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Symmetric-Object Oriented Motion Estimation Approach Test over Wireless Multimedia Sensor Networks for Different Motion Modes

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□ ABSTRACT □

Video signals have become an essential part of our everyday life. Major efforts have been done to develop systems and networks to support video applications. However, video processing is a resource-demanding task mainly in motion estimation stage. Therefore, classical motion estimation algorithms do not fit constricted resource systems such as wireless multimedia sensor networks. In this paper, we consider SYMO-ME which is a symmetric-object oriented motion estimation approach in wireless multimedia sensor networks. It reduces the high complexity of motion estimation process by taking into consideration frame objects properties and shapes. It aims to save sensors energy and other resources by exploiting the symmetry property of video frames objects. Based on adaptability criterion, we offer a novel classification of fast block matching algorithms. Three different SYMO-ME based block matching motion estimation algorithms are implemented. We compared and evaluated those algorithms under different motion modes and analyzed the impact of both search range and block size parameters. Performance evaluation of several extensive simulations is done via three basic evaluation metrics reflecting efficiency of motion estimation algorithm, energy cost, and video quality

Keywords: Wireless Multimedia Sensor Networks, Motion Estimation, Object Oriented Approach, Energy Consumption, Block Size, Search Parameter.

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اختبار طريقة تخمين الحركة كائنية التوجه المتناظرة في شبكات الحساسات اللاسلكية الداعمة للوسائط المتعددة من أجل أنماط مختلفة للحركة

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□ ملخّص □

غدت الإشارات الفيديوية جزءاً أساسياً من حياتنا اليومية، وكرست الجهود الحثيثة لتطوير مختلف الأنظمة والشبكات بهدف دعم تطبيقات الفيديو. لكن تعد معالجة المعطيات الفيديوية مهمةً معقدةً وبالغة المتطلبات خاصةً فيما يتعلق بمرحلة تخمين الحركة. حيث أن الخوارزميات التقليدية لتخمين الحركة لا تلائم الأنظمة محدودة الموارد كما هو الحال في شبكات الحساسات اللاسلكية الداعمة للوسائط المتعددة. يركز هذا البحث على الطريقة SYMO وهي طريقة كائنية التوجه لتخمين الحركة بين الإطارات الفيديوية المتعاقبة في شبكات الحساسات اللاسلكية الداعمة للوسائط المتعددة. تخفض SYMO من تعقيد مرحلة تخمين الحركة فهي تأخذ بالحسبان خصائص أشكال الكائنات في الإطارات الفيديوية فتحافظ على طاقة وموارد العقد الحساسة من خلال استغلال خاصية التناظر لتلك الكائنات. واعتماداً على درجة التكيف في أسلوب تخمين الحركة، يعرض البحث تصنيفاً جديداً لخوارزميات تخمين الحركة ويهدف إلى اختبار ثلاث خوارزميات، من أصناف مختلفة، اعتماداً على الطريقة كائنية التوجه. ويشمل تقييم الأداء ثلاثة محددات أساسية تعكس كفاءة خوارزمية تخمين الحركة، واستهلاك الطاقة، وجودة المعطيات الفيديوية وذلك تحت أنماط مختلفة من الحركة إضافة إلى دراسة وتحليل أثر تغيير معاملي تخمين الحركة المتمثلين في مجال البحث وحجم كتلة البكسلات المستخدم.

الكلمات المفتاحية: شبكات الحساسات اللاسلكية الداعمة للوسائط المتعددة، تخمين الحركة، الطريقة كائنية التوجه، الطاقة المستهلكة، حجم كتلة البكسلات، معامل البحث.

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Introduction

Wireless multimedia sensor network (WMSN) is an evolution of traditional scalar wireless sensor network (WSN) in order to enable new promising video supported applications [1-3]. Studies in [4, 5] and many other papers confirmed that motion estimation (ME) is the key of video processing task. It benefits from the high correlation among successive video frames and exploits their temporal domain redundancy. This is done by determining the shift of a particular region in the current frame considering a suitable region in a reference frame. However, motion estimation is the most computationally-expensive and resources greedy operation over the video processing system [5-7].

