Target Recognition Approach for Efficient Sensing in Wireless Multimedia Sensor Networks

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Abstract In Wireless Multimedia Sensor Networks (WMSN), image-based sensing applications face the issue of energy efficiency and the availability of resources. This issue leads to image sensing and transmission severely exhausting the sensor energy, potentially flooding the network with unnecessary data at the application level. Compression of the image fails to solve this issue efficiently, due to the complexities of the algorithm. Thus, the approach of employing image sensing to detect an event of interest locally prior to transmission of the Region of Interest (ROI) would avoid useless data transmission, and consequently save energy. This approach promises to extend the life of the entire network while reducing the sensing time. The main contribution of this work is to establish a low-complexity scheme for image sensing in WMSN. This scheme based on 2D General Fourier shape descriptors for target recognition and notification to the end user. This current paper outlines the specification of the proposed scheme and its implementation on wireless multimedia sensors. It addresses the performances evaluation regarding time and energy consumption. The results reveal the high levels of accuracy of the proposed approach in efficiently recognizing the target and notifying the end user. It shows a significant performance that overcomes the efficiency of alternative similar sensing approaches that have been proposed in the literature.

1 INTRODUCTION

Wireless Sensor Networks (WSNs) have a number of limitations related to processing, storage, and communication capabilities, which severely restrict their adequacy for multimedia sensing and communication. In the majority of the new applications of IoT and advanced communication systems, the low cost of WSNs leads to them being viewed as an attractive technology. The deployment of WMSN is very attractive in the context of remote image-based target recognition and tracking applications. However, issues of power consumption are of fundamental concern in these systems, leading to questions concerning their efficiency and raising the need to design new low-power approaches to deliver multimedia content with a certain level of quality of service to the end user.

The literature has confirmed that, due to the complexities of these algorithms, image compression techniques employed in WMSN form inefficient approaches for low-power sensing (Chefi A, 2014). One attractive method of minimizing power consumption and extending the lifetime of a network is to apply a local event-based sensing and detection scheme. One way to accomplish this method is the use of an ROI descriptors, firstly, to detect, locally, whether the image captures phenomena of interest and secondly, to send the minimum required data to the end user. This approach reduces the transmitted data to the sink node. Consequently, it preserves the energy of the source sensor, along with that of the complete network. This method is based on notifying the end user solely when an interesting phenomenon has been detected in the observation scenes. It requires the detection of the presence of a new object, recognizing the target and notifying the end user with the minimum number of bytes to increase the network lifetime. This requires the design of a low-complexity approach for image-based target recognition, in order to implement it in an efficient manner in the context of WMSN. A potential candidate, for this objective, is the application of shape descriptors (i.e., General Fourier descriptors) for their low levels of complexity and accuracy in the recognition process (Yang et al., 2008)

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The main contribution of this paper is to present a promising new multimedia sensing-scheme, based on the concept of event detection, employing 2D General Fourier Descriptors as the feature's extraction method. The novelty of this scheme is its ability to reduce communication overheads and per-node power consumption, while also ensuring efficient notification to the end user. Furthermore, it addresses the performance of this scheme in relation to efficient detection and low-energy processing. This paper presents comparisons with related solutions and demonstrates the power of the proposed concept.

2 RELATED WORK

There are a number of contributions to the literature addressing the design of efficient image-based techniques for object recognition. However, these primarily addressed computer-based applications, and, as a result of design limitations, cannot be adapted directly in sensors. Yang et al. (2008) classified a number of approaches to the extraction and representation of shape-based features according to their processing methods. They presented a number of different functions, i.e., a one-dimensional function for shape representation; polygonal approximation; a spatial interrelation feature; moments; scale-space approaches; and shape transform domains. This survey concluded GFD techniques to be highly efficient and accurate for object recognition.

