Salp swarm algorithm based optimal speed control for electric vehicles

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ABSTRACT

The paper is all about the implementation of a novel bio-inspired meta-heuristic salp swarm algorithm (SSA) for speed control of brushless DC (BLDC) motor drive that is run in sensorless control mode. The angular speed of the motor is evaluated using an extended kalman filter, in which the dynamics of the motor are nonlinear. The error in speeds between actual and estimated is fed to the PID controller. To achieve the good transient operation of the motor drive, the parameters of the PID are tuned with the SSA. The optimum PID gains are determined by the minimization of integral square error and then final optimum gains are validated on the laboratory testbed. The proposed method is also tested in various cases to check the performance of the drive. The experiments are also performed at low speeds to know the superiority of the proposed method.

Keywords:
BLDC motor
Extended kalman filter
Meta-heuristic algorithm
Salp swarm algorithm

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1. INTRODUCTION

Electric vehicles are popular means of transportation in the present day. Because of reasons like high efficiency, zero carbon emissions, maintenance-free, fast torque production, cost-effectiveness; the market growth of electric vehicles has surged in recent years. The major components in an electric vehicle are the electric motor, battery, power electronic converter, speed controller and transmission unit. More recently electric vehicle sales across the world are increasing. In India, government is also promoting electric vehicles by giving incentives for manufacturers as well as the customers’ who are buying the EVs.

The brushless DC (BLDC) motor is emerging in different fields such as electric vehicles, industrial and commercial applications due to their excellent characteristics viz, good control flexibility, noise-free operation, wide speed range and good speed regulation [1]. There are two types in the category of BLDC motors. One is a permanent magnet synchronous motor (PMSM) (motor with distributed stator winding and the other motor is BLDC with concentrated stator winding [2]. The BLDC motor is more popular because of its low cost and better control flexibility as compared to its counterpart. The motor runs in self-control mode which means that the stator winding will be given a power supply from the rotor angular position information. Therefore, we could run the motor more than the synchronous speed. In closed-loop speed control of this drive, rotor position and speed sensors are essential [3]. Figure 1 shows an electric vehicle employing a BLDC motor. The speed of the vehicle is regulated by controlling the BLDC motor [4].
position of the rotor is sensed using the hall sensor and is fed back to the controller which controls a three-phase IGBT inverter. To improve the drive performance and avoid the cost of the hall sensors, sensorless speed control is proposed in the literature [5]-[8]. The speed can be estimated using observers like extended Kalman filter (EKF), cubature Kalman filter. More recently many researchers worked on sensorless speed regulation of BLDC motor [9]–[12], and some of them used BLDC motor drive control in real-time applications [13], [14].

The PID based speed controller is extensively used in industrial applications whereas in Ziegler-Nichols method is used for tuning suitable PID gains. Many researchers proposed the metaheuristic optimization approaches for getting PID gains offline and obtaining better performance in real-time using these fixed gains at various operating conditions of the motor drives [15]–[17]. Further, the speed regulation of the BLDC motor drive using optimization methods is also proposed recently [18]–[21].

![Schematic diagram of an electric vehicle using BLDC motor](image)

Figure 1. Schematic diagram of an electric vehicle using BLDC motor

This paper proposed an optimal sensorless speed control of BLDC motor using salp swarm optimization which is a bio-inspired heuristic optimization algorithm. It is nothing but imitating the behavior of salp swarms in deep oceans in search of food. An objective function using an integral square error is formulated to improve the operating speed profile of the electric vehicle. The speed of the BLDC motor is estimated using an EKF. Initially, extensive simulations have been performed on BLDC motor for speed control using salp swarm optimization and later the optimal PID gains are used for hardware implementation in off-line. The rest of the paper is organized as follows. BLDC motor drive and sensorless speed control using EKF are discussed in section 2. The description of salp swarm optimization is presented in section 3. Simulation results are provided in section 4. Hardware implementation and description is given in section 5, following that the conclusions are given in section 6.