Motion estimation algorithms, according to [8], can be classified into two basic classes: (1) Pixel-based algorithms, and (2) Block-based algorithms. The first class results in heavy complexity load and huge associate size of data. In fact, this class is not appropriate for critical condition and constricted resource systems like WMSN [9]. Whereas, the second class overcomes that by exploiting the high correlation between each pixel and its neighbors. Block-based algorithms separately deals with non-overlapping blocks of pixels rather than individual pixels in the current frame according to matching process. Consequently, this class is called Block Matching Algorithms (BMAs) [8, 10]. Unfortunately, and according to (Jbeily et al., 2015b; Po and Ma, 1996) BMAs still separately and exhaustingly find the motion vector of every individual block all over the frame from the top-left corner to the bottom-right one [11,12]. Actually, this is still too heavy and many attempts tried to reduce the linked deep complexity. Moreover, additional possible intra frame redundancy (i.e. frame content related redundancy) may be exploited. SYMmetric-Object oriented approach for Motion Estimation (SYMO-ME) which is one of the most recent approaches that exploits this kind of redundancy was proposed in [11].

Research Importance and Objectives

In this research, we consider SYMO-ME which is an important symmetric-object oriented motion estimation approach in wireless multimedia sensor networks. SYMO-ME aims to save sensors energy and other resources by exploiting the symmetry property of video frames objects. However, the [11] paper tested SYMO-ME only for one of motion modes and under one condition of motion estimation parameters. In our research, we expand that limited study to cover not only different modes of motion, but also different conditions of motion estimation parameters. Moreover, we introduce a novel classification of fast block matching algorithms based on adaptability criterion. Basing on this, we evaluate SYMO-ME with three different classes-related BMAs.

1. Background

1.1. Block Matching Motion Estimation

Video coding standards have widely adopted BMAs for motion estimation due to their effectiveness and simplicity for both hardware and software implementation [9, 11]. BMAs exploit two kinds of correlation over video sequences: (1) Correlation between each pixel and its neighbors in each frame. Therefore BMAs deal with the video frame not as pixels but as a group of blocks, and thus they are called block based. (2) Correlation between blocks in successive frames and thus they are called matching based. In BMA both current and reference frames are divided into blocks in a fixed size, as explained in figure 1.

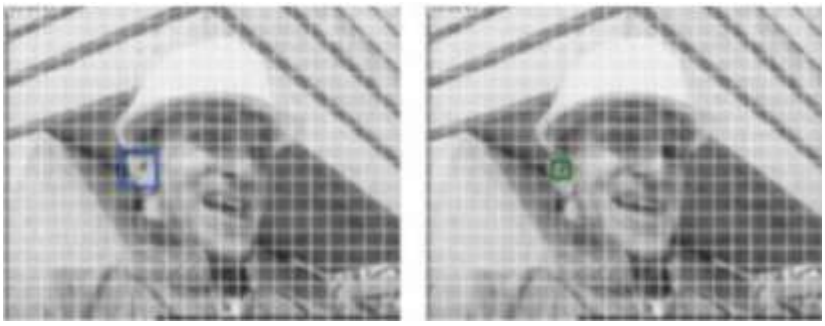

Figure1. Current and reference frames in a block motion estimation process

For each individual block from the top-left corner to the bottom-right one in the current frame, a searching process is conducted for its best matching block among a group of candidate blocks in the reference frame is done. Each candidate block is a Search Point (SP). Search points are positioned in a search region that is called a search window. Because this window is limited by a search parameter (p), the search will be performed within a square region of [- p, +p] around the position of the current block [10], as shown in figure 2.

