation module will be integrated and will propagate over time. The performance and the navigation accuracy of the INS are determined by its errors.

In the last research (H.S. Kim et. al. 2004), an INS compensation (Periodic Drift Compensation) algorithm for auto sailing system was proposed. A low cost IMU was used for measuring the accelerometer data. To develop the compensation algorithm, we used a repetitive method to reduce the external environment changes and verified the proposed algorithm by using experiment results.

In this paper, the constant drift compensation algorithm is applied into another situation of a moving vehicle and compared with the method of using Kalman filter. The computer simulations are carried out using Matlab.

2. The Kalman Filter and Periodic Drift Compensation Methods

In this section, the method of using Kalman filter is described. The Periodic Drift Compensation method is also reviewed. To apply Kalman filter for estimation, the error model based on linearization is used. More details can be seen in B. Boberg and S.L. Wirkander (2002). The state equations can be written in the following form

$$\dot{v}_N = f_N - 2\Omega v_E \sin L + \frac{v_N v_D}{R+h} - \frac{v_E^2 \tan L}{R+h}, \tag{1}$$

$$\dot{v}_E = f_E + 2\Omega(v_N \sin L + v_D \cos L) + v_E \frac{v_D + v_N \tan L}{R+h}, \tag{2}$$

$$\dot{v}_D = f_D - 2\Omega v_E \cos L - \frac{w_E^2}{R+h} - \frac{v_N^2}{R+h} + g, \tag{3}$$

$$\dot{L} = \frac{v_N}{R+h}, \tag{4}$$

$$\dot{\lambda} = \frac{v_E}{(R+h)\cos L}, \tag{5}$$

$$\dot{h} = -v_D \tag{6}$$

where v_N, v_E and v_D are the components of the vehicle's velocity vector relative to the earth, L and are the latitude and longitude, respectively, h is the height of the vehicle over the earth's surface, is the earth angular speed, and R is the radius of the earth. The specific force component f_N, f_E and f_D are considered input signals. Similarly in B. Boberg and S.L. Wirkander (2002), to compare the two methods we will use the Kalman estimation algorithm, but for the discrete time case to estimate the INS error from an error model based on linearization. In this case, we consider the model

$$A(t+1) = Ax(t) + Bu(t) + Bw(t) \tag{7}$$

$$y(t) = Cx(t) + v(t) \tag{8}$$

where t is the time, x and y are the state and the measurement vectors. A, B and C are the system matrices. w and v are discrete white noise, respectively.

2.1 The Kalman Filter

The time-varying Kalman filter is a generalization of the steady-state filter for time-varying systems or LTI systems with non-stationary noise covariance. Given the plant state and measurement equations as in (7), (8) the Kalman filter is designed as in B. Boberg and S.L. Wirkander (2002).

Input signals includes noise, by using Kalman Filter, we can receive the output filtered signal. After that, we can use two methods: constant compensation algorithm and periodic compensation algorithm, for reduced velocity and position error.

2.2 Drift Compensation Algorithm

For compensating the constant drift of accelerometer, the following algorithm will be used generally.

Step1: Acquire the acceleration sensor values with drift on x, y and z axes, respectively.

$$\bar{a}_x = a_x + \delta a_x \tag{9}$$

where a_x denotes original acceleration sensor value and δa_x denotes an accelerometer value with drift on x axis, respectively.

Step 2: Calculate the velocity by using numerical integral method.

$$\bar{v}_x(t+1) = \int_t^{t+1} \bar{a}_x(\tau)d\tau + \bar{v}_x(t) \tag{10}$$

Step 3: Compensate the drift for velocity

$$v_x(t+1) = \bar{v}_x(t+1) + d_v \tag{11}$$

Step 4: Calculate the position by using numerical integral method.

$$\bar{x}(t+1) = \int_t^{t+1} \bar{v}_x(\tau)d\tau + \bar{x}(t) \tag{12}$$

Step 5: Compensate the drift of position

$$x(t+1) = \bar{x}(t+1) + d_p \tag{13}$$

In the above algorithm, the drift can be compensated by on-line calculation, thus v_x and x can be obtained respectively, where an accumulated position error will be reduced by small sampling time, but computational error will be increased. To obtain design method for the drift compensation gains d_v and d_p, we will show two methods; constant compensation algorithm and periodic compensation algorithm.