2. PROPOSED BLDC MOTOR DRIVE AND ITS DYNAMICS

The laboratory prototype for the proposed motor drive scheme for real-time implementation is shown in Figure 2. Implementation of the drive consists of different subsystems, such as inverter, speed controller (PID controller), and hysteretic current control. The control of the motor drive is based on the reference current value generated by the speed controller [22]–[24]. The angular speed of the BLDC motor is estimated using EKF and is given to the controller as shown in Figure 3. The dynamics of the BLDC motor are given in (1)-(6). The BLDC motor has been modelled by considering stator phase currents (\(i_a, i_b, i_c\)), rotor speed (\(\omega_m\)), and rotor angular position (\(\theta_r\)) as state variables of the drive system.

\[
\frac{di_a}{dt} = \frac{1}{L-M} \left[ v_a - R_a i_a - kp \omega_m e_a (\theta_r) \right] 
\]

\[
\frac{di_b}{dt} = \frac{1}{L-M} \left[ v_b - R_a i_b - kp \omega_m e_b (\theta_r) \right] 
\]

\[
\frac{di_c}{dt} = \frac{1}{L-M} \left[ v_c - R_a i_c - kp \omega_m e_c (\theta_r) \right] 
\]

\[
\frac{d\omega_m}{dt} = \frac{-B}{J} (\omega_m) - \frac{1}{J}(T_e - T_i) 
\]

\[
\frac{d\theta_r}{dt} = \frac{P}{2} \omega_m 
\]

The electromagnetic torque value of the motor is, \(P = T_e \omega_m\)
In the above equations, L and M are self and mutual inductances of stator winding respectively. Where \( R_s \) is stator resistance per phase and \( \omega_m \) is rotor speed in rad/sec. The factor \( k_p\omega_m e_a(\theta_r) \), is contributing induced EMF in phase-A and this is mostly speed dependent. Here, \( k_p(=2NlrB_{max}) \) is called EMF or voltage constant, wherein \( B_{max} \) is maximum flux density, \( N \) is the number of turns, \( l \) is length and \( r \) is internal radius of one phase of winding. Moreover, it is considered that \( E = k_p\omega_m \) is the peak value of the trapezoidal electromotive force and the actual value of EMF will vary depending on the rotor position. Where, \( J \) is the moment of Inertia, \( B \) is the viscous friction coefficient of the motor, \( T_e \) is electromagnetic torque produced in the motor and \( T_l \) is the load torque required for a given load. Figure 4 shows the Back-EMF values with respect to the rotor angular position. One can observe that it is in between \( 0 < \theta_r < \pi/6 \) for phase-A. This is similar for other two phases.

Figure 2. Drive schematic for laboratory execution

Figure 3. Sensorless speed control using EKF

Figure 4. Back-EMF waveform and current excitation for phase-A with rotor-position
To minimize the cost of the electric vehicle, the hall sensors which are used for position measurement are eliminated. The motor’s angular speed is estimated using the current measurements. The procedure for state estimation using EKF algorithm is given below. It includes the initialization of states, state covariance matrix, and $P_{k-1}$; and prediction of state vector and state covariance using (7), (8) respectively.

$$\hat{x}_k = F_k(\hat{x}_{k-1}) \quad (7)$$

$$P_k^- = F_{k-1}P_{k-1}^+ F_k^T + Q_k \quad (8)$$

Update the covariance matrix using (9).

$$P_k^+ = [I - K_kH_k]P_k^- \quad (9)$$

Calculate the Kalman gain and update the states using (10) and (11).

$$K_k = P_k^-H_k^T[H_kP_k^- + R]^{-1} \quad (10)$$

$$\hat{x}_k^+ = \hat{x}_k^- + K_k[y_k - S_k(\hat{x}_k^-)] \quad (11)$$

Where, $F_{k-1} = \frac{\partial F_k}{\partial x}$ and $H_k = \frac{\partial S_k}{\partial x}$. However, the real challenge of closed-loop speed control is tuning of PID gains. Hence the PID gains are selected optimally at the best fitness function.

3. OPTIMAL SPEED CONTROL USING SALP SWARM ALGORITHM

SSA optimization is a bio-inspired heuristic algorithm inspired by the salp swarms. Salps live in deep oceans and the salp swarm behavior is modelled for solving the optimization problems [25]. The salps are grouped to form chains where a group of followers follows the leader. The leader position is updated based on the food location. The drive scheme with SSA is shown in Figure 5 to obtain the optimum PID gains.