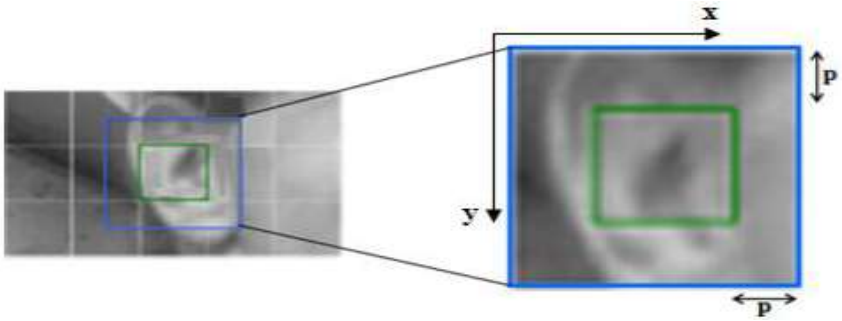

Figure 2. Search window in the reference frame

The position of the best matching block determines the block shift between frames. This shift is represented by a displacement vector which is commonly known by motion vector (MV). We can point out that for any block matching algorithm, two major parameters must be taken into consideration, the block size and the search parameter.

Researches like [8, 13] sorted BMAs into two essential categories: (1) Exhaustive Block Matching Algorithm (EBMA): It is called the full search algorithm due to the fact that it examines all possible search points over the whole search window to choose the best matching one resulting in inappropriate load [9, 14] . (2) Fast Block Matching Algorithms (FBMAs): Unlike EBMA, FBMAs try to reduce the complexity associated with EBMA [8, 10]. Therefore, they examine not all but only some positions through the search window depending on a search pattern.

Nevertheless and as we pointed up, FBMAs still both separately and exhaustingly find the motion vector of every individual block all over the current frame from the top-left corner to the bottom-right one. This results in an unacceptable load which does not fit critical condition applications and constricted resources systems such as WMSNs.

1.2. Symmetric-Object Oriented Approach for Motion Estimation

Video frames extremely reflect what we see around us in everyday life. Most major object related property around us is symmetry [15]. Authors in [11] stood on this fact of symmetry property omnipresence where it is really rare, and even impossible, to find a scene without any symmetry aspect. Therefore, they exploited symmetrical intra frame redundancy where parts of symmetric objects tend to submit symmetric motions. Their proposal SYMO-ME clarified that motion vectors of one of that symmetric parts can be

exploited in motion estimation of the other remaining parts. The study in [11] examined SYMO-ME only for one of motion modes and under one condition of motion estimation parameters. Simulation results confirmed the efficiency of SYMO-ME in reducing the total number of search points for finding the motion vectors over a video frame compared with a group of considered BMAs. This saves the limited resources and improves the WMSN life time. Butterfly image which is the best example of reflectional symmetry was the inspiration source of SYMO-ME,as explained in figure 3.

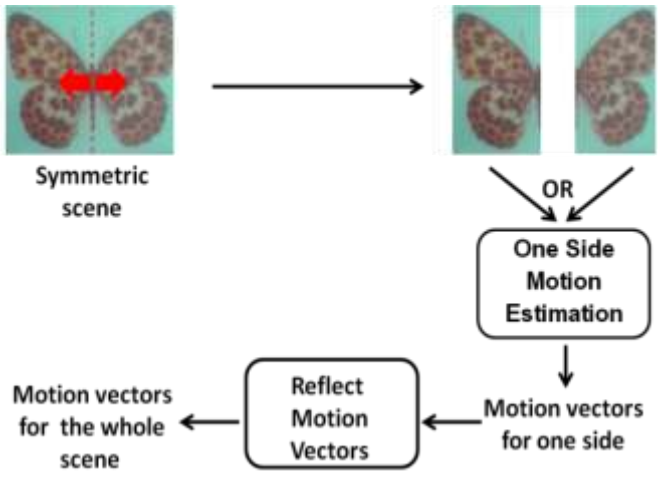

Figure 3. Symmetric-Object Oriented Approach for Motion Estimation

2. Novel classification of Fast Block Matching Searching Algorithms

Fast block matching searching algorithms depend on search patterns to decide the positions of search points for motion estimation process. Actually, many searching prototypes were proposed in the literature [13, 14]. In this paper, as shown in table 1, we provide our novel classification of FBMAs depending on search adaptability degree of the algorithm.