Further research has attested to the efficiency of employing GFD for feature extraction and enhancing accuracy (Teague, 1980; AlSabhan, 2016). Zhang (2002) considered GFD an effective detection method. However, he did not focus on object detection and recognition in the context of WMSN. Belongie et al. (2002), however, presented a simple and accurate scheme for object matching in the context of WMSN, based on the distance between shapes, while Vasuhi et al. (2012) employed the Haar wavelet for object feature extraction. However, both works failed to address the issue of power consumption. Zuo et al. (2012) outlined a distributed two-hop clustered image transmitting scheme, consisting of a trade-off between computation and processing load, reflected in enhancing the lifetime of the network. Irgan (2014) employed hardware platforms for power conservation (which have a high level of estimated implementation costs) and made no consideration of a scalable solution. Nikolakopoulos et al. (2013) outlined a new scheme based on quadtree decomposition for image compression, suggesting it as an efficient solution for a low-power solution in WMSN. Wang et al. (2008) outlined an artificial immune system-based image pattern recognition. This, however, contains very high levels of associated energy consumption, rendering it unsuitable for low-power processing.

3 IMAGE-BASED SENSING SCHEME FOR TARGET RECOGNITION

In the proposed approach, the sensor should be capable of locally detecting the appearance of a new object within the camera scene. It needs to decide locally if the detected object is with interest to the end user, followed by notifying the end user with a few-bytes. The proposed concept is intended to avoid transmitting multiple-images with the potential to exhaust the local battery and load the network with an unnecessarily high volume of data as a result of the characteristics of multimedia applications.

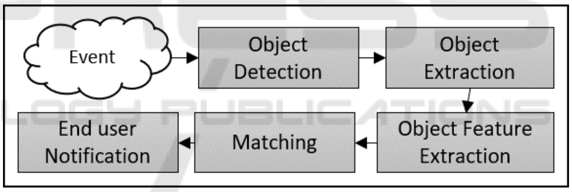

Figure 1: Structure of the image-based sensing scheme based on GFD.

In order to achieve an efficient sensing scheme, the design of the new approach focuses on addressing the limitations of low-cost sensors, by ensuring: (1) low computational complexity; (2) a low level of required memory storage; and (3) an avoidance of congesting the network bandwidth by limiting the per-node communication overhead. These goals are accomplished by allowing the end-user to remotely configure the smart multimedia sensors by means of target shape descriptors. Each sensor, subsequently, begins to sense the surrounding environment in a periodic manner. Once an event is detected, the sensor commences the object detection and extraction process internally from the captured scene and applies feature extraction methods to obtain a set of features vectors to match with a previously memory loaded set. A notification is submitted to the end user when the matching indicates significant similarities. Otherwise, the sensed event is discarded, and the sensor recommences the search for an event. The structure of the proposed scheme for object detection and recognition is described by the sequential steps described in Figure1.

The proposed approach is a new scalable multimedia sensing scheme capable of satisfying the constraints of the limited energy and resources in WMSN. In this approach, each multimedia sensor node performs the sensing scheme for target detection and recognition in an autonomous manner. It decides whether the object appearing in the camera scene is of interest to the end user, based on local recognition-processing tasks. The basic assumption of this approach is the reduction of node communication activities through the radio link while increasing local processing activities. Thus, the capacity of this scheme to extend the per-node lifetime depends on the complexity of the different tasks involved during the processing cycle of the detected object. The structure of proposed scheme consists of the sequential steps as outlined below.

3.1 Detection of New Object

The detection of a new object is based on the approach of background subtraction. It divides the image into a set of blocks of eight by eight pixels. The difference between the new image and the background image is calculated at the pixel level intensity changes, in order to detect a new object. If the foreground block is noted by $\beta_n(j)$ and background $\beta_{n-1}(j)$ respectively, then when the whole difference through all the image blocks is greater than a certain threshold (T_{ther}), a new object should be detected, as expressed in (1) (Lu, 2012).

$$\sum_{j=1}^{k} |\beta_n(j) - \beta_{n-1}(j)| > T_{ther} \tag{1}$$

3.2 Extraction of the Region of Interest

The set of blocks representing the ROI of useful information in the image will be isolated to reduce the processing load. Once the object is detected, the scheme will extract set of blocks that form the useful area and isolate it from unnecessary blocks. These blocks will subsequently be transformed to binary level for further processing to identify the shape (see Figure 2). This step reduces both the memory occupancy and energy consumption related to pixel processing.

