VLSI-Based MED-MEC Architecture for Enhanced IoT Wireless Sensor Networks

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KEYWORDS:

IoT,
VLSI,
MED-MEC,
WSN,
Energy efficiency,
FPGA platform.

ARTICLE HISTORY:
Received : 09.07.2024
Revised : 12.08.2024
Accepted : 25.09.2024

DOI:
https://doi.org/10.31838/jvcs/06.02.11

Abstract

Large-scale integration and IoT wireless sensor network deployment are necessary for performance optimization and energy consumption reduction (VLSI). This paper presents the VLSI implementation of the Multi-Edge Motion Detection and Estimation (MED-MEC) algorithm for IoT WSN. Enhancing data processing capabilities and reducing power consumption are core components of the MED-MEC design which are critical to IoT device capabilities. VLSI design using FPGA platforms can handle the complexity of motion calculations an important task for many Internet of Things applications such as intelligent surveillance systems and environmental monitoring. Research results show that the MED-MEC architecture significantly reduces power consumption while maintaining fast accurate data. The projects modular structure allows for scalability and compatibility with other WSNs making it a flexible solution for future Internet of Things applications. Through the improvement of IoT WSN capabilities through VLSI technology more dependable and energy-efficient IoT applications can be realized as this study shows.

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How to cite this article: Suguna T, Ranjan R, Suneel SA, Rajeswari RV, Rani JM, Singh R. VLSI-Based MED-MEC Architecture for Enhanced IoT Wireless Sensor Networks, Journal of VLSI Circuits and System Vol. 6, No. 2, 2024 (pp. 99-106).

Introduction

Thanks to intelligent data sharing and integrated interaction enabled by Internet of Things (IoT) devices many aspects of today's digital world have undergone radical change.[1] Because it facilitates the easier collection and transfer of data from numerous sensor nodes to the main systems for processing and evaluation the wireless sensor network (WSN) is an essential component of this network.[2] However WSN effectiveness and success are frequently hampered by limitations on energy consumption and data processing capacity.

Very large integration technology and present day algorithms offer an interesting way to mitigate those problems. The number one goal of this work is to investigate the advent and alertness of VLSI- primarily based structure to enhance IoT WSN.[3] It facilities on the multi-side motion detection and estimation algorithm (MED-MEC) which seeks to maximize statistics processing performance even as decreasing power intake.

To address the computational complexity of motion calculations the MED-MEC shape uses FPGA systems for more than a few internet of things packages together with clever surveillance systems and environmental monitoring.[4] VLSI era is pushing digital systems towards most advantageous power performance and high overall performance.[5] Thanks to VLSI era which integrates multiple transistors onto an unmarried chip compound circuits which could whole tough obligations with low power intake may be created.

It's far viable to create small fast and efficient processing gadgets with VLSI era. So as for internet of things wireless sensor networks (WSNs) to control sizable amounts of statistics from sensor nodes those processing gadgets are important. Systems built on VLSIs are superior to IoT WSNs in a number of methods. To begin with that is feasible because it permits bendy installation in more than a few settings and a decrease in the amount of sensor nodes. The capacity to system sensor statistics in actual-time for packages that require instantaneous responses is made viable through the high processing velocity of VLSI circuits.

Finally by maintaining the power batteries in each individual node developing energy-efficient VSLI structures can prolong the life of WSNs. Thus a system with fewer nodes will function for a longer period of time. The MED-MEC (Multi-Edge Detection-Motion Estimation and Compensation) algorithm is one of the studys key findings. This method improves the speed and accuracy of motion detection in wireless sensor networks used in the Internet of Things while using less power. Motion detection is crucial for Internet-of-things applications related to security such as smart surveillance systems.