Figure 5. Drive scheme with SSA

Salp Swarm Algorithm [25]

Initialization:
The following parameters are initialized for the proposed method.
Maximum iteration max= 100; Population of salps $N = 30$;
Upper bound $ub= [200\ 20\ 0.2]$; Lower bound $lb= [20\ 0.2\ 0.002]$;
dimension of the problem $d = 3$ and current iteration $i = 0$;

If $i < \text{max}$

Calculate the fitness of the swarm:
Integral square error of the speed is considered an objective function for tuning the PID controller gains.

$$\text{Objective function } F = min \left( \int_0^T (\omega_r - \omega)^2 \, dt \right) \quad (12)$$

Where, $\omega$ is the actual speed and $\omega_r$ is the reference speed

Calculate the fitness of each salp using (12).
Select the leader:
Select the salp with best fitness as the leader $L$.
Update the parameter $\alpha_i$ as given by (13).
\[ \alpha_1 = 2e^{-\frac{i}{\text{max}}} \]  

\((13)\)

(Update the position of Leader: 
for each salp \( j = 1:30 \)
if \( j = 1 \)
The position of the Leader \( \zeta^i_k \) is updated using \((14)\):

\[ \zeta^i_k = \begin{cases} 
P_k + \alpha_1((u_k - l_k)\alpha_2 + l_k) & \alpha_3 > 0.5 \\
P_k - \alpha_1((u_k - l_k)\alpha_2 + l_k) & \alpha_3 < 0.5 
\end{cases} \]

\((14)\)

where \( P_k \) is the position of the food in the \( k \)th dimension and \( \alpha_2, \alpha_3 \) are constants which are randomly generated in \([0 1]\).
else
Update the follower’s position:
The position of the follower \( \zeta^i_k \) is updated using \((15)\):

\[ \zeta^i_k = \frac{\zeta^i_k + \zeta^{i-1}_k}{2} \]

\((15)\)

end
end
Return the Leader L

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Final PID gains obtained for speed controller are \( K_p = 163.4896; \) \( K_i = 9.2613; \) and \( K_d = 0.0500 \) and the convergence of the objective function is as shown in Figure 6. It is observed that the speed of the convergence of the proposed algorithm is superior to the PSO algorithm as shown in Figure 6. The algorithm implementation flow is shown in Figure 7.

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**Figure 6.** Convergence curve of SSA in speed control of BLDC motor

**Figure 7.** SSA implementation flowchart

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4. **SIMULATION RESULTS**

The proposed control idea of the BLDC motor with EKF is first simulated in MATLAB/Simulink. The PID gains obtained after tuning with SSA are loaded into the controller. Now the performance of the...
motor is evaluated for various test cases with various reference speeds and loading conditions. One can see that the motor reached to given reference speed smoothly. Figure 8, Figure 9, and Figure 10 shows that the actual speed of the motor tracks the given staircase, ramp, and triangular commands respectively. Also, a good transient and steady-state behavior is observed with the proposed algorithm.

Figure 8. Speed control with SSA for staircase input
Figure 9. Speed control with the SSA for ramp input
Figure 10. Speed control with the SSA for triangular input

5. HARDWARE IMPLEMENTATION AND RESULTS
The effectiveness of the proposed work has been tested using hardware implementation after the extensive simulations on MATLAB/Simulink environment. Hardware execution of the proposed work consists of a BLDC motor with mechanical load arrangement, a dSPACE DS1103 R&D controller board, voltage source inverter, Hall Effect sensors for voltage and current measurements. The prototype of the block diagram given in Figure 3 is developed as shown in Figure 11 for experimentation. One can read [3], [11] for more details of the modelling and hardware implementation. The BLDC model parameters are given in Table 1.

Figure 11. Hardware implementation testbed
Table 1. BLDC motor parameters

| Parameter          | Value                     |
|--------------------|---------------------------|
| Resistance ($R_L$) | 1.5Ω (line–line)         |
| No. of Poles (P)   | 6                         |
| Power              | 1.5 hp                    |
| Moment of Inertia (J) | $8.2614 \times 10^{-5}$ kg.m$^2$ |
| Inductance (L-M)   | 6.1 mH (line–line)       |

The transient and steady-state behavior of the drive with the proposed salp swarm algorithm is validated with various reference speeds, as described follows.

- **Case 1-Low-speed of 30 rpm**: Experiments are conducted on closed-loop speed control for 30 rpm step reference and its performance depicted in Figure 12. The motor tracks the reference speed within 1 sec. The noise and speed oscillations are due to higher cogging torque at low speed and as well as non-sinusoidal EMF of the motor. Figure 13 shows the rotor angular position at 30 rpm and it shows 0 to 2π (0 to 6.28 rad).

