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Track alignment inspection based on machine vision and inertial system

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Inertial Measurement System for Track Alignment Inspection Based on a Novel Machine Vision

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Abstract. Track alignment inspection is one of the most important method to ensure safe transportation. Due to the cumulative error of the gyroscope and the accelerometer, the conventional inertial measurement has low accuracy under the low speed. In order to solve this problem, a novel inspected method for railway space curve based on multi-sensors fusion of machine vision and inertial measurement is proposed. By using extended Kalman filter, the fusion of the computer vision and inertia information is obtained. Moreover, the inspected performance of the proposed method is investigated by experiment. Compared with previous methods in other works, the results demonstrate that the new method has higher accuracy. Furthermore, it is found that the measurement accuracy of the proposed method has improved nearly 10 times.

1 Introduction

In the case of rail vehicles, large irregularities may lead to high dynamic forces between wheel and rail【】. Therefore, monitoring the state of railway space curves is essential to ensure train safety, especially on high speed rail corrdors【】. During the past decade, several methods have been applied to get the railway space curve. In generally, the former inspected methods are mainly divided into static detection【】and dynamic detection【】. The static detection are currently performed by manual inspections, such as total station and GPS precision network. However, such inspections are subjective, ineffective and do not produce an auditable visual record. Meanwhile, the dynamic detection is often used by inertial measurement unit【】. Due to the cumulative error of the gyroscope and the accelerometer, the conventional inertial measurement has low accuracy under the low speed. Recent advances in computer vision technology【】, have resulted in a new method to solve the problem. Moreover, machine vision technology has been gradually adopted by the railway industry as a track inspection technology. As the coordinate system of inertial measurement unit and machine vision technology is different, resulting in great differenty for the fusion of the two methods.

Considering the many disadvantages of inertial measurement and computer vision, this paper proposes a novel inspected method for railway space curve based on multi-sensors fusion of machine vision and inertial measurement is proposed. By using extended Kalman filter, the fusion of the computer vision and inertia information is obtained. Moreover, the measurement accuracy of the proposed method is investigated by six degrees of freedom platform and experimental line. And the results demonstrate that the measurement accuracy of the new method is less than 0.5mm. Compared with the conventional inertial measurement method, it is found that the measurement accuracy efficiency of the proposed method has improved nearly 10 times.

2 Mathematical modeling of inspected method

The inspection system utilized in this paper is shown in Fig. 1, According to the characteristics analysis of the conventional perturbation and observation algorithm, it is found that three parameters $V_{pv}(0)$, ΔV_{pv} and sig play a key role in P&O algorithm, which is depicted in Eq.(1).

$$V_{pv}(k+1)=V_{pv}(k)+sig\Delta V_{pv} \quad k=0,1,2\cdots\cdots \qquad (1)$$

$$\Delta sig=\frac{\Delta P_{pv}}{\Delta V_{pv}}=\frac{P_{pv}(k)-P_{pv}(k-1)}{V_{pv}(k)-V_{pv}(k-1)} \qquad (2)$$

$$sig=\begin{cases}\Delta sig<0, & -1\\ \Delta sig>0, & 1\end{cases} \qquad (3)$$

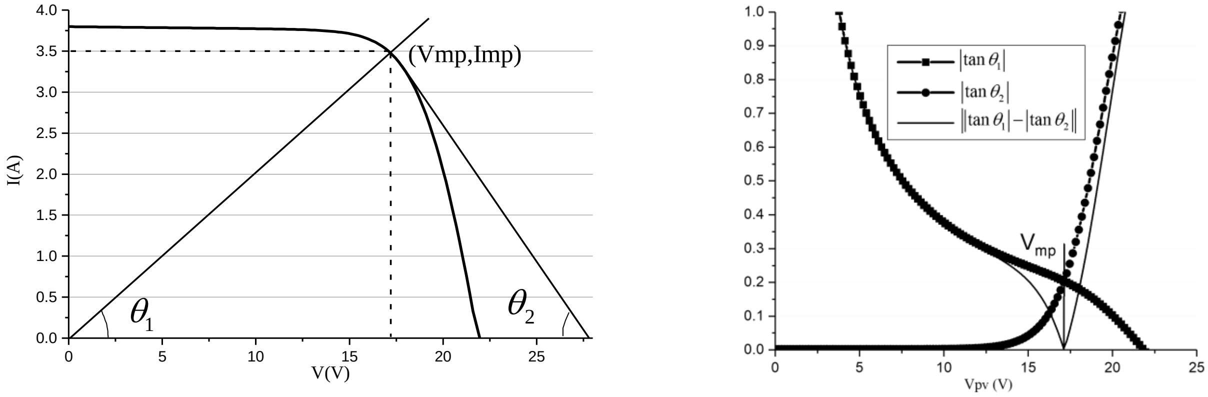
And the estimation of initial voltage $V_{pv}(0)$ can be deduced by:

$$V_{pv}(0)=V_{oc,ref}-\left(\frac{n_s I_{sc,ref}}{m_p^2}+\frac{V_{oc,ref}}{m_p n_s R_{p,ref}}\right)R_{s,ref}-n_{ref}V_{th,ref}\ln\left(\frac{n_s n_{ref}V_{th,ref}+\dfrac{V_{oc,ref}}{n_s}-I_{mp,ref}R_{s,ref}}{n_s n_{ref}V_{th,ref}}\right) \qquad (4)$$

And the step size ΔV_{pv} can be calculated by using tangent error method, as shown in Eq.(5), Eq.(6) and Fig.1.

$$\Delta V_{pv}(k)=\beta\Delta V_{pv}(k-1) \qquad (5)$$

$$\beta=\left\|\tan\theta_1\right|-\left|\tan\theta_2\right\| \qquad (6)$$



a

b

Fig. 1. The method of ΔV_{pv}.

a- the scheme of tangent error method, b- the absolute tangent error at standard test conditions

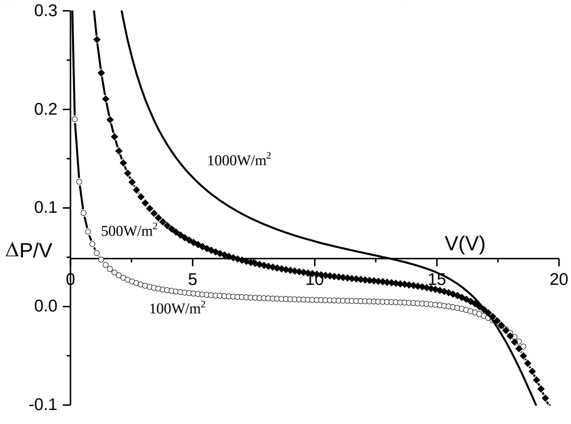


Fig. 2. The relationship of $\Delta P_{pv}/V_{pv}$ under different irradiance levels.

By using Lambert W function, the disturbance power ΔP can be given by:

$$\Delta P=\frac{Z_2\left[R_p(I_L+I_o)-2V_{mp}\right]}{R_s+R_p}-\frac{V_{mp}\left[R_p(I_L+I_o)-2V_{mp}\right]}{R_s+R_p}-W\left[\frac{R_sR_pI_o}{n(kT/q)(R_s+R_p)}\exp\left(\frac{R_p(R_sI_L+R_sI_o+V_{mp})}{n(kT/q)(R_s+R_p)}\right)\right]$$
$$\frac{n(kT/q)V_{mp}}{R_s}+\frac{n(kT/q)Z_2}{R_s}W\left[\frac{R_sR_pI_o}{n(kT/q)(R_s+R_p)}\exp\left(\frac{R_p(R_sI_L+R_sI_o+Z_2)}{n(kT/q)(R_s+R_p)}\right)\right] \tag{7}$$

Where $Z_1=V_{mp}-U$. According to the Eq.(7), it can be seen that: when V_{pv} converges to the maximum power point, ΔP_{pv} becomes very small. In other words, if $V_{pv}=V_{mp}$, then $\left|\Delta P_{pv}/V_{mp}\right|=0$. Similarly, when the amount of changes in $K=\left|\Delta P_{pv}/V_{mp}\right|$ exceeds the incremental threshold level K, it implies that the environment changes rapidly, which is shown in Fig.2. Therefore, the direction of the perturbation and observation *sig* can be determined by the value $\Delta P_{pv}/V_{mp}$.In summary, the proposed algorithm for photovoltaic motion carriers is illustrated in Fig.3, in which the black boxes are added parts with respect to the traditional perturb and observe algorithm.