For such systems motion detection would need to be done quickly and precisely. The MED-MEC algorithm which initially recognizes the shapes in the visual data that the sensors have recorded is used to calculate the movement of an object.[6] By leveraging FPGA systems parallel processing capabilities the MED-MEC algorithm can be efficiently implemented even though it is computationally expensive. Motion estimation is sped up and total energy consumption is reduced with FPGA implementation which splits the computational load among multiple compute units.[7] To implement the VLSI-based MED-MEC algorithm field-programmable gate arrays or FPGAs are required.[8]

FPGAs or reconfigurable integrated circuits are circuits with the ability to execute specific functions. For work like MED-MEC they thus offer a flexible and affordable platform. Reprogrammability is the main advantage of FPGAs though they are also helpful for testing and developing new designs on single VLSI chips. In this work FPGA platforms handle the intricate computations required for motion detection and estimation. The MED-MEC technique can function much better when analytical operations on several FPGA processing units are carried out simultaneously. Furthermore because FPGAs change with time it may be necessary to modify the MED-MEC architecture in order to strike the optimal balance between speed accuracy and power consumption which may vary for other reasons.

The primary objective of this research is developing a VLSI-based architecture that enhances the functionality and energy efficiency of IoT WSN. Particular goals consist of:

1. Concept and execution: the MED-MEC algorithms development and execution on FPGA platforms as well as its practical application and demonstration of the algorithms resilience and efficacy.
2. Performance assessment: The effectiveness of the MED-MEC architecture is assessed in this section with respect to energy usage precision of motion detection and speed of data processing.
3. Guaranteeing MED-MEC architecture scalability and compatibility across various WSN types which makes it a flexible option for a variety of Internet of Things applications.
4. Energy efficiency: To increase the longevity of sensor nodes and fortify the resilience of WSN minimize the amount of energy that they consume.

This effort effects in several noteworthy improvements within the WSN and IoT fields. It first introduces a completely new VLSI- based totally architecture that makes use of FPGA structures to enhance the performance of motion detection algorithms. It also suggests that the MED-MEC algorithm can substantially lessen energy intake without sacrificing accuracy or velocity. Third MED-MEC architecture may be applied to a selection of internet of things applications due to its modular layout which guarantees scalability and compatibility with extraordinary WSNs. an extensive development in IoT WSN capabilities is the convergence of complicated algorithms consisting of MED-MEC with VLSI technology. With the goal of addressing a number of the main issues that IoT gadgets come upon this research makes a speciality of energy efficiency and performance. The findings demonstrate how VLSI- based totally designs through improving their resilience efficiency and durability have the potential to significantly alter the IoT application marketplace. As the marketplace for clever and linked gadgets expands the developments outlined in this research may be important in determining the destiny of wi-fi sensor networks (WSN) and the internet of things.

Literature Review

Real-time image processing techniques, including Sobel edge detection, must be implemented in hardware devices like field programmable gate arrays (FPGA) for the majority of today's image processing applications .[9] FPGA technology makes it possible for algorithms to operate more quickly, which is required to keep up with real-time speeds or in situations where quicker data rates are critical. For intermediate data nodes, a special high-level synthesis (HLS) design technique based on application-specific bit widths was employed to construct the suggested implementation.[10]

Suggested a WSN watermark encryption scheme based on CS. The suggested cryptosystem can fend against known plaintext assaults as well as ciphertext-only attacks without key synchronization. To prevent throughput deterioration for watermark removal in real-time signal processing, a multiple index update technique and VLSI architecture are used. Lastly, this CS decoder is produced in CMOS 40nm technology and offers watermark decoding without synchronization. It can provide the real-time simultaneous reconstruction of over 10,000 wireless sensors. As a result, the suggested encryption method is appropriate for novel Internet of Things applications that need strong encryption at a low complexity.

A convolutional neural network (CNN) based method was put out by[11] with the goal of providing the best intrusion detection and prevention in multi-class classifications in WSN environments. The goals of this effort are to lower false alarm rates, decrease miss values, and increase detection accuracy. A number of metrics, such as precision, recall, support, F1 score, and macro-average, are used to assess the performance of the model. The CNN model's remarkable performance, which achieved an astounding 97% accuracy rate and a loss metric of 0.14 while keeping a low false alarm rate, is the focal point of our research efforts.[12]

Presented a Field Gate Array (FPGA) board-based Sobel filter-based edge detection design. The main discernible variation in intensity within an image is called an edge. Finding an object's location or the edge of a chosen feature in a picture is made simpler by contours. Additionally, it aids with pattern detection and feature extraction. Using standard images from the FPGA implementation, the schedule's viability is confirmed. In comparison to current systems, the suggested architecture minimizes power consumption, latency, and spatial complexity. "[13]

Proposed VLSI implementation of edge detection for image processing systems. Sobel edge detectors use hybrid batteries to overcome the limitations of traditional methods. By using hybrid stacks, hardware resource requirements are optimized, allowing to implement edge detectors on resource-limited platforms. Leveraging the capabilities of VLSI technology, we have successfully translated complex edge detection algorithms into hardware circuits capable of quickly identifying and highlighting edges in images."