- **Case 2-High-speed of 2000 rpm and 3000 rpm**: Experiments are conducted on 2000 rpm. Figure 14 (a) gives the behaviour of the closed-loop speed control for 2000 rpm and its zoomed view is shown in Figure 14 (b). From this, one can notice that the motor tracks the given set speed so closely. The steady-state speed error is negligibly low. Similarly, one more experiment is conducted at a higher speed of 3000 rpm. Figure 15 (a) shows the speed control of the BLDC motor drive at 3000 rpm and its zoomed view is shown in Figure 15 (b). From these experiments, the superiority of the closed-loop speed control by means of the PIDs obtained from the SSA can be recognized.
6. CONCLUSION

Thus, this paper successfully implemented the bio-inspired metaheuristic salp swarm algorithm (SSA) for closed-loop speed control of the Brushless DC (BLDC) motor drive. The effectiveness of the drive operation is shown for both lower and higher step reference speeds. The extensive simulation results show that the proposed SSA can be used offline for practical implementation of BLDC motor drive’s speed control. This is further supported and justified by the experimental validation results achieved presented.

REFERENCES

[1] F. Naseri, E. Farjah and T. Ghanbari, “An Efficient Regenerative Braking System Based on Battery/Super capacitor for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles with BLDC Motor,” IEEE Transactions on Vehicular Technology, vol. 66, no. 5, pp. 3724-3738, May 2017, doi: 10.1109/TVT.2016.2611655.

[2] B. Singh and S. Singh, “State of the Art on Permanent Magnet Brushless DC Motor Drives,” Journal of Power Electronics, vol. 9, no. 1, pp. 1-17, 2009, doi: 10.6113/IPE.2009.9.1.1.

[3] D. Potnuru, K. A. Mary and Ch. Saabu, “Design and implementation methodology for rapid control prototyping of closed loop speed control for BLDC motor,” Journal of Electrical Systems and Information Technology, vol. 5, no. 1, pp. 99–111, 2018, doi: 10.1016/jjesi.2016.12.005.

[4] X. Nian, F. Peng and H. Zhang, “Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor,” IEEE Transactions on Industrial Electronics, vol. 61, no. 10, pp. 5798-5808, 2014, doi: 10.1109/TIE.2014.2300059.

[5] S. Sashidhar, V. Guru Prasad Reddy and B. G. Fernandes, “A Single-Stage Sensorless Control of a PV-Based Bore-Well Submersible BLDC Motor,” IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 7, no. 2, pp. 1173-1180, June 2019, doi: 10.1109/JESTPE.2018.2810506.

[6] S. Chen, W. Sun, K. Wang, G. Liu and L. Zhu, “Sensorless High-Precision Position Correction Strategy for a 100 kW@2 000 r/min BLDC Motor With Low Stator Inductance,” IEEE Transactions on Industrial Informatics, vol. 14, no. 10, pp. 4288-4299, 2018, doi: 10.1109/TII.2018.2793947.

[7] T. Li and J. Zhou, “High-Stability Position-Sensorless Control Method for Brushless DC Motors at Low Speed,” IEEE Transactions on Power Electronics, vol. 34, no. 5, pp. 4895-4903, 2019, doi: 10.1109/TPEL.2018.2863735.

[8] A. Lee, C. Fan and G. Chen, “Current Integral Method for Fine Commutation Tuning of Sensorless Brushless DC Motor,” IEEE Transactions on Power Electronics, vol. 32, no. 12, pp. 9249-9266, 2017, doi: 10.1109/TPEL.2017.2652847.

[9] L. Yang, Z. Q. Zhu, B. Shuang and H. Bin, “Adaptive Threshold Correction Strategy for Sensorless High-Speed Brushless DC Drives Considering Zero-Crossing-Point Deviation,” IEEE Transactions on Industrial Electronics, vol. 67, no. 7, pp. 5246-5257, 2020, doi: 10.1109/TIE.2019.2931501.

[10] M. Sun, X. Zhou and H. Qian, “Sensorless control for high-speed brushless DC motors driven by current source inverter,” CSAA/IET International Conference on Aircraft Utility Systems, 2020, pp. 1128-1135, doi: 10.1049/icp.2021.0398.