In constant compensation algorithm, after using Kalman Filter, we can calculate, and compensate for velocity and position by velocity drift d_v and position drift d_p.

2.3 Design Method for Periodic Drift Compensation Gains

In the last research (H.S. Kim et. al. 2004), an INS compensation (Periodic Drift Compensation) algorithm for auto sailing system was proposed. The main procedure to design the periodic drift compensation algorithm can be briefly described as the following:

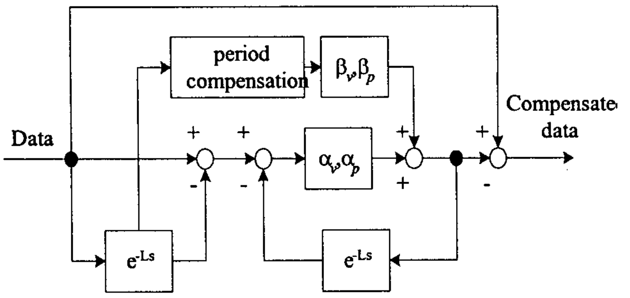

Fig. 1 Block Diagram of Periodic Drift Compensation

In Fig. 1, the parameters α_v and α_p denote the velocity and position errors compensation gains and β_v and β_p denote the periodic compensation gains for velocity and position errors, respectively.

< Procedure for Calculation of Periodic Compensation Gains >

Step 1: Calculate the natural frequency and its magnitude for accelerometer circumstance by FFT method.

Step 2: From the FFT results, decide the dominant frequency L of accelerometer.

Step 3: Make periodic L data table from decided dominant frequency modes.

Step 4: Initialization of periodic L data table.

Step 5: Calculate the velocity drift compensation gain

$$\begin{aligned} d_v(t+1) &= \beta_v(\max(peak)+\min(peak))/2 \\ &+\alpha_v(\bar{v}_y(t+1)-\bar{v}_y(t+1-L)-d_v(t)) \end{aligned} \tag{14}$$

where max(peak) and min(peak) denote the maximum and minimum value from obtained acceleration sensor data, respectively.

Step 6: Calculate the position drift compensation gain

$$\begin{aligned} d_p(t+1) &= \beta_p(\max(peak)+\min(peak))/2 \\ &+\alpha_p(\bar{y}(t+1)-\bar{y}(t+1-L)-d_p(t)) \end{aligned} \tag{15}$$

In the above procedure, the step 5 and 6 will be calculated by periodically on the calculation routine. And the calculated values should be saved and used it in next calculation.

3. Simulation

3.1 Using Kalman Filter

We consider accelerometer data from simulation signals. The sampling time is 0.01[s], and the data in steady state for 60[s]. The data including acceleration input and Gaussian noise are give in Fig. 2.

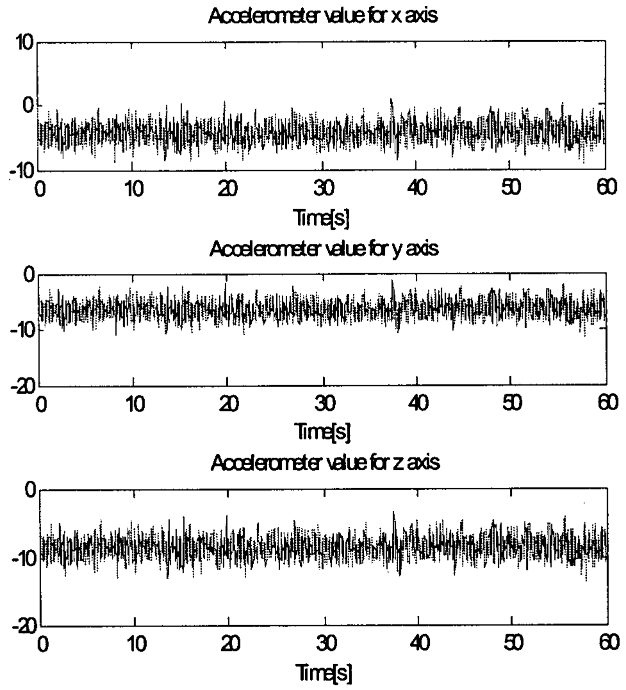

Fig. 2 Accelerometer value included noise

After using Kalman Filter, the simulation results with accelerometer are give in fig.3