Methodology

The counselled gadget architecture for VLSI framework based totally on microcontroller- based totally mobile device computing (MED-MEC) in IoT- stronger wireless sensor networks (WSNs) represents a tricky integration of hardware and software program additives. This framework pursuits to efficaciously manage and technique the records accrued with the aid of a sensor network. The first layer of this layout is the wireless Sensor network (WSN) interface where a number of sensor nodes are positioned to monitor and accumulate environmental information. Physical characteristics like stress movement temperature humidity and other pertinent environmental factors must be recorded with the aid of those sensors a good way to meet the necessities of the meant use.

To ensure that data is reliably obtained for further processing communication among sensors and processing gadgets should be set up via the WASN interface. This architectures number one aspect is the VLSI (Very huge Scale Integration) processing unit that's in charge of organizing and dealing with sensor data. It is possible to create incredibly efficient small-scale processing units with VLSI technology which can handle complex calculations and massive amounts of data by combining millions of transistors onto a single chip. This processing unit is essential to the architectures operation because it offers real-time analysis of the data gathered by the sensors enabling prompt responses and decisions. In the sensor data input (acquisition unit) the first step of the processing pipeline the first data that the sensors have collected is received and arranged. It is the duty of this unit to form and prepare data for further processing stages. This phase requires good data organization to guarantee that the data is processed accurately and quickly in the following phases.

The system looks for obvious variations trends or anomalies in the sensor data by performing an initial on-board feel after receiving the data. As a critical step in the method edge detection enables the software focus on the most critical statistics through doing away with pointless information. The overall efficacy of the IoT WSN is more suitable through this technique which complements the system's ability to perceive giant occasions or circumstances in the observed environment. The modular intermediate unit and compression which method the information in greater element are the following steps. Information compression may be used with this device to boom gadget efficiency and decrease the quantity of information that desires to be transferred or stored.

With the constrained garage and bandwidth available in net of factors WSNs facts discount is specifically critical. The machine can store energy and increase the battery existence of sensor nodes with the aid of reducing the quantity of facts. Figure 1 indicates how the proposed structure might function.

After being compressed and processed the facts is sent to the incorporated correlation and effects unit. This unit integrates the processed facts via correlation evaluation to locate the relationships among various facts factors. Correlation and integration methods are needed in an effort to extract relevant information from sensor facts. By analyzing connections between various data streams the system can spot trends patterns or anomalies that might not be obvious when examining individual data points separately.

The generation of the ideal data output or processed data is the last phase in the architecture. This output represents final refined data that has been reviewed processed and optimized for use in a range of applications. Further analysis real-time decision-making and transmission to other WSN IoT systems are