[11] F. J. Lionel, J. Jayan, M. K. Srinivasan, and P. Prabhakaran, “DC-link current based position estimation and speed sensorless control of a BLDC motor used for electric vehicle applications,” International Journal of Emerging Electric Power Systems, vol. 22, no. 3, pp. 269–284, Jun. 2021, doi: 10.1515/ijeps-2020-0235.

[12] U. K. Soni and R. K. Tripathi, “Sensorless control of high-speed BLDC motor using equal area criterion based precise commutation scheme with Fuzzy based phase delay compensation,” International Transactions on Electrical Energy Systems, vol. 31, no. 9, pp. 3-30, 2021, doi: 10.1002/2050-7038.13001.

[13] M. S. Amiri, M. F. Ibrahim, and R. Ramli, “Optimal parameter estimation for a DC motor using genetic algorithm,” International Journal of Power Electronics and Drive Systems, vol. 11, no. 2, pp. 1047-1054, 2020, doi: 10.11591/ijpeds.v11i2.pp1047-1054.

[14] D. S. Nayak and R. Shivarudraswamy, “Solar fed BLDC motor drive for mixer grinder using a boost converter,” International Journal of Power Electronics and Drive Systems, vol. 11, no. 1, pp. 56-63, 2020, doi: 10.11591/ijpeds.v11i1.pp56-63.

[15] H. E. A. Ibrahim, F. N. Hassan, and A. O. Shomer, “Optimal PID control of a brushless DC motor using PSO and BF techniques,” Ain Shams Engineering Journal, vol. 5, no. 2, pp. 391–398, 2014, doi: 10.1016/j.asej.2013.09.013.

[16] A. H. Yakout, H. Koth, H. M. Hasianen and K. M. Aboras, “Optimal Fuzzy PIDF Load Frequency Controller for Hybrid Microgrid System Using Marine Predator Algorithm,” IEEE Access, vol. 9, pp. 54220-54232, 2021, doi: 10.1109/ACCESS.2021.3070076.

[17] A. H. Yakout, M. A. Attia, and H. Koth, “Marine Predator Algorithm based Cascaded PIDA Load Frequency Controller for Electric Power Systems with Wave Energy Conversion Systems,” Alexandria Engineering Journal, vol. 60, no. 4, pp. 4213–4222, 2021, doi: 10.1007/s41776-021-00301-1.

[18] K. Kolano, “Improved Sensor Control Method for BLDC Motors,” IEEE Access, vol. 7, pp. 186158-186166, 2019, doi: 10.1109/ACCESS.2019.2960580.

[19] R. Devarapalli, N. J. Naga Lakshmi and U. Prasad, “Application of a Novel Political Optimization in Optimal Parameter Design of PI Controller for the BLDC Motor Speed Control,” International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFET), 2020, pp. 1-6, doi: 10.1109/ICEFET49149.2020.9186957.

[20] J. He, C. Yan, and X. Wang, “Torque Ripple Suppression of Brushless DC Motor Drive System Based on Improved Harmonic Injection Active Disturbance Rejection Control,” Sensors, vol. 22, no. 1069, pp. 1-21, 2022, doi: 10.3390/s2201069.

[21] G. S. R. Manoj and T. K. S. Kumar, “A Differentiation Approach for Robust PID Controller for a Linear BLDC Motor,” Third International Conference on Smart Systems and Invention Technology (ICSSIT), 2020, pp. 594-600, doi: 10.1109/ICSSIT49817.2020.9214279.

[22] B. K. Lee and M. Elsahi, “Advanced Simulation Model for Brushless DC Motor Drives,” Electric Power Components and Systems, vol. 31, no. 9, pp. 841–868, Sep. 2003, doi: 10.1080/15325000390227191.

[23] R. Karthik, E. Tejendra, R. Gowrav, H. Harsh, and Y. V. Pavan Kumar, “Methods for Effective Speed Control of DC Shunt Motor—Part 1: Classical PID Controller Tuning Methods,” Control and Measurement Applications for Smart Grid, Lecture Notes in Electrical Engineering, vol. 822, pp. 202-207, 2019, doi: 10.1007/978-3-030-76642-3_14.

[24] D. Potnuru, K. B. Chandra, I. Arasaratnam, D. Gu, K. A. Mary, and S. B. Ch, “Derivative-free square-root cubature Kalman filter for non-linear brushless DC motors,” IET Electric Power Applications, vol. 10, no. 5, pp. 419–429, 2016, doi: 10.1049/iet-epa.2015.0414.

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