Table 1. Classification of Fast Block Matching Algorithms based on search adaptability degree

FBMA Class	Initial search pattern shape	Initial search pattern size	Searching steps number	Algorithm Example
Full Fixed	Fixed	Fixed	predetermined	Three Step Search, Four Step Search
Semi Fixed	Fixed	Fixed	undetermined	Diamond Search, Hexagonal Search
Full Adaptive	Varied	Varied	undetermined	Adaptive Rood Pattern Search

3. Simulation Results and Analysis

3.1. Simulation Environment and Setup

We used MATLAB 7.12.0 (R2011) to implement our simulation. Two different video sequences with one object depicting reflectional symmetry in each were used. The first is 'Akiyo' whose object motion changes slowly and locally. While the second is 'Sport-exercise' video whose object motion changes quickly and widely. We used group of picture (GoP) equal to 5, and minimum absolute difference (MAD) as a block matching criterion because of its simplicity comparing with the other cost functions [10, 14]. These parameters are suitable for the buffer of video sensors in WMSNs [11, 16]. From the

different three FBMAs classes, we investigated three well known algorithms under SYMO-ME namely Four Step Search (FSS) [12], Diamond Search (DS) [17] and Adaptive Rood Pattern Search (ARPS) [18]. The characters of the analyzed videos are illustrated in table 2, and their stills are in figure 4.

Table 2. Analyzed Videos Characters

Analyzed Video	Frame size	Group of Picture	Number of frames	Motion mode	Symmetry kind
Akiyo	144x176	5	150	Slow, local changes	Reflectional
Sport-Exercise	240x224	5	130	Quick, wide changes	Reflectional

Figure 4 Stills of the analyzed videos

3.2. Performance evaluation metrics

Results evaluation was done based on three metrics: (1) Efficiency of SYMO-BMA, (2) Motion estimation energy cost, and (3) Video quality. Moreover, the effect of the two motion estimation major parameters: block size and search parameter was investigated. Different sizes of blocks were used: 4x4, 8x8, 16x16 with different search parameters: 7, 9, 11 ,13 for each.

3.3. Simulation results

Several extensive simulations were conducted to evaluate the efficiency of the SYMO-BMAs. We present here the results for the performance evaluation metrics of the two analyzed videos.

3.3.1 Efficiency of the SYMO-BMA:

Efficiency is a term of the algorithm speed and complexity [9]. It is measured by the average total number of search points per frame. The efficiency of the SYMO-BMA under different values of block size and search parameter are shown in Table. 3 and Table. 4 for the 'Akiyo' and 'Sport-exercise' video sequences, respectively.

Table. 3 Average total number of search points per frame, 'Akiyo'

Block Size	Search Parameter	SYMO – BMA		
		FSS	DS	ARPS
4x4	7	16760	17429	10925.2
	9	16760	19504	12211.6
	11	16760	21367	13503.9
	13	16760	23077	14785
8x8	7	3796.8	3742.3	2474.6
	9	3796.8	4107.1	2726.4

	11	3796.8	4423.6	3007
	13	3796.8	4727.7	3316.1
16x16	7	972.4	952.1	686.6
	9	972.4	1069.1	785
	11	972.4	1179.7	871.6
	13	972.4	1288.6	949.9

Table. 4 Average total number of search points per frame, 'Sport-exercise'