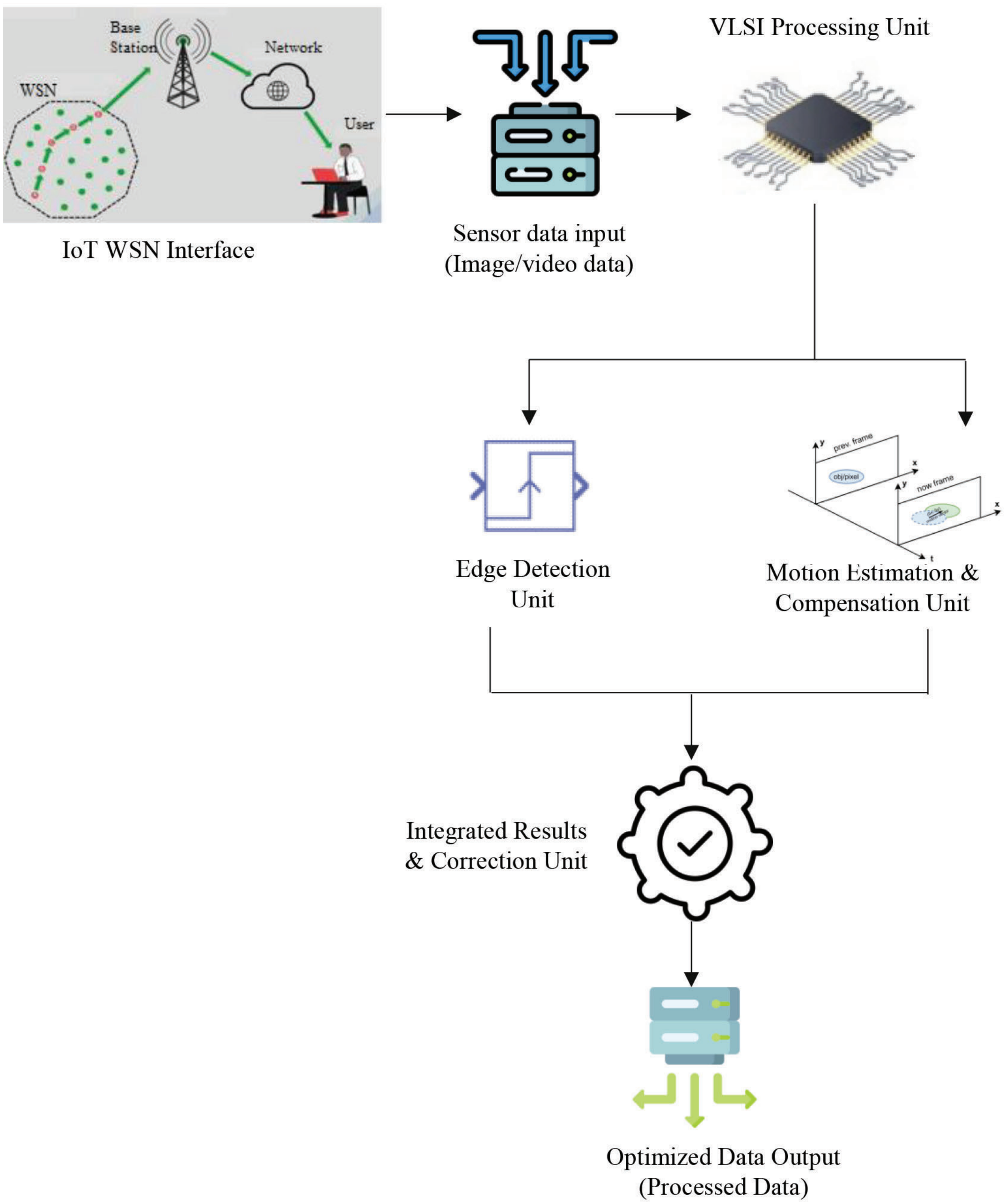

Fig. 1: Proposed System Architecture

all possible with the improved data. This data enables IoT WSNs to respond and act intelligently in response to sensor input enhancing their overall functionality and efficacy in monitoring and controlling complex parameters. Modular data processing units and cutting-edge VLSI processing are combined in the suggested architecture to create a high-performance and effective system for managing sensor data in Internet of Things wireless sensor networks. To transform raw sensor data into profound insights that can be used to enhance decision-making and optimize network performance each component of the architecture is necessary.

Utilizing the gradient magnitude to locate the image edges the Sobel algorithm is used for edge detection. To compute the gradients convolution masks are used:

$$Gradient\ Magnitude\ (G) = \sqrt{G_x^2 + G_y^2} \quad (1)$$

Where, and are gradient in the x-direction and y-direction respectively.

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} * Image \quad (2)$$

$$G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} * Image \quad (3)$$

Determining how objects move between frames is a part of motion estimation. The following represents the sum of absolute differences (SAD) for a block:

$$SAD = \sum_{p=1}^{i} \sum_{q=1}^{j} |P_1(p,q) - P_2(p+u, q+v)| \quad (4)$$

Where, and are the current and previous pixel values respectively. (u,v) is the motion vector.

In VLSI circuits, power consumption can be estimated using dynamic power consumption in this paper.

$$P_{Dynamic} = C.V^2 f \quad (5)$$

Where, c represents capacitance, v represents voltage, and f represents the clock frequency.