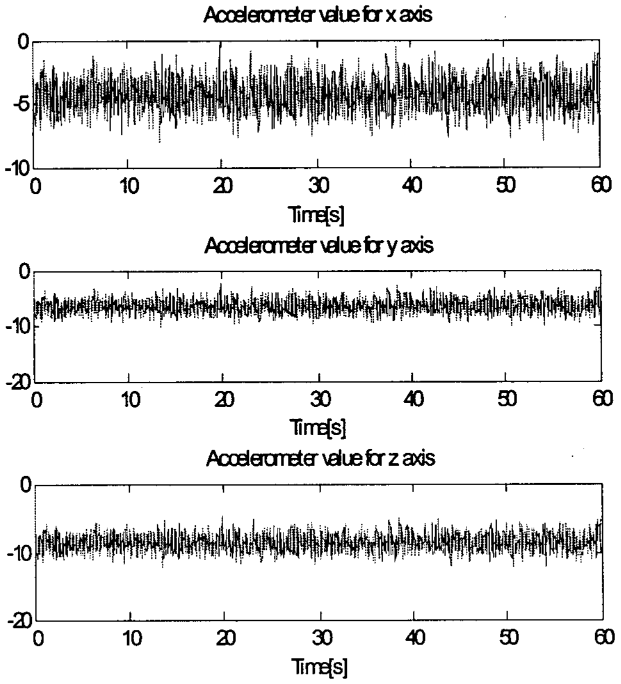

Fig. 3 Accelerometer value after using Kalman filter

After using Kalman filter, the distance can be calculated by using double integral and its results without bias compensation is shown in Fig. 4.

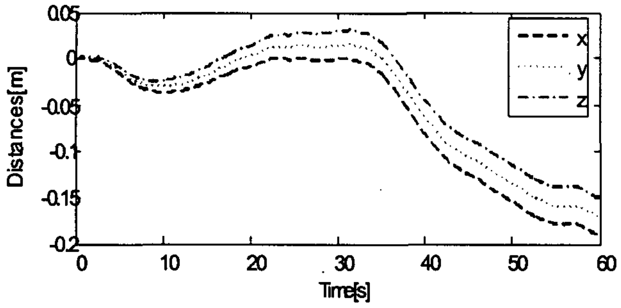

Fig. 4 Distance without bias compensation

In Fig.4, we observe that the errors of distance on x,y and z axes increased .

Table 1 Calculated Bias for 60 [s] on each axes

	x axis	y axis	z axis
Velocity Bias	-3.957e-006	-3.9576e-006	-3.9576e-006
Distance Bias	-0.000063	-0.000056	-0.000050

By using Table 1, we can compensate the velocity and the distances which calculated by integral method. The compensated distance data can be received as in Fig. 5.

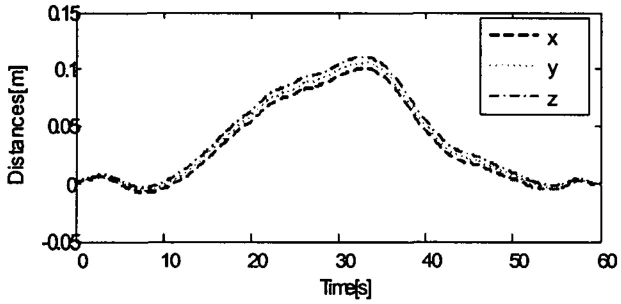

Fig. 5 Distance with constant bias compensation

From this result, we can observe that the constant bias compensation algorithm effects to the accelerometer bias compensation.

