J Supercomput (2013) 64:883–897
DOI 10.1007/s11227-010-0500-5

# Communication-resource-aware adaptive watermarking for multimedia authentication in wireless multimedia sensor networks

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Published online: 13 November 2010


**Abstract** Efficient multimedia and specifically image authentication is critical and in demand to protect data vulnerability in wireless multimedia sensor networks (WMSN). This is to prevent malicious intruders from modifying and forging image contents over a network. Watermarking technique has been widely used to assert an image data authentication over wired networks; however, resource constraints (e.g. processing power, communication energy) in small sensors and the state of error-prone wireless channels result in fundamental challenges for developing efficient watermarking schemes in WMSN. These challenges include how to embed/protect/extract watermark efficiently and robustly in low-cost sensors and how to transmit authenticated image and multimedia with high energy efficiency. In this paper, we propose a communication-resource-aware and adaptive watermarking scheme for multimedia authentication in WMSN. Our contribution is two folds. First, the transmission quality for the watermark as well as watermarked multimedia authenticity by embedding watermark with adaptive coding redundancies, and by unequally allocating network resources to protect the image and multimedia packets with the watermark information. Second, communication energy efficiency and real time performance are achieved with the watermark being adaptive to the network condition and the processing delay reduced due to the exploited inter-frame correlation. The simulation and experimental results demonstrate that the proposed adaptive watermarking system can achieve considerable gains in terms of energy saving, image transmission quality and multimedia authentication performance.

**Keywords** Watermarking · Authentication · Wireless multimedia sensor network

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## 1 Introduction

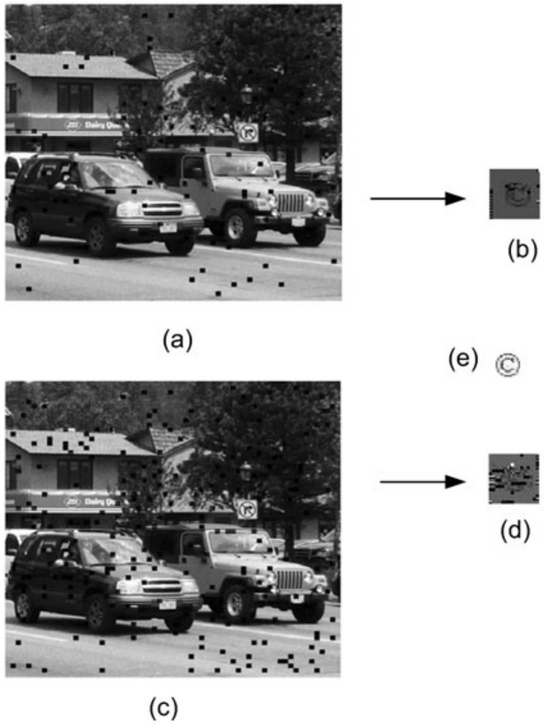
A growing number of sensor applications such as video surveillance and security facility monitoring require low-cost small-scale CMOS imaging sensors to capture image content from the field. However, image sensors generate a large size of data loads, resulting in the difficulty for both image processing and transmission especially considering the resource constraints in wireless sensors. The application of wireless multimedia sensor networks (WMSN) in monitoring critical areas such as battlefields and security facilities necessitates an authenticable secure multimedia transmission mechanism in WMSN. Unlike in the wired networks, malicious intruders have a high probability to access and modify multimedia data delivered over wireless networks. Among the existing approaches, watermarking is an effective multimedia authentication technique that has been widely used in many secure applications. It embeds identification data termed as watermark into a multimedia object such that the multimedia can be authenticated based on the extracted watermark. The robustness and imperceptibility are two main goals for the watermarking system. Previous studies in digital watermarking approaches [1–5] have been targeted toward these two goals. Among them, the watermarking schemes based in a transformed domain such as DCT and DWT [5–8] are robust against manipulation such as compression because the watermark is actually spread throughout the multimedia, not just operating on an individual pixel. However, these traditional watermarking systems only target at minimizing watermarked multimedia distortion to make watermark invisible and increasing robustness at the source coding site to resist lossy multimedia processing. The watermarked multimedia distortion caused by error-prone wireless environments during transmission has not been fully considered. The error prone wireless environments could significantly degrade the watermark system performance. When the watermarked multimedia are transmitted over wireless sensor networks, the degraded multimedia due to possible packet loss caused by channel error in wireless environments could make watermark undetectable at the trusted receiver site.

