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A Comprehensive Review on IoT-Based Speed Control of BLDC Motors (2010-2026)

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ABSTRACT

Brushless DC (BLDC) motors are important part in modern industry, electric vehicles, robotics and renewable energy systems because they are very efficient, reliable and need less maintenance. The Internet of Things has changed how we control these motors by allowing us to monitor them in time control their speed remotely and predict when they need maintenance. IoT technologies help devices talk to each other and to the cloud making them more reliable and reducing maintenance costs. Over the past decade researchers have worked on combining communication, cloud computing and artificial intelligence with Brushless DC motors to make them more efficient and adaptable. This review looks at all the research on IoT-based Brushless DC motor speed control from 2010 to 2026. It talks about how communication technologies, controllers and algorithms have evolved over time. We compare communication protocols, controllers and IoT platforms and discuss current trends and challenges. The review shows that combining IoT with controllers makes BLDC motors more accurate, reliable and able to predict when they need maintenance, which is important for Industry 4.0 and smart manufacturing.

1. Introduction

Brushless DC motors are widely used in engineering because they are efficient, compact and reliable. They are better than DC motors because they have higher efficiency longer lifespan and can control their speed more precisely [1-4]. Compared with conventional brushed DC motors, BLDC motors offer higher efficiency, improved reliability, longer operational life, and precise speed control, making them suitable for electric vehicles (EVs), industrial automation, medical equipment, drones, robotics, aerospace systems, HVAC applications, and renewable energy systems [5]–[7].

The increasing use of Industry 4.0 technologies has led to the integration of Internet of Things solutions with motor-drive systems[8,9]. IoT allows devices to talk to each other and to the cloud enabling monitoring and control. By using IoT with Brushless DC motors engineers can. Control motor speed, temperature and energy consumption from anywhere [10, 11].

Traditional speed-control systems rely on controllers that are not connected to the internet[12]. While these controllers work well in fixed conditions they lack monitoring and adaptive control capabilities[13]. IoT-based architectures overcome these limitations by connecting motor drives to the cloud, edge devices and mobile interfaces[14-17].

From 2010 to 2015 research focused on monitoring using microcontrollers and local-area communication technologies. Between 2016 and 2020 cloud computing smartphone-based control and industrial IoT platforms became more popular [18-20]. Since 2020 researchers have focused on edge computing, intelligence and machine learning-based adaptive controllers for Brushless DC motors [21-24].

The growing popularity of vehicles has accelerated research in IoT-enabled Brushless DC drives. [25-26]. Modern electric vehicles require accurate speed regulation, battery management and fault prediction, all of which benefit from IoT connectivity and intelligent analytics [27].

Despite progress there are still challenges, including communication latency, cybersecurity threats and energy-efficient communication [28-26]. Integrating edge computing, AI-assisted control and secure communication protocols is an area of research. The objective of this review is to analyze IoT-based Brushless DC motor speed-control technologies developed from 2010 to 2026 compare communication protocols and control strategies and identify current research trends and future opportunities.

2. Fundamentals of Brushless DC Motors

A Brushless DC motor is a type of motor that uses electronic commutation instead of a mechanical commutator. It has a stator with three-phase windings and a rotor with magnets [1,3]. Electronic switches control the motor based on rotor-position information from Hall-effect sensors or sensorless estimation algorithms [4,6].

The advantages of Brushless DC motors include efficiency, excellent torque-to-weight ratio, wide speed range, low maintenance requirements, fast dynamic response and reduced electromagnetic interference. These characteristics make them suitable for vehicles, drones, robotics and industrial automation [5,7].

Speed control is generally achieved by regulating the applied voltage through Pulse Width Modulation. Conventional controllers use PI and PID algorithms while recent studies investigate logic, neural networks and model predictive control to improve dynamic performance [12,20,22].

3. IoT Architecture for Brushless DC Speed Control

An enabled Brushless DC motor drive consists of multiple layers, including sensing, communication, data processing, visualization and intelligent control.