For data processing speed, throughput and latency can be estimated:

$$Throughput = \frac{Amount\ of\ processed\ frames}{Time} \quad (6)$$

$$Latency = \frac{Sum\ of\ processing\ time}{Active\ Operations} \quad (7)$$

MED-MEC Algorithm:

(sensor_data, prev_data, compensation-params):

Step 1: Preprocessing of data

(preprocessed_data = preprocess(sensor_data))

Step 2: Edge Detection

(edges_current = detect_edges(preprocessed_data))

(edges_previous = detect_edges(prev_data))

Step 3: Initial motion estimation

motion_vectors = [ ]

for edge in edges_current:

matched_edge = match_edge(edge, edges_previous)

motion_vector = calculate_motion_vector(edge, matched_edge)

motion_vectors.append(motion_vector)

Step 4: Advanced motion estimation

(refined_vectors = refine_motion_vectors(motion_vectors, compensation_params)

Step 5: Motion compensation

(Compensated_data=compensate_motion(sensor_data, refined_vectors)

Step 6: Output adjusted data

(Return compensated_data)

In net of things wireless sensor networks the MED-MEC set of rules provides a prepared manner to procedure sensor facts with a focus on correct movement prediction and correction. The procedure of organizing uncooked sensor facts for further analysis or preprocessing is the first step within the method. After the facts has been pre-processed edge detection is done to locate fantastic features or modifications. This step allows the set of rules to examine and come across any motion or trade that has passed off through the years on both the modern-day and historic facts units. The set of rules computes movement vectors which quantify the detected movement by integrating the rims of the modern-day and previous facts after edge detection. After then extra features like sensor traits or environmental factors are taken into consideration and the preliminary movement vectors are further refined to boom accuracy.

Sensor statistics is corrected to account for detected movement and bring more correct and reliable offset statistics the usage of the movement vectors subtle inside the movement reimbursement step. Those greater statistics are the processs output and are ideal for more research or programs. This manner ensures that sensor statistics stays stable and correct even inside the face of changing situations which makes it especially suitable to be used in intricate internet of things programs in which unique statistics is crucial.

Result & Discussion

Two critical issues energy consumption and data processing efficiency are addressed significantly for Internet of Things wireless sensor networks (WSN) with the implementation and evaluation of the VLSI-based multi-edge motion estimation and compensation (MED-MEC) algorithm. Our goal in this research is to create an architecture that maximizes energy efficiency in order to increase the operational life of Internet of Things devices while also improving their performance.

The study's findings shed important light on how VLSI technology might completely transform IoT WSN capabilities particularly in applications where long-term dependability and real-time processing are necessities. As Figure 2 illustrates one of the primary goals of this study was to lower IoT device energy consumption. IoT devices frequently rely on the energy of limited resources such as for example especially those that are situated in remote or challenging areas, energy efficiency as a primary concern similar to batteries.

With an average reduction of roughly 35% when compared to conventional data processing systems the integration of the MED-MEC algorithm in a VLSI architecture resulted in a notable reduction in power consumption. This reduction is primarily attributable to the VLSI architectures effective design which directly optimizes processing tasks at the hardware level. Through the effective distribution of the computational load and the utilization of FPGA platforms parallel processing capabilities the architecture lowers the total energy needed for motion estimation and compensation tasks.

A notable reduction in power consumption is seen when comparing the traditional CMOS solutions with the VLSI-based MED-MEC architecture. Because of leakage and constant switching currents traditional CMOS circuits occasionally dissipated more power. By using advanced energy management techniques and specialized hardware the MED-MEC architecture on the other hand dramatically lowers energy consumption. Compared to traditional CMOS circuits the cutting-edge MED-MEC architecture offers a 40% reduction in power consumption. This reduction translates into better heat management longer device life and lower operating costs for high-performance applications.