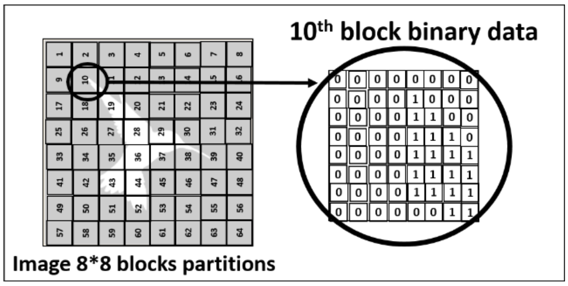

Figure 2: Binarizing useful extracted blocks.

3.3 Extraction of Feature's Vectors

Our presented approach for extracting a set of signature features vector is based on General Fourier Descriptor (GFD). It is one of shape classification and description approach, employed in a large number of application fields based on image processing, due to: (1) ease of computation; (2) low complexity; (3) robustness to noise; and (4) compactness. From a mathematical perspective, a comparison with Zernike Moments (ZM) (i.e., a well-known technique for describing shapes (Zhang et al., 2002)) reveals that GFD has no redundant features because there is no repetition and it permits examination of features in both radial and angular directions. These are also compared in the implementation section below from the perspective of in-node power consumption.

GFD is primarily deployed to transform the shape signature using Fourier transformation based on signature region. Firstly, GFD transforms the input image *f(xi,yi)* of size N*M where f defined by $\{f(x_i,y_i): 1 \le i \le M, 1 \le j \le N\}$ into a polar image $f(r,\theta)$ using the following equations:

$$r = \sqrt{(x-\acute{x})^2 + (y-\acute{y})^2} \tag{2}$$

$$\theta = tan^{-1}\left[\frac{y-\acute{y}}{x-\acute{x}}\right] \tag{3}$$

where $\acute{x}$ and $\acute{y}$ are the mass center of the shape. They are calculated by the following equations:

$$\acute{x} = \frac{1}{M}\sum_{i=0}^{M-1} x_i \tag{4}$$

$$\acute{y} = \frac{1}{N}\sum_{i=0}^{N-1} y_i \tag{5}$$

Secondly, the Fourier transformation takes place in order to extract the signature feature vector set, referred to as Fourier Descriptors (FD), using the following equation:

$$FD(\rho,\varphi) = \sum_{r=0}^{R}\sum_{\theta_i=0}^{T} f(r,\theta_i)e^{j2\pi\left(\frac{r}{R}\rho+\frac{2\pi i}{T}\varphi\right)} \tag{6}$$

Where ρ and φ reflect the image size, $\theta_i = \frac{i2\pi}{T}, 0 \le \varphi < T$ and R *is radial resolution and* T *is angular resolution*

The FD is translation invariant. However, in order to achieve the rotation and scaling invariant, a normalization step should be applied to the extracted feature vector set, as in the following equation:

$$GFD = \left\{\frac{|FD(0,0)|}{area}, \frac{|FD(0,1)|}{|FD(0,0)|}, \dots, \frac{|FD(0,n)|}{|FD(0,0)|}, \dots, \frac{|FD(m,n)|}{|FD(0,0)|}\right\} \tag{7}$$

where m is the maximum number of radius frequencies, and n is the maximum number of angular frequencies. To establish an efficient signature description, Zhang et al. (2002) recommended thirty-six GFD features, reflecting four radial frequencies and nine angular frequencies. The most important step is that of the extracted shape vectors, which play a significant role in the overall performance of the identification scheme. An examination of the image based object identification approach reveals a need to focus on how they address the important challenges of WMSN, the most significant of which are as follows:

3.3.1 Low Sensing Power Consumption

The processor consumes a considerable proportion of power from the overall sensor resident battery. In computational theory, there is a proportional relationship between the total number of processor clock cycles and the arithmetic and logic operations undertaken in a microprocessor. This is also true of the amount of power consumed.