Block Size	Search Parameter	SYMO – BMA		
		FSS	DS	ARPS
4x4	7	41463	48486	25793
	9	41463	58006	29289
	11	41463	66935	32750
	13	41463	75603	35923
8x8	7	10141	11788	6719.7
	9	10141	14167	7649.7
	11	10141	16400	8569.0
	13	10141	18623	9753.9
16x16	7	2399.3	2797.1	1670.9
	9	2399.3	3407.3	2043.4
	11	2399.3	4012.1	2406.5
	13	2399.3	4620.3	2777.3

The results show that by increasing the block size, the average total number of search points per frame will decrease significantly for all examined SYMO-BMAs. In fact, this seems logical where each examined block is a search point. For example, when p=7, increase the block size from 4x4 to 8x8 to 16x16, results in corresponding decrease the average total numbers of search points per frame for SYMO-DS by 78.5%, and 74.5% in 'Akiyo' and by 75.6%, and 76.2% in 'Sport-exercise', while for SYMO-ARPS the decreasing is by 77.3%, and 72.25% in 'Akiyo', and by 73.9% and 75.1% in 'Sport-exercise'.

For a fixed block size, the average total numbers of search points per frame for SYMO-DS and SYMO-ARPS increase by increasing the search parameter. This results from the increase in the corresponding search window and from the adaptability property of these algorithms. However, SYMO-FSS related values are independent of search parameter because of the strict full fixed search pattern with limited unvarying search steps of the origin FSS algorithms.

Among the examined SYMO-BMAs, SYMO-ARPS provides the best efficiency in terms of the least average total number of search points per frame for the two kinds of motion.

3.3.2 Motion Estimation Energy Cost:

Energy is the most important and critical resource in WMSNs [6,19]. Study in [14] considered the number of search points to directly represent the energy cost. While authors in [5, 10] relied on the execution time of the motion estimation algorithm in addition. However, from our point of view these considerations may give an identifier to the consumed energy but they are not enough and we cannot depend only on them to judge the power consumption. Therefore, we evaluated the motion estimation energy consumption depending on the energy model which was proposed in [11]. This model depends exactly on the energy consumption values of different executed instructions during motion estimation process on one of the most popular sensors named Mica2 sensor node [20]. The energy cost of the considered SYMO-BMAs, measured by milli Joule -mJ, are offered in

table 5 and table 6 for the two analyzed video sequences and different values of block size and search parameter.

Table. 5 Average energy consumption measured by mJs, 'Akiyo'

Block Size	Search Parameter	SYMO – BMA		
		FSS	DS	ARPS
4x4	7	4.424	4.601	2.884
	9	4.424	5.148	3.223
	11	4.424	5.640	3.565
	13	4.424	6.092	3.903
8x8	7	4.0094	3.9519	2.6132
	9	4.0094	4.3372	2.8791
	11	4.0094	4.6714	3.1759
	13	4.0094	4.9925	3.5018
16x16	7	4.1076	4.0217	2.9006
	9	4.1076	4.5159	3.3160
	11	4.1076	4.9830	3.6818
	13	4.1076	5.4432	4.0125

Table. 6 Average energy consumption measured by mJs, 'Sport-exercise'

Block Size	Search Parameter	SYMO – BMA		
		FSS	DS	ARPS
4x4	7	10.946	12.800	6.809
	9	10.946	15.314	7.7323
	11	10.946	17.671	8.6460
	13	10.946	19.959	9.4837
8x8	7	10.709	12.4476	7.0960
	9	10.709	14.961	8.0781
	11	10.709	17.319	9.0488
	13	10.709	19.666	10.300
16x16	7	10.134	11.815	7.1577
	9	10.134	14.393	8.6312
	11	10.134	16.947	10.165
	13	10.134	19.516	11.731

The results confirm that the energy cost is extremely related not only to the number of search points but also to block size parameter, nature of the searching algorithm, and the motion mode in the examined video. Where, for 'Akiyo', the video with slow local narrow range motion, power consumption decreased by limited increasing of block size from 4x4 to 8x8. However, the negative effect of block size increasing to 16x16 appears by increasing the power consumption in spite of decreasing the related search points. On the other hand, for 'Sport-exercise', the video with fast wide range motion that bad effect does not appear and the power consumption decreases by increasing the block size for both SYMO-FSS and SYMO-DS which are full fixed and semi fixed FBMAs respectively. While, for the full adaptive FBMA, SYMO-ARPS, energy cost increases by increase the block size. Nevertheless, SYMO-ARPS still provides the least energy cost comparing with the other algorithms' corresponding values.