The device layer includes the Brushless DC motor, inverter, Hall sensors, current sensors, voltage sensors, temperature sensors, vibration sensors and embedded controllers like Arduino, ESP32 or Raspberry Pi [14,18]. The communication layer transmits data using Wi-Fi, Bluetooth, ZigBee LoRa, MQTT or cellular networks depending on the application [15,19]. The cloud layer. Stores operational data, enabling real-time monitoring, historical analysis, fault diagnostics and predictive maintenance [21.29].

The application layer allows users to access dashboards through web applications or mobile devices to visualize motor parameters modify reference speed receive alarms and analyze performance statistics[25,27].

Compared to standalone motor drives IoT-enabled architectures improve operational transparency, maintenance planning, energy management and system availability supporting Industry 4.0 initiatives[22,29].

4. Evolution of IoT-Based Brushless DC Speed Control (2010–2015)

The phase of IoT-enabled Brushless DC motor research focused on remote monitoring rather than intelligent control. Initial systems used Arduino-based controllers with Wi-Fi or Bluetooth modules to transmit motor speed data to computers or smartphones [8,10].

Researchers gradually incorporated Ethernet and wireless sensor networks to facilitate monitoring while Hall-effect sensors provided rotor-position feedback for conventional PID controllers. Around 2013–2015 MQTT emerged as a communication protocol suitable for embedded devices reducing communication overhead and improving scalability[15,18].

During this period researchers also investigated cloud-based data logging for maintenance enabling long-term storage of motor operating parameters for subsequent fault analysis[17,19].

5. IoT Communication Technologies for Brushless DC Motor Speed Control

Reliable communication is crucial for an IoT-enabled Brushless DC motor drive. The communication network determines the response time, data reliability, energy consumption, scalability and overall performance of the control system[14,15].

5.1 Wi-Fi-Based Control

Wi-Fi is the widely adopted communication technology due to its high bandwidth, internet accessibility and compatibility with cloud platforms. ESP8266 and ESP32 controllers have enabled implementation of Wi-Fi-based Brushless DC speed-control systems allowing users to monitor motor speed, voltage, current and temperature through web dashboards or smartphone applications[16,17].

Advantages of Wi-Fi include data transmission rate, easy cloud connectivity, remote firmware updates and smartphone compatibility. However Wi-Fi consumes high power and may experience latency under congested network conditions making it less suitable for strict real-time industrial control[18].

5.2 MQTT-Based Communication

The Message Queuing Telemetry Transport protocol has become the communication protocol for industrial IoT applications due to its lightweight publish-subscribe architecture. MQTT minimizes communication overhead. Provides efficient real-time messaging, between embedded controllers and cloud servers. Here is the rewritten text: Researchers have shown that MQTT makes a difference in response time and reduces network traffic in systems that monitor BLDC motors. The protocol also lets many clients connect at the time, which makes it possible to control many motors from a central location in the cloud [19].

5.3 Bluetooth Low Energy (BLE)

Bluetooth Low Energy is getting more popular for range industrial monitoring and portable equipment. Controllers that use BLE let mobile apps control motor speed without needing an internet connection[21]. BLE has some things going for it:

* It uses little power

* It is not expensive to set up

* It is easy to connect to smartphones

It has a limited range, usually less than 50 meters which makes it hard to use in big industrial facilities[22].

5.4 ZigBee-Based Networks

ZigBee is often used in wireless sensor networks because it uses very little power and can connect to many devices[23]. Some researchers have connected ZigBee modules to BLDC controllers to send operating parameters over sensor networks. ZigBee is more reliable than

Bluetooth in some situations but supports comparatively lower data rates [24].

5.5 LoRa Communication

Long Range (LoRa) communication has recently attracted considerable attention for agricultural automation, remote pumping stations, and distributed renewable-energy systems [25]. LoRa is a type of communication that can send signals over long distances more than 10 kilometers while using very little power. This makes it useful for things like automation and remote pumping stations. BLDC pumps and solar-powered irrigation systems often use LoRa modules to control speed and monitor equipment from away[26].