As shown in Fig. 1, the watermarked image distortion degrades the extracted watermark quality significantly. In this experiment the images in Figs. 1(a) and 1(b) are received image under the packet loss ratio 0.005 and 0.01 separately. Figures 1(c) and 1(d) are extracted watermark from these two received watermark images individually. The original embedded watermark is shown in Fig. 1(e). Compared with the original embedded watermark, the extracted watermark from Fig. 1(c) is almost not recognizable due to high watermarked image distortion. This suggests that improving watermarked image quality does not only ensure the image quality itself, but also can increase the authentication performance due to its high quality. It is critical to let both watermark and watermarked image tolerate error-prone transmission environments.

Therefore, a high-quality and efficient watermarking system in WMSN has to be robust against transmissions, and both the watermark and the watermarked multimedia have to be ensured of their quality for authentication with the resource efficiency.

In terms of the authentication study in wireless networks, the traditional binary data authentication schemes can only provide data integrity in a strict sense when the image content are not differentiated with other types of data. The simple bit-flips due to wireless channel error may fail the authentication of the trusted multimedia content [18, 20]. However, the digital image is a type of unique multimedia, and packet

**Fig. 1** Image distortion impact on the watermark quality




losses are usual scenarios in wireless environment. It is important that the trusted image still can be authenticated even some image packets are lost due to channel error. Thus, there is a strong need to develop an efficient authentication system to ensure image integrity that can resist error prone wireless channels. Some research works [8–12, 20] have been conducted in stream level authentication for image data. In [18], the researchers proposed a multimedia stream authentication scheme that maximizes the authentication performance by allocating network resource unequally on different multimedia/image packets. In [8], the unequal authentication allocation (UAA) scheme is proposed to unequally allocate source/channel coding rates and authentication bits in the compressed multimedia streams. Research in [20] studied a content aware stream authentication scheme to optimize authenticated media quality for JPEG2000 image streaming in lossy channels. All these approaches require the hash chain based authentication for each packet at the stream level with significant overheads. It is hard to implement them in the resource-limited wireless sensor networks. Also, simple content-aware authentication regardless of the channel-level information may significantly degrade the whole system performance and make it hard to provide image integrity. In this paper, we propose a resource efficient watermark based authentication system in the cross-layer manner in WMSN. In this system, the watermark system can joint designing image authentication with resource allocation, and energy efficiency optimization in WMSN. Both watermark and watermarked image are protected by carefully allocating network resource and selecting appropriate watermark embedding positions. The image content and traffic characteristics and transmission strategies are jointly through a cross layer approach. Specifically in the proposed scheme, adaptive watermarking positions are dynamically chosen to embed watermark according to network conditions so that both the energy efficiency and security can be achieved. In our previous study [23], we have studied the fundamental relationship between the resource and watermark security protection. In this paper, a watermark based authentication aware network resource management scheme is proposed with consideration of both inborn decoding and resource efficiency. The watermark and watermarked image distortion are significantly reduced without incurring too much energy consumption overheads. In addition, with respect to selective watermark position's neighbor information in wavelet domain and its children's wavelet coefficients, the system could achieve more robustness and invisibility. Our simulation results demonstrate that the adaptive watermarking system can achieve both authentication performance (watermarking quality) and energy efficiency in WMSN. The rest of this paper is organized as follows. In Sect. 2, we describe the framework of adaptive watermark schemes that behave in cross-layer manner with communication resource efficiency in WMSN. In Sect. 3, we formulate the optimization problem of energy constrained quality-driven multimedia authentication with the modeling of the watermark and watermarked multimedia distortion as well as network resource management in a cross layer fashion. The cross layer optimization is analyzed and the effective solution is proposed. We also discuss the practical related channel monitoring and real time performance issues. The simulation results are shown in Sect. 4, and the conclusion is drawn in Sect. 5.