3.3.2 Preserve Memory Capacity

Sensor nodes are equipped with a low memory capacity, to ensure the memory size is not exhausted by the extraction of the signature information. The memory in the current scheme is preserved through the set extracted signatures features being expressed in a limited size (i.e., one feature vector requires eight bytes, ensuring that thirty-six feature vectors are required for 288 bytes).

3.3.3 Communication Overhead

The limited size of the extracted feature vector set promises few communication overheads, while also minimizing traffic over the bandwidth in comparison to sending whole image bytes or employing the compression method. An efficient sensing scheme for object identification in WMSN is essential for the consideration of limitations and challenges. There are a large number of effective shape descriptor approaches employed in the image processing field for object identification and classification, a minor set is also present (due to the constraints of the sensor node's design) capable of being adapted in WMSN. These constraints are divided into two factors: (1) low process capability and (2) limited memory capacity. Further approaches can be adapted for use in the context of WMSN, but these require definite modifications in node design, which raise the cost of implementation, resulting in imperfect scalability.

3.4 Target identification

The Mean Square Errors (MSE) was employed to identify whether the isolated signature forms a promising target, in order to estimate the similarity between the remotely loaded reference descriptors within the local memory.

$$MSE = \frac{1}{n}\sum_{I=1}^{n}(x_i - \bar{x}_i)^2 \tag{8}$$

Where n represents the total vector set, x_i denotes the i^th^ feature vector of the extracted signature and $\bar{x}_i$ denotes the i^th^ feature vector of the reference. The features vector set obtained from the previous step was employed to establish the similarity with the remotely loaded reference features vector set. If the difference is less than certain threshold $T_{Difference}$, the detected object is declared as the target, and the sensor notifies the user. Otherwise, the detected object does not represent useful information to the end user, and the image is therefore ignored.

3.5 End User Notification

Finally, when the sensor identifies the target, it notifies the end user. Notification is undertaken according to the requirements of remote user applications. Thus, this step represents the potential for achieving a considerable saving in time and power-consumption by sending a single byte message, a set of feature vectors or useful extracted blocks from the image. On-demand notification requests by the end user relieve the bandwidth from congestion by minimizing both the volume of transmitted data and the need for retransmitting in case of error. The approach leads to unheavy traffic load, thus prolonging the life of the entire network.

4 IMPLEMENTATION AND PERFORMANCES ANALYSIS

4.1 Target Recognition Capabilities

The scheme based on the GFD algorithm using Matlab was implemented to establish the efficiency of the selected shape descriptor and demonstrate that it satisfies the requirements of accurate recognition. A set of images (AlSabhan, 2016) was employed to evaluate the capability of the scheme in target recognition to recognize an object under different invariance conditions, i.e., rotation, scale, and translation. The images employed were those in the experiment of 64*64 and 128*128 grayscale eight bpp. Figure 3 demonstrates the test image set, which was composed of twelve images.

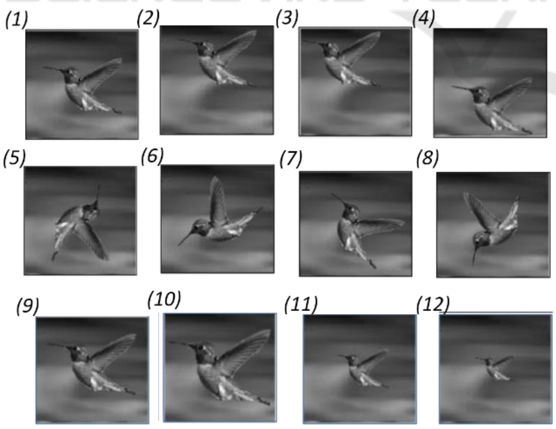

Figure 3: Testing images set: (1) original reference; (2) Translated object to up; (3) to corner; (4) to down; (5) Rotated object by 30°; (6) by 55°; (7) by 65°; (8) by 90°; (9) maximize object by 55%; (10) maximize by 65%; (11) minimize by 25%; and (12) minimize by 35%.