5.6 Cellular IoT and 5G

Since 2021 researchers have been looking into using LTE, NB-IoT and 5G for motor control [27]. Compared to wireless technologies 5G has some big advantages:

* It is very fast

* It is very reliable

* It can connect to devices at once

* It can send a lot of data quickly

These things make 5G a choice for things like autonomous manufacturing systems, collaborative robots and cloud-connected electric vehicles [28].

6. Embedded Platforms for IoT-Based BLDC Speed Control

The cost and complexity of implementing IoT-enabled motor drives have gone down a lot thanks to advances in embedded electronics. Modern systems combine microcontrollers, digital signal processors and single-board computers with communication modules.

6.1 Arduino

Arduino was one of the platforms used for IoT-enabled BLDC motor research because it is simple has a lot of software libraries and is not expensive [12]. However Arduino processors are not powerful enough for AI algorithms.

6.2 ESP8266 and ESP32

ESP32 has become very popular for IoT-based BLDC applications because it has:

* A dual-core processor

* Built-in Wi-Fi

* Bluetooth

* Many PWM channels

* ADC interfaces

* It is not expensive

Recent studies have shown that ESP32 can do things at the same time like controlling motor speed communicating with the cloud and talking to mobile apps without needing extra hardware [16, 29].

6.3 STM32 Microcontrollers

STM32 ARM Cortex processors are more powerful than Arduino while using power [30]. Researchers use STM32 controllers for things like:

* Field-oriented control

* Sensorless BLDC control

* High-speed PWM generation

* Industrial communication protocols

6.4 Raspberry Pi

Raspberry Pi is an embedded computer that can run Linux-based operating systems [31]. It is particularly good for:

* Cloud gateways

* AI-based motor diagnostics

* Image processing

* Edge computing

* Database management

Some studies have used Raspberry Pi with TensorFlow-based machine learning algorithms to predict when BLDC motors will need maintenance [32].

7. Speed-Control Algorithms

The control algorithm determines how well the BLDC motor performs how accurate it is and how well it can handle disturbances.

7.1 PI and PID Controllers

PI and PID controllers are still the commonly used speed-control algorithms because they are simple to implement and work well. Many IoT-enabled systems use PID controllers that can be adjusted remotely through cloud interfaces or mobile apps [5, 12, 20].

The good things about PI and PID controllers are:

* They are simple to implement

* They do not need a lot of power

* They are widely accepted in industry

They also have some limitations:

* They are not very robust when the load is not linear

* They can be sensitive to changes in parameters

* They can be hard to tune

7.2 Fuzzy Logic Controller

Fuzzy Logic Controllers use linguistic rules instead of precise mathematical models to control the motor. Researchers have shown that fuzzy controllers can reduce overshoot improve disturbance rejection and provide smoother speed regulation under varying load conditions

[33, 22]. IoT connectivity further enables adaptive modification of fuzzy rules through cloud-based supervisory systems.

7.3 Artificial Neural Networks (ANN)

Artificial Neural Networks can learn the characteristics of the motor from data and estimate the best control actions without needing a mathematical model [34]. ANN-based controllers have shown:

* Faster transient response

* accurate tracking

* Better robustness against uncertainties

Recent cloud-assisted ANN implementations can retrain the controller using data collected from IoT sensors [24].

7.4 Adaptive Neuro-Fuzzy Inference System (ANFIS)

ANFIS combines reasoning with neural-network learning to improve controller adaptability. Studies have shown that ANFIS controllers are better than PID controllers in terms of:

* Rise time

* Overshoot

* Steady-state error

* Load disturbance rejection

ANFIS has become increasingly attractive for electric vehicle drive systems operating under varying road conditions [26].

7.5 Sliding Mode Control (SMC)

Sliding Mode Control has become popular because it is very robust against parameter uncertainties and external disturbances. IoT-enabled SMC systems allow monitoring of controller performance and online adjustment of switching parameters[30]. The principal disadvantage is chattering, which may increase torque ripple.