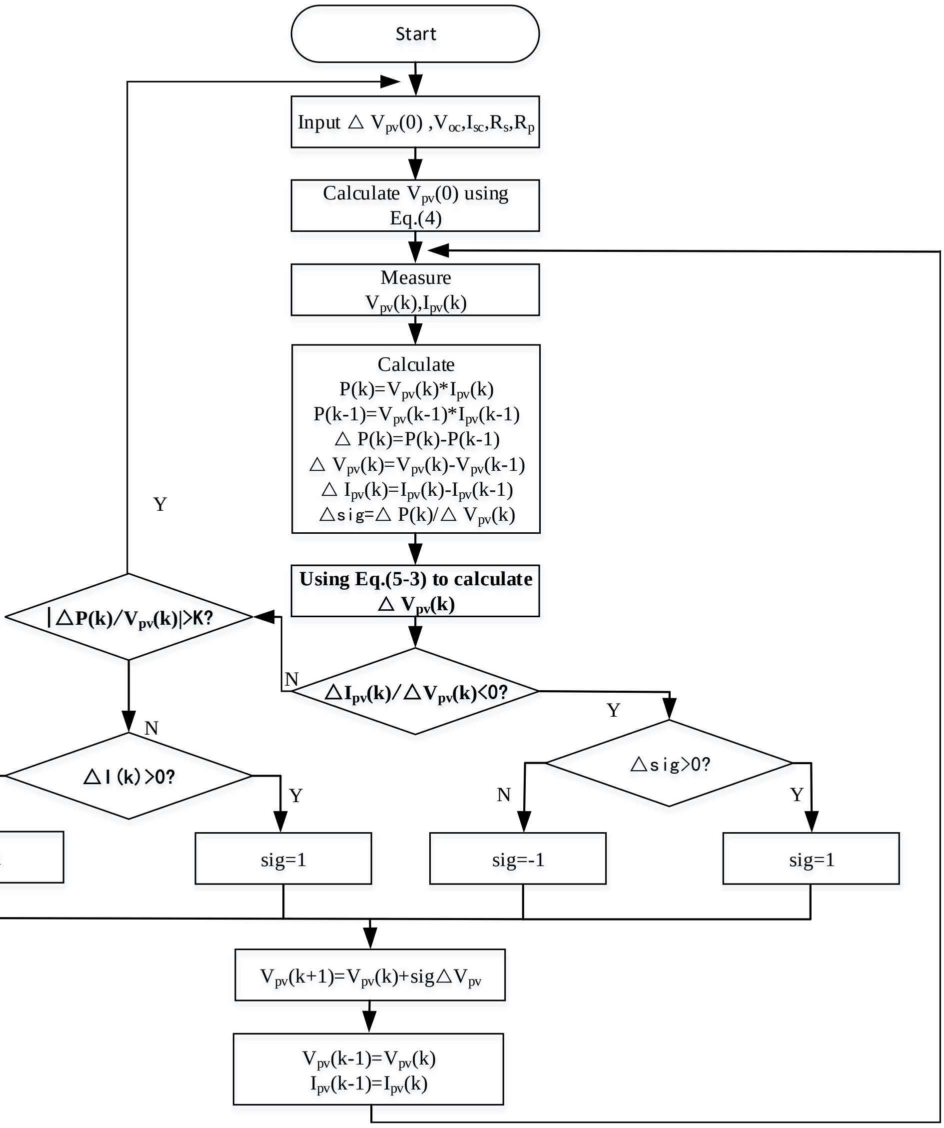


Fig. 3. Flow chart of proposed MPPT algorithm.

3 Results and Discussion

In order to confirm the validity of the proposed method, simulation and experimental results of the proposed MPPT algorithm are provided to validate the tracking performance in a common platform.Fig.4 shows the simulation diagram of photovoltaic motion carrier system. And the specifications for the PV system are listed in Table1.Moreover, the simulation results with different methods of the PV system are depicted in Fig.5. Besides, experimental results of PV system under varying environment is given in Fig.6 and Table 2.

With the Fig.5, it is easy to see that the proposed perturb and observe algorithm is closest to the theoretical values, which has perfect tracking effect under the multi-changing irradiances, especially in terms of speed and efficiency. Compared with the traditional algorithm, it also can be concluded that the proposed method not only has low oscillating power at the stable condition, but also never loses its tracking direction under the fast and slow changing irradiance levels.

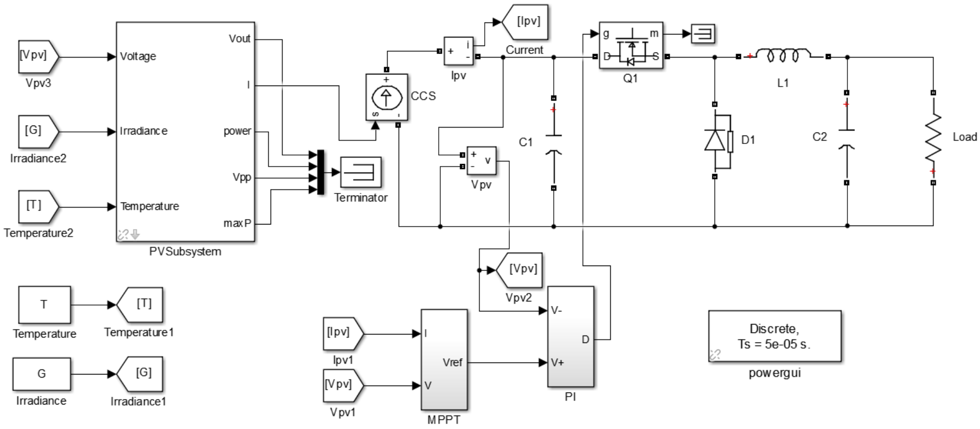


Fig. 4. Simulation diagram of PV system.