## 2 Wavelet based resource-aware adaptive watermarking algorithm

Early spatial domain based watermarking system is not robust enough against lossy image compression and other manipulations and can only accommodate few bits watermarking. Thus the frequency-based watermark method has been proposed and achieved higher capacity and robustness. Among them, several methods using DWT [5–7] to hide watermark in frequency domain have provided extra robustness against a variety of attacks. The embedding algorithm using qualified significant wavelet tree (QSWT) proposed by Ming-Shing [1] takes the advantage of the wavelet transform. It uses DWT to separate the frequency bands of the multimedia and then embeds the logo into the frame's middle frequency band. This is because the low frequency band contains most energy of the image frame after applying the wavelet transform. The high frequency band contains noise information and the information here often gets lost during the compression. However, Ming-Shing's algorithm is not easy to determine the appropriate thresholds for embedding watermark and cannot be directly used for WMSN image authenticated transmission due to its lack of robustness against the packet loss. The error-prone transmissions in WMSN may still degrade the quality of the watermarked image significantly. Without overcoming this type of transmission distortion, the watermark may become undetectable even when the image is received at the trusted receiver. In our proposed scheme, several adaptive threshold values are chosen to embed watermarks according to the network condition with the consideration of energy efficiency. The logo watermarks are embedded in the host multimedia by pursing the optimized values in the selective location of LH3/HL3 coefficients.

Further, the invisibility of watermarking requires maximizing the distortion reduction of decoded watermarked image frame $\{Q_d\}$. Embedding the watermark into as few number of QSWT trees as possible is one solution. Also, in the transmission process, the objective is to maximize the watermark distortion reduction $\{Q_w\}$ and ensure the authentication success. In order to stand against the distortion due to the packet loss in error-prone wireless environment, we need to embed the watermarks with high degree of redundancy into QSWT trees as many as possible. With these redundancies, although some of QSWT trees with watermark information could be lost, the watermark still can be recovered and detectable. However, the watermark redundancies would increase the watermarked image distortion. Therefore, there is a tradeoff between $Q_d$ and $Q_w$. The optimal number of QSWT trees where the watermark logo is embedded must be adaptive to the network condition measured by the packet loss ratio (PLR). In addition, the communication energy has to be used in an efficient way in WMSN. These watermark redundancies need more network resources to protect it, thus require extra energy consumptions. In the proposed algorithm, finding an optimal number of QSWT trees can be regarded as finding the optimal thresholds $T_1$ and $T_2$. Carefully selecting the thresholds $(T_1, T_2)$ and coding watermark redundancies will affect the quality of the watermarked, as well as the total energy consumption. We define $F_w$ as the watermarking function, which indicates how watermark is embedded. $\{p_1, p_2, \dots, p_{m\times w}\}$ is a set of the positions where the watermark is embedded under the specified watermarking scheme. In our proposed adaptive watermarking technique, the two adaptive thresholds $\{T_1, T_2\}$ are used to filter and decide the appropriate embedding positions for watermarks Thus, the embedding positions are the function of these two thresholds. The watermark distortion reduction $Q_w$ and the decoded image distortion reduction $Q_d$ at receiver site can be expressed in (1). They are closely related to the packet loss ratio of watermarked image during wireless transmissions, and how many and at what positions the watermarks are embedded.

$$\{Q_w, Q_d\} = F_w\big(\big\{p_1(T_1, T_2), p_2(T_1, T_2), \dots, p_i(T_1, T_2)\big\}, \mathrm{PLR}\big) \tag{1}$$

As shown in the above equation, the distortion of watermarked image can be degraded from two aspects. One is at the source coding site where watermark is embedded. The other occurs in the transmission process, where the image packet is possibly dropped off due to error-prone wireless environments. At source coding site, the watermark should be embedded to as few insignificant positions as possible to make it invisible. In the transmission process, extra network resource should be allocated to protect this insignificant embedding transmission so that the watermark distortion would be low and the watermark would still be detectable.