To verify the constant bias compensation, we make an accelerometer test by simulation. We can consider the sensor is shaked on x,y and z axes with sinusoidal and Gaussian noise signals. After using Kalman filter, the velocity and position can be compensated. The results are given in Fig. 6 - Fig. 8.

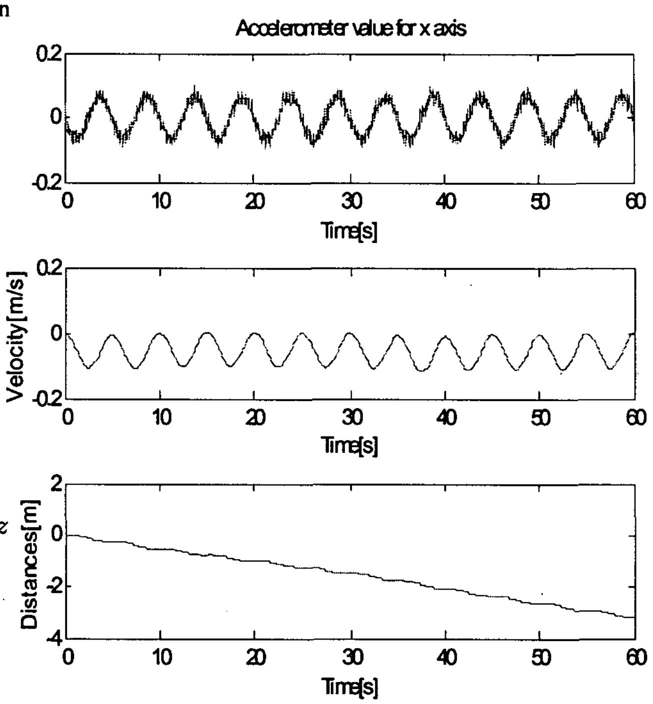

Fig. 6 Constant bias compensated data on x axis

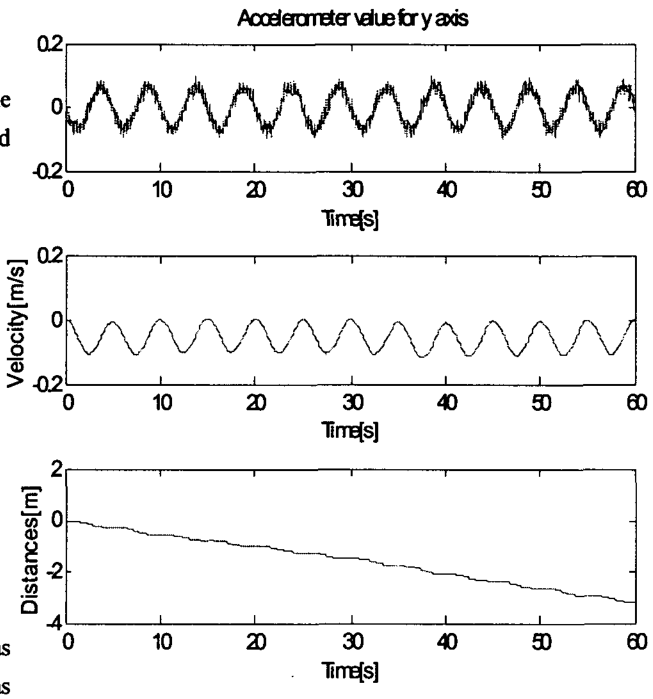

Fig. 7 Constant bias compensated data on y axis

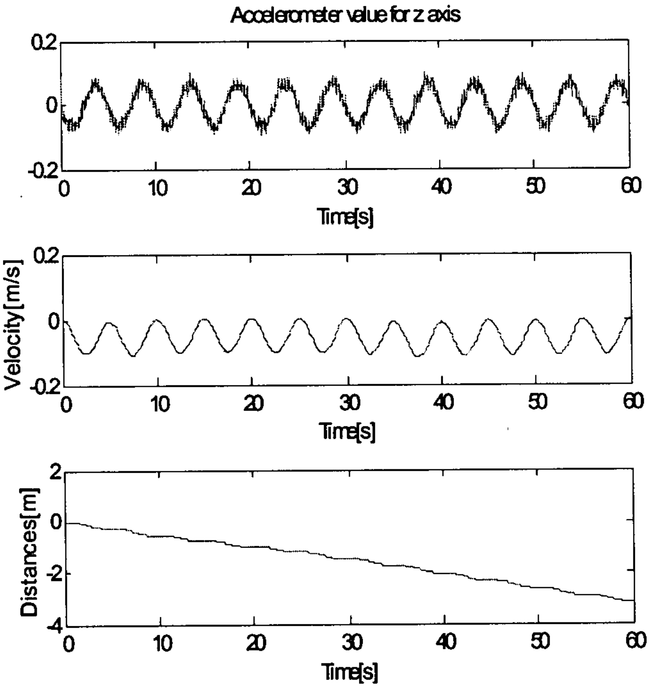

Fig. 8 Constant bias compensated data on z axis.

By using Kalman filter, we can reduce noise and use constant bias compensation. But the distances are increased by external environment changes.

3.2 Periodic Bias Compensation