Table 1 Specifications for the PV system.

DC-DC converter				MPPT controller				
L_1 (mH)	C_1 (μF)	C_2 (μF)	f (kHz)	P	I	$V_{pv}(0)$ (V)	$\Delta V_{pv}(0)$ (V)	K (W/V)
2	470	1000	20	0.5	0.125	16.79	0.0012	0.14

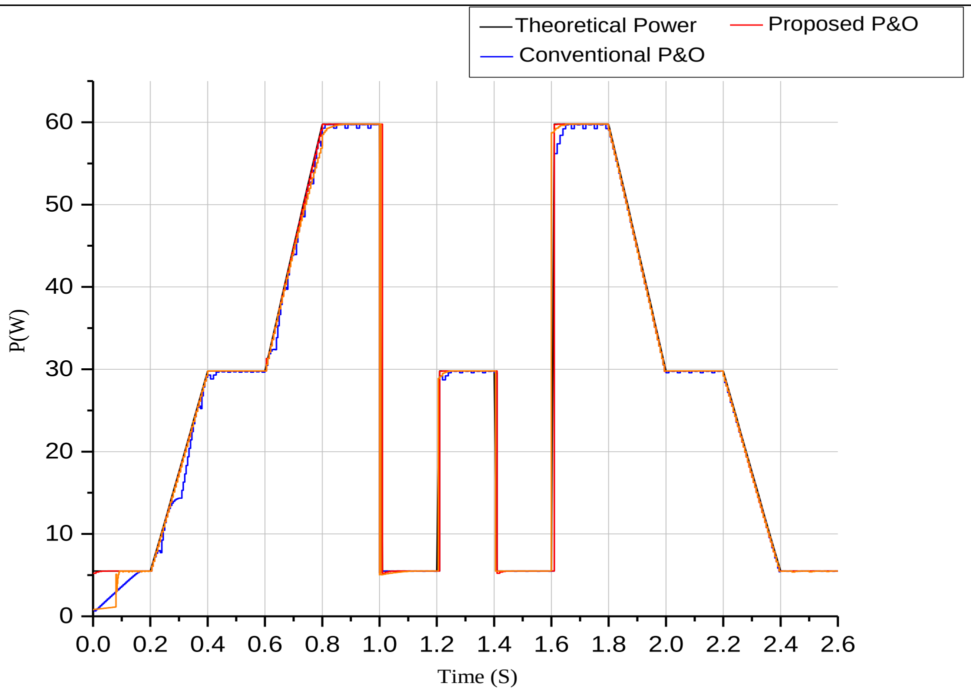


Fig. 5. Simulation results of PV system with different methods.

Fig.6 shows the experimental results obtained from prototype PV system under varying environment. with traditional P&O and proposed method. It is easy to see that the proposed algorithm has higher efficiency. In addition, Table 2 reveals that the tracking efficiency of the proposed method has increased by nearly 8.2%.

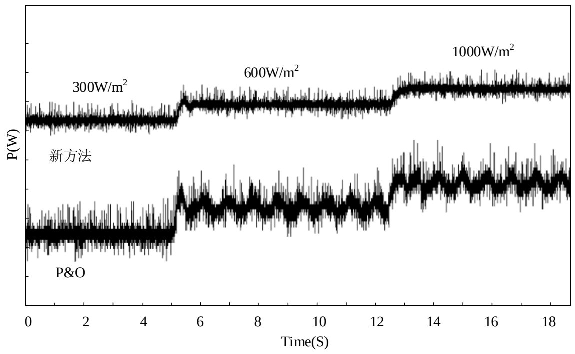


Fig. 6. Experimental results of PV system with different methods under varying environment.

Table 2 Output power under different irradiances

Item	Proposed			Conventional		
irradiance（W/m^2）	300	600	1000	300	600	1000
output power（W）	17.56	35.89	59.77	14.35	34.63	58.09
efficiency（%）	99.96	99.98	99.99	81.67	96.25	97.18

5 Conclusions

An improved perturbation and observation algorithm for photovoltaic motion carriers is proposed in this paper. By using tangent error method and Lambert W function, a novel technique is proposed to improve the tracking speed and efficiency. And the accuracy of the proposed model is evaluated by using simulation and experiment. Comparing with conventional P&O, the proposed method has the best accuracy, speed and efficiency during the whole tracking times, especially in fast changing irradiances.

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