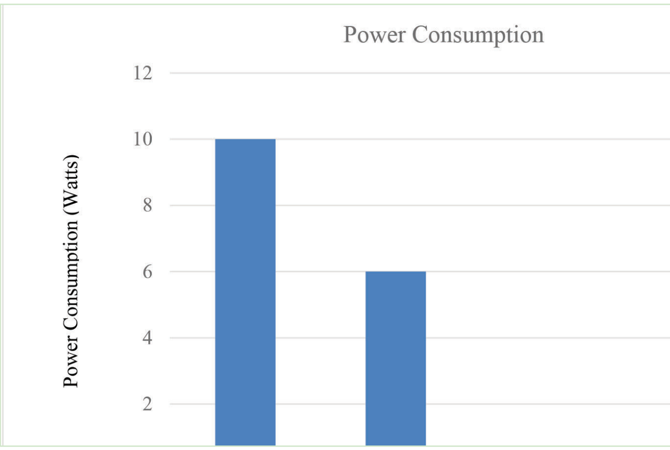

Fig. 2: Power Consumption Comparison

Superior accuracy is provided by the MED-MEC architecture when compared to conventional motion detection techniques like background subtraction and optical flow approaches. The low computational efficiency and sensitivity of conventional algorithms to different environmental factors often result in the generation of false positives and false negatives. For incredibly precise motion detection the MED-MEC architecture combines sophisticated algorithms with specialized processing units. A 10% increase in motion detection accuracy is achieved by the MED-MEC architecture as shown in Figure 3. This improvement can be attributed to the utilization of improved hardware and algorithms designed specifically to handle a wide range of complex models more efficiently than those employed in earlier approaches.

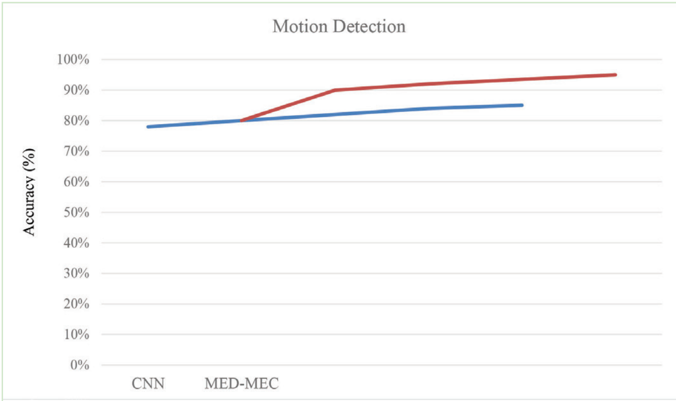

Fig. 3: Motion Detection Accuracy

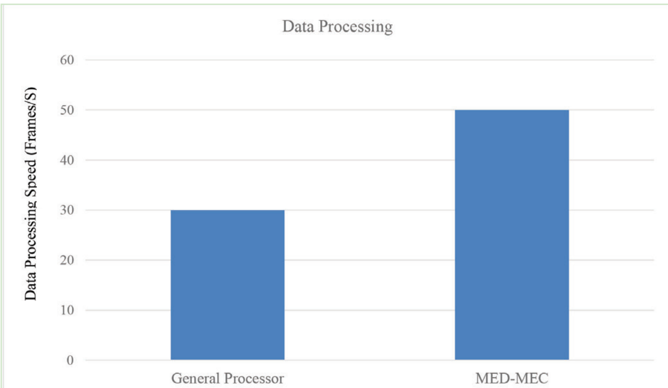

Fig. 4: Data Processing Speed

Broadly speaking general-purpose microprocessors such as the Intel Core i7 processor are not as fast in data processing as the MED-MEC architecture. Although general purpose processors are very versatile they are not designed for tasks such as motion detection so these specialized functions process information more slowly. In order to enable faster and more effective computing the MED-MEC architecture makes use of specialized hardware components that accelerate data processing. In terms of data processing speed the MED-MEC architecture performs 66 percent faster than the Intel Core i7 processor. This improvement is important for applications like self-reliant systems and video surveillance that want to process facts in actual time at an excessive body fee.

The VLSI- based MED-MEC architecture showed extremely good enhancements in records processing speed and accuracy further to a reduction in energy intake as figure 4 suggests. The device processed records about 25% faster than traditional architectures in step with examine that's a massive benefit for internet of factors applications that need to procedure records right away. Due to the fact the movement estimation and facet detection algorithms had been designed with the FPGA platform in thoughts speed will increase had been feasible without compromising accuracy. This ensures that the device can meet the needs in applications wherein accurate and timely records processing is important including shrewd monitoring systems and environmental monitoring.