In this subsection we used Period bias compensation. First, we verify the environment changes. To do this, we use FFT method to check the main frequency term which effects the accelerometers. The FFT result is shown in Fig. 9.

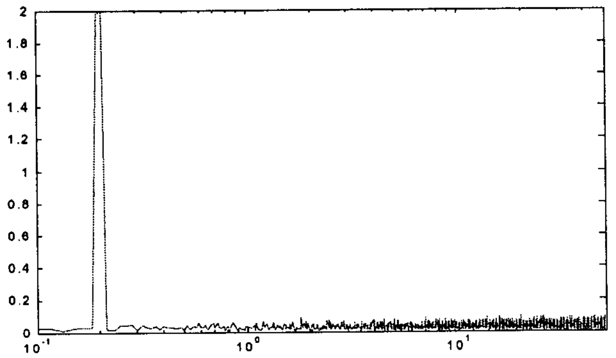

Fig. 9 FFT results on x axis

In Fig. 9, the main frequency is 0.199967 [Hz] and its magnitude is 3.025656. From the frequency, the period is calculated as 5.0008[s]. In simulation for periodic bias compensation, we define the parameters as Table 2.

Table 2 Parameters for periodic bias compensation

	x axis		y axis		z axis	
	V	D	V	D	V	D
α	0.5	0.5	0.5	0.1	0.5	0.1
β	6.0	2.0	5.0	1.0	5.0	4.0

By using the parameters in Table 2 and the periodic compensation algorithm, we can get the results in Fig. 10 - Fig. 12, where the same accelerometer's data with those of Fig. 6 - Fig. 8 are used.