In energy-constrained WMSN, there is a tradeoff between the energy consumption and the robustness of watermarking. Therefore, how to adapt watermarking thresholds to minimize the energy consumption while guaranteeing the watermark authentication is essential and becomes our goal. The new adaptive watermarking system should not only target the original image distortion minimization at the source code site, but also consider the qualities of watermarked image and watermarks during its transmission. Otherwise, the watermarked image may not be authenticated due to degraded quality. Based on this principle, we formed the maximization problem for both watermarked image and watermarks. We look for an optimized resource allocation strategy and appropriate watermark thresholds under the tolerable watermark distortion and energy consumption bound.

As shown in Fig. 1, the watermark logo at $w$th row and $m$th column can be embedded to $i$ trees. If we have total $N_t$ trees under the thresholds $(T_1, T_2)$, the watermark logo has $p \times q$ pixels. The extra number of trees to be protected is $N_t - p \times q$. The appropriate number of trees are determined by the adaptive threshold $T_1 + \Delta_1$ and $T_2 + \Delta_2$.

The probability of receiving all the watermark elements $(p \times q)$ after coding redundant watermarks into the host image can be described in (2).

$$\zeta = \left(1 - \mathrm{PLR}^{\lfloor N_t/p\times q\rfloor + 1}\right)^{\bmod (N_t/p\times q)} \cdot \left(1 - \mathrm{PLR}^{\lfloor N_t/p\times q\rfloor}\right)^{(p\times q - \bmod (N_t/p\times q))} \tag{2}$$

$\zeta$ represents the Watermark Authentication Success (WAS) Probability [23] under certain channel conditions. It has to be bounded to achieve the correct authentication with energy efficiency $1 - \zeta$ represents the Watermark Authentication Failure (WAF) probability, which is defined by $\theta$.

We propose a wavelet-based adaptive watermarking scheme that embeds the recognizable multimedia logo to the selective coefficients at the three-level Discrete Wavelet Transform (DWT) middle frequency bands of an image frame, based on the network conditions.

As shown in Fig. 2 at the application layer, two thresholds $T_1$ and $T_2$ are adaptive to ensure that enough embedded positions can be identified. They allow extra watermark redundancies to be embedded into the multimedia so that the watermark becomes more tolerable to the wireless channel errors. The image packets can be divided as the packets with watermark information (WM packet) and the ones without the watermark information (NWM packet). In order to improve the watermark transmission quality and thus further enhance authentication performance, the WM packet will be more protected by allocating extra network resource while NWM packets are less protected due to the limited resource in the sensor networks. The goal of the proposed watermark system is to improve the authentication system performance while the received multimedia quality is also guaranteed. The decoded watermark quality directly impacts the watermark authentication performance. At the same time, the watermarked multimedia is also critical to many applications. The received multimedia may be useless even it still could be authenticated due to the good watermark quality. In addition, the watermark quality could also be affected by decoded watermark multimedia quality at the receiver's site. There are a tradeoff between the watermark quality and watermarked multimedia quality since the watermark redundancies could distort the multimedia quality at the source coding site. It is important to find an optimal transmission and embedding strategy that could balance the watermark quality, watermarked multimedia quality and energy efficiency in the proposed watermark system. The algorithm of the proposed adaptive wavelet [23] based watermark scheme is described in Algorithm 1 table. The two thresholds $T_1(m) + \Delta_1$ and $T_2(m) + \Delta_2$ are adapted to find appropriate positions to embed the watermark. In next section, we will conduct a mathematical analysis on both watermark multimedia and watermarked multimedia distortion over wireless channels.

**Algorithm 1**: Adaptive wavelet based watermark algorithm

1: Apply three levels of DWT on Frame $n$, and get LH2 and LH3 wavelet sub-bands;

2: Convert LH2 and LH3 from a large block into a set of smaller sub-blocks; the size of sub-block is $M$.

3: Calculate the mean of those sub blocks in LH3 and save them in an array which is called $T_1$. Also do the same for LH2 and save those means to an array called $T_2$.