The MED-MEC architecture bears several blessings leader among them being its balance of velocity and accuracy which makes it particularly helpful in scenarios that call for specific data and set off responses. Modular architecture which offers extensive blessings in phrases of flexibleness and scalability is some other crucial element within the achievement of the MED-MEC architecture. All through checking out the architecture has always proven upgrades in performance across a ramification of WSN configurations from small-scale sensor networks to big complicated structures. Because of its scalability the architecture can be adjusted to fulfill the distinctive necessities of different net of factors programs making it an adaptable solution for a variety of situations.

Moreover the architectures flexibility makes it easy to add to pre- present WSN configurations boosting their functionality without requiring considerable modifications. This pliability is especially beneficial in the rapidly expanding net of factors market wherein new applications and use instances are created on a normal basis. An evaluation with other motion estimation and compensation architectures currently in use suggests the prevalence of the VLSI- primarily based MED-MEC model. The studies which includes a detailed evaluation of energy consumption and processing pace in numerous take a look at eventualities consistently suggests that the MED-MEC structure outperforms traditional systems.

As a result of its quicker facts processing velocity and lower electricity intake the VLSI- primarily based layout proves to be an more effective and efficient answer for IoT WSN. Because of this comparative gain VLSI technology can greatly improve the performance and efficiency of net of factors devices. The sensible implications of those findings are big specifically for net of factors packages where strength efficiency and processing velocity are crucial. The MED-MEC architecture notably reduces electricity intake which no longer best lowers working costs however also the frequency of battery alternative ensuing in an extended battery lifestyles for net of factors (IoT) devices. That is specifically important for gadget this is placed in far off or difficult-to- reach areas where maintenance is difficult.

Quicker processing speeds also make sure that IoT structures can reply quickly to changing conditions and offer correct and timely records for selection-making tactics. For effective control and response in programs along with environmental monitoring wherein the MED-MEC structure is especially helpful actual-time records is therefore vital. The paper also highlights the broader methods wherein VLSI generation can enhance WSN IoT capabilities. Adding state-of-the-art algorithms like MED-MEC to VLSI- based architectures can greatly improve processing overall performance and energy performance. Further to enhancing the overall performance of person IoT gadgets this technique will increase the general scalability and resilience of IoT structures.

With the growing marketplace for smart and connected gadgets the technologies mentioned in this observe will play a critical function in shaping the future of wireless sensor networks (WSN) and the internet of factors. In summary the introduction of the VLSI- primarily based MED-MEC architecture has appreciably advanced the development of excessive- performance and energy-green internet of factors networks. Primarily based on empirical research architectures that optimize energy intake and velocity and accuracy of statistics processing may be created via using VLSI generation. Due to its scalability and flexibility the MED-MEC architecture can adapt to a huge variety of desires within the quickly changing IoT landscape contributing to its versatility. For a huge variety of IoT applications it is the precise answer. Because the internet of factors expands the standards blanketed in this observe will useful resource within the development of greater sturdy green and honest IoT systems.

Conclusion

This paintings demonstrates the way to integrate VLSI-based MED-MEC structure in net of things wi-fi sensor networks (WSN) with great gains in processing speed accuracy and performance. Compared to conventional CMOS-based systems the MED-MEC design significantly reduces power consumption by about 40% thanks to the use of specialized hardware and enhanced power management. This reduction is particularly important in low-power or remote scenarios to extend the life of IoT devices. MED-MEC architectures multiprocessing capabilities based on FPGA allow it to process data 66 percent faster than general-purpose processors such as the Intel Core i7. Intelligent surveillance and environmental monitoring are two applications that require real-time data management and high frame rates so this development is crucial. Additionally the advanced edge detection and motion estimation algorithms of the MED-MEC architectures allow for a 10% improvement in motion detection accuracy when compared to conventional methods. The MED-MEC architecture is a flexible solution for a broad range of Internet of Things applications due to its scalable and modular design that supports a variety of WSN configurations. Our results show how VLSI technology can significantly expand the reach of Internet of Things networks and pave the way for the development of more dependable high-performing and efficient smart devices. As the Internet of Things grows the ideas covered in this study will play a significant role in determining how connected technologies are developed in the future.

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