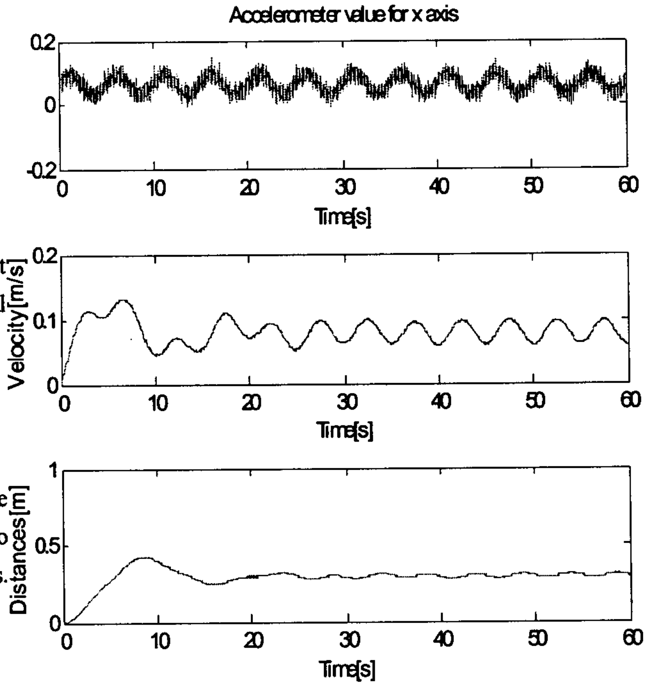

Fig. 10 Periodic bias compensated data on x axis

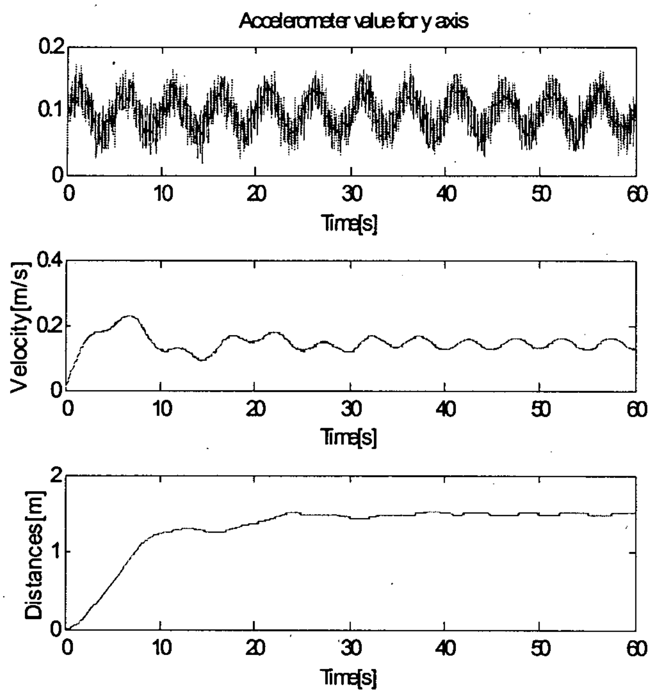

Fig. 11 Periodic bias compensated data on y axis

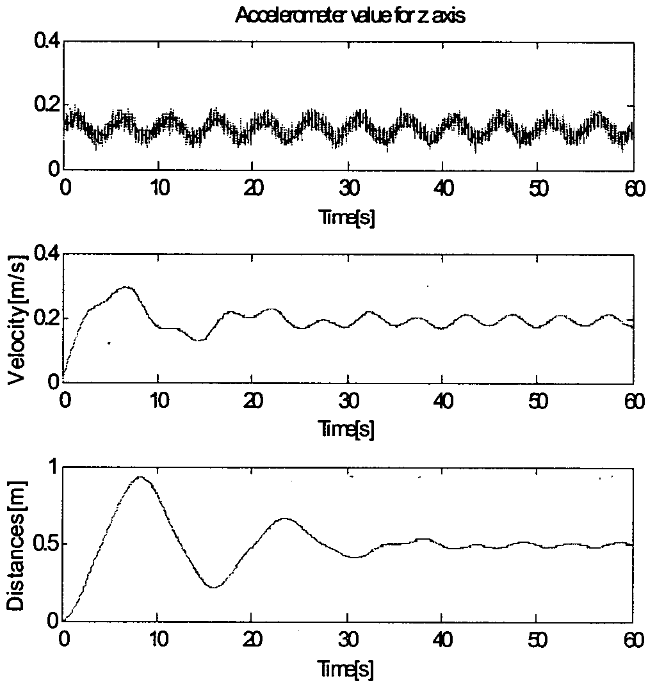

Fig. 12 Periodic bias compensated data on z axis

4. Conclusions

In this paper, we apply method of using Kalman filter for estimate acceleration data and compensate constant bias. But by this way can only reduce velocity and distance error to some extent. The compensated error is still relatively large. This due to the fact that Kalman filter requires linearization of error model. With FFT method through periodic bias compensation, we can reduce the error effectively. In the future research, we will try to compare the Extended Kalman Filter with periodic compensation algorithm in nonlinear cases. Additionally, angle sensors might be consider to improve the accuracy of position for vehicle.

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