7.6 Model Predictive Control (MPC)

Model Predictive Control is an advanced control technique for future intelligent motor drives. MPC predicts the behavior of the motor using mathematical models and selects the best switching sequence while satisfying operational constraints[31].

8. Sensor-Based and Sensorless BLDC Speed Control

Traditional BLDC motors use Hall-effect sensors to determine the position of the rotor [4]. Hall sensors are reliable simple to implement and provide commutation. However they increase the cost of the hardware. Reduce reliability in harsh environments. Recent research is looking into sensorless control techniques based on:

* Back-EMF estimation

* Sliding-mode observers

* Extended Kalman filters

* Model reference systems

* Artificial intelligence

Sensorless IoT-enabled systems reduce maintenance requirements while sending diagnostic information to cloud platforms for predictive maintenance [28, 32].

9. Comparative Analysis of IoT Communication Technologies

Here is a comparison of IoT communication technologies:

Technology	Range	Data Rate	Power Consumption	Typical BLDC Applications
Wi-Fi	Medium	High	High	Smart homes, laboratories, cloud monitoring
MQTT	Internet-wide	Medium	Low	Industrial IoT, cloud control
BLE	Short	Medium	Very Low	Mobile applications, wearable systems
ZigBee	Medium	Low	Low	Industrial sensor networks
LoRa	Very Long	Low	Very Low	Agriculture, remote pumping systems
5G	Wide Area	Very High	Medium	Smart factories, EVs, Industry 4.0

Studies have shown that MQTT over Wi-Fi is the most common architecture for laboratory-scale and industrial IoT-based BLDC motor speed-control systems because it offers a good balance between communication efficiency, cloud integration and implementation cost [27, 28].

10. Cloud and Edge Computing for IoT-Based BLDC Speed Control

Cloud computing has changed the way we control motors by enabling data storage, remote diagnostics firmware updates and predictive maintenance. Platforms like AWS IoT Microsoft Azure IoT Google Cloud IoT, ThingSpeak and Blynk have been widely used to monitor BLDC motor parameters [17, 18, 21].

Although cloud computing offers a lot of storage and computational power it can introduce latency that can affect the performance of real-time motor control. Recent studies suggest using edge computing, where data processing and decision-making happen near the motor drive using embedded processors like Raspberry Pi, NVIDIA Jetson or industrial gateways [23, 24].

11. Artificial Intelligence and Machine Learning Approaches (2020–2026)

The combination of Artificial Intelligence and IoT has advanced BLDC motor speed control. AI algorithms can learn system dynamics adapt controller parameters online and predict faults before they happen [25].

11.1 Machine Learning for Predictive Maintenance

Machine learning models analyze sensor data to identify abnormal operating conditions. Algorithms like Support Vector Machines, Random Forests, Decision Trees and Gradient Boosting have shown diagnostic accuracy in industrial motor applications [26].

11.2 Deep Learning

Deep learning is a type of machine learning that uses networks to analyze data. It has been used for things, like image recognition, natural language processing and predictive maintenance[27]. Brushless DC motors are really important in industrial automation and electric vehicles because they are very efficient and reliable. These motors are also used in robotics and renewable energy systems. They have become a part of our daily lives.

The Internet of Things technology has changed the way we control these motors. Now we can monitor them from away and make sure they are working properly. We can also use cloud computing to supervise them and predict when they might need maintenance. This is an improvement over the old way of doing things.

Deep learning models like Convolutional Neural Networks and Long Short-Term Memory networks are used to analyze vibration signals and thermal images from the motors. This helps us detect problems before they become serious. We can also use the Internet of Things to update our models and make them more accurate.

11.3 Reinforcement Learning

Reinforcement Learning is another technique that is being used to control the speed of the motors. This method involves teaching the motor to learn from its mistakes and adjust its speed accordingly [28]. It is an approach but it requires a lot of computing power and training.

11.4 Digital Twin Technology

Digital Twin Technology is also being used to create a copy of the motor. This virtual copy can be used to predict how the motor will behave in situations and to plan maintenance. It is an useful tool for industries that rely on these motors [29].