Based on the recommendations of Zhang et al. (2002), the GFD radiance frequencies were set in equation (6) to three, and angular frequencies to eight, thus giving a total set of twenty-four different features vectors. The features of these objects were employed to calculate the similarity with the reference target-image features vectors, using MSE to identify the target. Figures 4 and 5 illustrate the extracted features for all images in Figure 3 using GFD and ZM (AlSabhan, 2016) techniques, respectively.

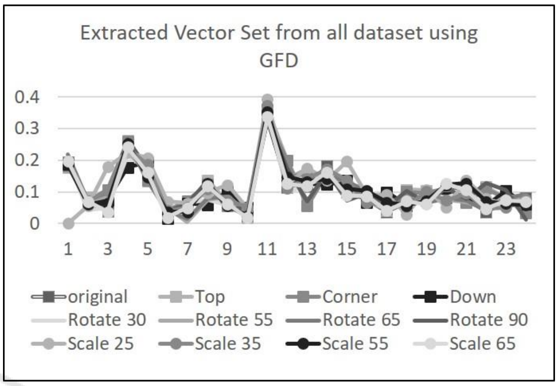

Figure 4: Extracted vector set using GFD.

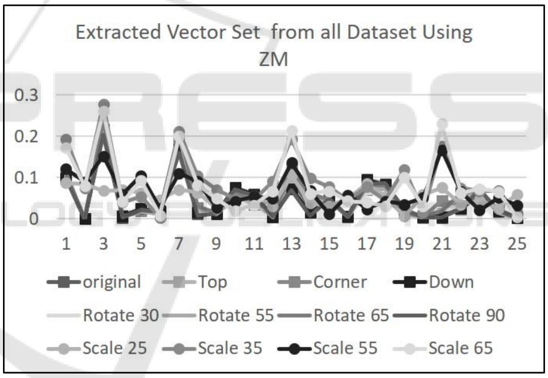

Figure 5: Extracted vector set using ZM.

In figures 4 and 5, curves represent by how much the tested images are close to the reference, by measuring the deviation of the signature features' vectors from the reference features vector set using MSE. These curves can be seen as being almost identical using GFD or ZM, but GFD reveals more accurate results with a neglected difference in comparison to ZM for scaled objects, with a very low difference, i.e., less than 1. This resulted from the nature of the ZM computational algorithm, which is insensitive to rotation only and needs to normalize the object to a predefined scale ratio. However, the use of a pre-processor step to establish the object in normalization form overrides this difference but increases the complexity of the algorithm. ZM needs to consider the re-center of the object and to return it to a predetermined scale size. This pre-processing step is not mandatory in GFD, due to the normalization equation (7) that drives the GFD ability to be invariant to all object translation, scaling and rotation, thus resulting in lower processing complexity and energy consumption than in ZM. Table 1 provides a summary of the capacity of the proposed scheme to recognize the target employing GFD and ZM methods. This reveals a high accuracy in acknowledging that the target with MSE almost equals zero under different positions, including translation, rotation, and scaling. In ZM, the scaled image loses some of its details and ZM is highly sensitive to such differences. A comparison between GFD and ZM results revealed that GFD feature vectors contain less deviation from the reference vector set in comparison to the ZM results, and in particular for scaled images.

Table 1: MSE between features of the target and the new object extracted by GFD and ZM techniques.