Again for a permanent block size, the energy consumption of both SYMO-DS and SYMO-ARPS increases by increasing the search parameter. But, SYMO-FSS related values don't change.

3.3.3 Video Quality:

Tables 7 and 8 show the video quality of the studied SYMO-BMAs for the two analyzed video sequences. The quality is represented by average peak signal to noise ratio per frame parameter and measured by dB.

Table. 7 Average Peak Signal to Noise Ratio measured by Decibel, 'Akiyo'

Block Size	Search Parameter	SYMO – BMA		
		FSS	DS	ARPS
4x4	7	33.3622	33.3259	33.6984
	9	33.3622	33.0660	33.4584
	11	33.3622	32.8646	33.1980
	13	33.3622	32.6914	32.9865
8x8	7	33.3289	33.2352	33.5881
	9	33.3289	32.9564	33.4027
	11	33.3289	32.7394	33.2245
	13	33.3289	32.5626	33.0359
16x16	7	31.9110	31.8937	32.0786
	9	31.9110	31.5448	31.9018
	11	31.9110	31.2987	31.6825
	13	31.9110	31.1293	31.4231

Table. 8 Average Peak Signal to Noise Ratio measured by Decibel, 'Sport-exercise'

Block Size	Search Parameter	SYMO – BMA		
		FSS	DS	ARPS
4x4	7	33.5486	32.9550	33.1045
	9	33.5486	33.1678	33.3670
	11	33.5486	33.4350	33.5338
	13	33.5486	33.7048	33.8624
8x8	7	32.2521	32.0811	31.6927
	9	32.2521	32.1677	31.8558
	11	32.2521	32.2479	32.2531
	13	32.2521	32.3475	32.6928
16x16	7	31.5366	31.1562	30.7359
	9	31.5366	31.2775	30.9180
	11	31.5366	31.4338	31.3270
	13	31.5366	31.5816	31.5475

Increasing the block size causes an increase in the discard of motion details. This leads to decrease in the average peak signal to noise ratio as shown in the results. Actually, the decrease is small. This is because the details of the scene in the examined frames of the both analyzed videos are very limited.

For 'Akiyo' video whose motion is local and small, SYMO-FSS algorithm which is belonged to full fixed BMA class is not affected by increasing the search parameter for a fixed block size. While for both SYMO-DS and SYMO-ARPS, which are belonged to semi-fixed and full-adaptive BMA classes respectively, the average peak signal to noise ratio suffers a very small degradation. However, for 'Sport-exercise' video whose motion is wide and large, the average peak signal to noise ratio for both SYMO-DS and SYMO-ARPS increases by increasing the search parameter. This is due to increase the search area which enables tracking the wide range motion and raise the possibility of finding the fittest matching motion vector.

4. Conclusion and Recommendation

In this paper and according to a novel proposed classification of fast block matching algorithms, three different classes-related algorithms namely FSS, DS, and ARPS are implemented under symmetric-object oriented motion estimation approach, SYMO-ME. We have examined this approach on two different modes of motions. SYMO-ARPS supplied the most suitable performance for WMSNs in terms of complexity and power consumption without a noticeable degradation of video quality. We have also investigated the influence of both block size and search parameter. The results proved the importance of the convenient selection of those two major parameters in order to save resources and

quality. As a future work, we recommend to investigate the efficiency of implementing variable size block matching under SYMO-ME for WMSN.

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