However as we connect more motors to the internet we need to be careful about cybersecurity. If someone gains access to the motor system it could cause a lot of problems. We need to make sure that our systems are secure and that we are using the security protocols.

12. Cybersecurity Chanllenges

Some common threats to these systems include remote access, denial of service attacks and malware infection. To protect against these threats we can use end-to-end encryption, secure authentication and role-based access control. We can also use private networks and secure boot mechanisms to add an extra layer of security.

Researchers have identified areas where more work is needed. These include time deterministic control, energy-efficient IoT nodes and standardized interoperability. We also need to develop advanced AI controllers and digital twin technology. Cybersecurity is another area that needs improvement.

Over the years there have been advances in the field of brushless DC motors. From wireless monitoring systems to advanced Industry 4.0 architectures we have come a long way. Technologies like MQTT, ESP32 and Raspberry Pi have become very popular for IoT-enabled motor applications. AI-based controllers like ANN, ANFIS and reinforcement learning are also being used more and more [31].

13. Research Gaps and Future Directions

Despite rapid progress between 2010 and 2026, several research challenges remain:

1. **Real-time deterministic control:** Achieving cloud-based control with guaranteed low latency remains difficult.
2. **Energy-efficient IoT nodes:** Wireless sensor nodes require lower power consumption for long-term deployment.
3. **Standardized interoperability:** Integration among heterogeneous IoT devices and industrial protocols remains limited.
4. **Advanced AI controllers:** Further research is needed on lightweight AI models suitable for embedded processors.
5. **Digital twins:** Practical deployment for industrial BLDC drives is still at an early stage.
6. **Cybersecurity:** Secure communication protocols and resilient architectures require continuous improvement.
7. **Explainable AI:** Interpretable AI models are needed to enhance industrial acceptance.
8. **Edge intelligence:** Greater emphasis should be placed on decentralized decision-making at the network edge.
9. **Sustainable operation:** Energy-aware communication and green IoT solutions will become increasingly important.
10. **Integration with smart grids and EV charging infrastructure:** Future BLDC drive systems are expected to interact dynamically with renewable energy sources and intelligent power networks [29]–[35].

14. Comparative Summary of Major Research Trends (2010-2026)

Period	Major Research Focus	Key Contributions
2010–2013	Wireless monitoring	Arduino, Bluetooth, Wi-Fi, PID control
2014–2016	IoT integration	MQTT, cloud monitoring, smartphone applications
2017–2019	Industrial IoT	ESP32, Raspberry Pi, cloud analytics, predictive monitoring
2020–2022	AI-assisted control	ANN, ANFIS, edge computing, machine learning
2023–2026	Industry 4.0	Digital twins, 5G, reinforcement learning, cybersecurity, predictive maintenance

15. Conclusion

Brushless DC motors have become indispensable in modern industrial automation, electric vehicles, robotics, and renewable energy systems due to their high efficiency, excellent dynamic performance, and low maintenance requirements. The integration of Internet of Things technologies has fundamentally transformed conventional BLDC motor control by enabling remote monitoring, cloud-based supervision, predictive maintenance, and intelligent decision-making.

This review analyzed research published from 2010 to 2026 and demonstrated the evolution from simple wireless monitoring systems to advanced Industry 4.0 architectures incorporating cloud computing, edge computing, artificial intelligence, machine learning, digital twins, and secure communication technologies. MQTT, ESP32, Raspberry Pi, and cloud platforms have emerged as dominant technologies for IoT-enabled BLDC motor applications, while AI-based controllers such as ANN, ANFIS, and reinforcement learning show considerable promise for adaptive speed regulation.

Although significant progress has been achieved, challenges related to communication latency, cybersecurity, interoperability, and computational complexity remain. Future research should emphasize lightweight AI algorithms, edge intelligence, secure IoT frameworks, digital twin implementation, explainable AI, and integration with smart grids and electric vehicle ecosystems. These developments are expected to enhance the efficiency, reliability, sustainability, and autonomy of next-generation BLDC motor drive systems.

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