	Mean Square Error (MSE)	
Image Number	ZM	GFD
2	0.0001	5.410-06
3	0.0001	3.00E-06
3	0.0002	9.10E-07
4	0.0001	2.50E-07
5	0.00001	6.00E-07
6	0.0002	1.10E-05
7	0.0001	1.80E-06
8	0.0004	1.00E-05
9	0.0007	1.00E-06
10	0.0045	1.40E-07
11	0.0004	1.00E-05
12	0.0048	5.10E-07

These results establish that the proposed scheme provides a robust and accurate method of shape descriptors to recognize a specific target. It also establishes a high capacity for capturing significant features of the sensed object while minimizing the complexity of the algorithm by its invariant characteristics, leading to the potential for lower power consumption.

4.2 Energy Consumption Evaluation

The efficiency of the proposed image-based sensing scheme for low-power target recognition should be evaluated in relation to its capability to save energy in the camera node, consequently extending the lifetime of the network, as well as evaluating the memory occupancy in the node. The proposed scheme generates a set of twenty-four different features vectors, extracted from the image of the detected object. Each of these vectors requires four bytes to be represented in the memory, leading to a total of ninety-six bytes from the memory storage capacity. In comparison to the features extracted with ZM (AlSabhan, 2016), a hundred bytes are required in the memory to store the set of twenty-five features of four bytes. Table 2 summarizes the storage required for both detection and recognition schemes.

Table 2: Memory storage for sensing scheme based on GFD and ZM

Size of	ZM	GFD
Stored program text	10 KB	3 KB
Stored background image (64*64 of 8bpp)	4 KB	4 KB
Captured image (64*64 of 8bpp)	4 KB	4 KB
Stored 24 reference descriptors (float-number)	100 bytes	96 bytes
Region of interest in binary	512 bytes	512 bytes
Extracted ROI descriptors	100 bytes	96 bytes
Total Approx.	19 KB	12 KB

This scheme can save up to 7KB of memory storage, while (due to the equation complexity of ZM) additional processing space is required in comparison to GFD. Recent memory designs have ensured that this algorithm can accomplish a reasonable low level of storage. The performance of the proposed scheme was estimated for implementation in wireless sensors (MICA2 sensors) in terms of energy and time. The focus was primarily placed on the evaluation of the processing related performances of the scheme using GFD. The AVRORA simulator for the ATmega128L microcontroller (MICA2) was employed to implement the algorithm. This tool determined the number of clock cycles for the Atmel series for the different tasks (J. Palsberg et al., n.d.). The power consumption and processing time were subsequently estimated using the characteristics of microcontrollers for MICA2. Grey-scale images of (128*128 pixels- 8bpp) and (64*64 pixels- 8bpp) were employed to extract the feature’s vector of the detected object with a size of ninety-six bytes as a total for twenty-four different image feature descriptors.

Tables 3 and 4 illustrate the time and energy consumption of internal processing when implemented in the Camera-equipped MICA2 sensor, using ATmega128L for both sensing schemes. Table 4 demonstrates identical measurements for a similar sensing scheme using ZM in the features extraction (AlSabhan, 2016). This reveals the consumed energy for 64*64 pixels of 8 bpp image is 2.59 mJ, and for 128*128 pixels of 8 bpp is 10.34 mJ, while in the sensing scheme using ZM, the internal processing was 33.5 mJ and 121 mJ, respectively to 64*64 pixels of 8 bpp and 128*128 pixels of 8 bpp image sizes.

Table 3: Evaluation of sensing scheme based on GFD features on MICA2.

	64 ∗ 64 pixels 8 bpp		128∗128 pixels 8 bpp	
	Time (s)	Energy (mJ)	Time (s)	Energy (mJ)
Object Detection and Extraction	0.1	2.25	0.39	9.06
Feature Extraction using GFD	0.015	0.34	0.06	1.37
Total scheme for GFD without Notification	0.12	2.59	0.45	10.43

Table 4: Evaluation of the sensing scheme based on ZM features on MICA2 sensors.

	64 ∗ 64 pixels 8 bpp		128∗128 pixels 8 bpp	
	Time (s)	Energy (mJ)	Time (s)	Energy (mJ)
Object Detection and Extraction	0.47	10	1.9	43
Target Normalization	0.06	1.5	0.26	6
Feature Extraction using ZM	0.98	22	3.18	72
Total scheme for ZM without Notification	1.51	33.5	5.34	121

Thus, the sensing scheme employing GFD features outperforms the scheme based on ZM, i.e., saving approximately 91% additional energy than the scheme using ZM features. This difference in power consumption is explained by the low-complexity of the extraction method of GFD features, which requires less pre-processing of the image.

Table 5 establishes different notification scenarios and their associated energy costs, assuming the use of IEEE 802.15.4 and ZigBee communication standards. The simulation program is developed using NesC language and evaluated on AVRORA, using the TinyOS platform. This table illustrates that the cheapest manner of notification is to send a 1-byte message, with costs increasing if the extracted feature set is sent to the end user (which is helpful in some applications for further classification), but remaining less than sending the whole image or RoI. The notification with the GFD features vector requires the same energy of the transmission of the ZM features. However, the accuracy of the features extracted by the GFD method should be noted, in addition to low energy consumption in the internal processing.

Table 5: End user's notification types using MICA2 sensors.

Notification Type	Time (s)	Energy (mJ)
Notification with 1 byte	0.01	0.3
25 ZM features vectors	1.0	30
24 GFD features vectors	0.96	28.8
ROI transmission	4.40	132
captured image	40.96	1228.8

4.2.1 Comparison with Related Works

In comparison to similar approaches for multimedia sensing, this current scheme presents a number of attractive characteristics in relation to both complexity and power consumption. A summary takes place below of the most relevant reported solutions in the literature and their characteristics in comparison to the current proposal efficient solutions for low-power sensing.

A comparison of the current scheme with compression techniques discussed in the literature establishes that this scheme achieves very low processing complexity and efficient power consumption. Irgan (2014) based the compression algorithm on the priorities of the segment blocks for compression, but consumed around (130 mJ), where that of Nikolakopoulos (2013) consumed approximately (45 mJ) for sending (64*64 of 8 bpp) of image size. The scheme of Zuo (2012) consumed approximately (1.4 J) for sending (512*512 of 8 bpp) of image size. However, the presented distributed processing fits within the context of the current scheme, in order to prolong the network life and it will be addressed as future work. Wang (2008) presented an image recognition pattern algorithm but failed to evaluate the performance analysis of power consumption from local processing. Pham (2013) presented a scheme for extracting ROI based on a hardware solution, which demonstrated high-performance levels in low-

complexity, but proved inflexible and was not considered as scalable.
Alhilal (2015) employed recognition methods based on centroid distance curvature features. However, these failed to prove highly accurate and contained a wide sensitivity to the characteristics of the detected object in the image. Alsabhan (2016) investigated ZM where it outperforms in term of the accuracy of detection and algorithm complexity.
As outlined in Section 4.2, this current design presents a low-complexity scheme and high detection and recognition capability using GFD. It is therefore concluded that the current work outperforms other solutions presented in the literature for image detection and recognition in WMSN, in term of accuracy, efficiency, and scalability.

5 CONCLUSIONS

This paper has presented a new sensing approach based on GFD, as a shape descriptor for target recognition in a monitored environment using WMSN. The presented scheme is intended to prolong the life of a network by minimizing the power consumed by both the internal processor and the transmitter antenna. The paper introduced the simulation results attesting to the robustness, accuracy, and low levels of complexity for target recognition in WMSN. It was concluded that, in comparison to a scheme based on ZM, the current scheme requires less memory space for processing. However, the internal sensor processing saves 91% of energy in comparison to the application of ZM. It is suggested that future work could include an investigation of the communication overheads in the network, which would result in a clearer concept of the efficiency of this solution for deployment in WMSN. Prior to such research, this current scheme will be upgraded to handle multiple target detection for simultaneous monitoring. It is concluded that the concept of distributed processing as an approach to energy saving appears promising. However, the design and the implementation of a generic clustering and processing architecture is still a subject of open research.

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