4: In this step we find the QSWT trees for every sub-block. At coefficient location LH3 $(i, j, m)$ in sub-block $m$, we check if it is greater than the threshold $T_1(m) + \Delta_1$, where $\Delta_1$ is the adaptive parameter. If yes, we check if at least three of its child coefficients (LH2$(2i-1, 2j-1, m)$, LH2$(2i-1, 2j, m)$, LH2$(2i, 2j-1, m)$, LH2$(2i, 2j, m)$) are greater than Threshold $T_2(m) + \Delta_2$, where $\Delta_2$ is the adaptive parameter. If they are, we set LH3 $(i, j)$ as one of the QSWT $(m)$, and sum up the coefficient values of the parent and all its children. Then we sort the sum of QSWT $(m)$ in decreasing order, and these are all the QSWT trees we get.

5: Whether a logo can be embedded into the current frame (frame $n+r$) based on the QSWT location is examined with the following function:
For $(i = 0; i <= n)$ {
  For $(j = 0; j <= m)$ {
  Difference = Difference + (LH3$_{n+r}(i, j)$ − LH3$_n(i, j)$)/LH3$_n(i, j)$
  }
}
If the variable *Difference* extends beyond a certain limit, we do not add the watermark. Else the following step is performed.

6: We apply the logo to these QSWT for each sub-block, using the following equation:
LH3$(i, j, m)$ = LH3$(i, j, m)$ + LH3$(i, j, m)$*0.02*sub-logo $(w, m)$;

## 3 Watermark and image distortion modeling with resource allocations

The information of natural digital multimedia is generally conveyed by layers of bit stream. With consideration of the distortion reduction at each layer, we form a performance metric for the overall multimedia sensor transmissions. The following expression in (3) gives the expected watermark distortion reduction at the receiver site:

$$\mu[Q_w] = \sum_{i=1}^{N_s}\left(\sum_{j=1}^{i} d_j\right)\left(\prod_{j=1}^{i}[1-\theta(j)]\right)(\theta(j+1)) \tag{3}$$

where $\mu[Q_w]$ is the expected distortion reduction when resource allocation strategy $\{r_1, r_2, \ldots, r_k\}$ is employed. $d_j$ is the distortion reduction brought by the source bytes in the $j$th packet. $\theta(j)$ denotes the WAF probability under certain channel condition when network resource is allocated to protect the $i$th packet. $\theta(j+1)$ is set to 1 to indicate the end of the bit stream. The related study can be referred to [13, 15]. Equation (3) gives the close form expression of expected watermark distortion reduction, which is the objective function of the proposed optimization algorithm. Our cross layer resource allocation problem for image transmission in sensor networks can be formulated as an energy-constrained quality maximization problem.

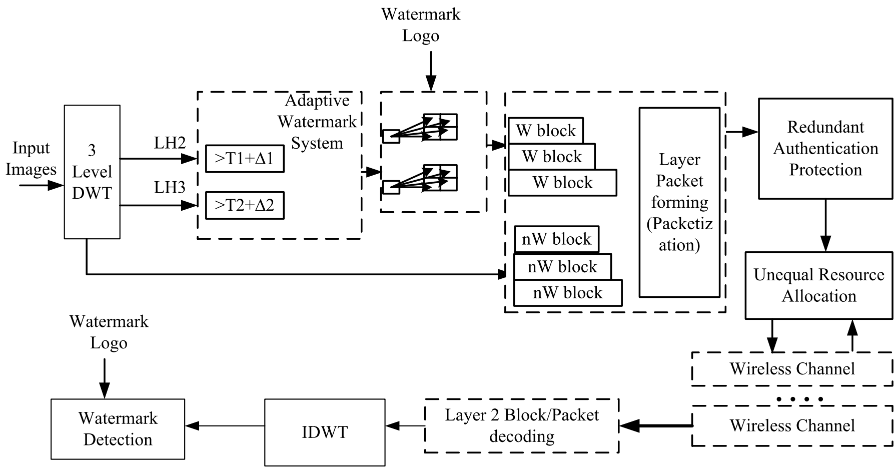



**Fig. 2** Resource-aware adaptive watermark system

The following expression in (4) gives the expected decoded watermarked image frame distortion reduction at the receiver site:

$$\mu[Q_d] = \sum_{i=0}^{N-1}\left(\left(\sum_{j=0}^{i} d_w(j)\right)\prod_{j=0}^{i}\big(1-\ell_w(j)\big)\right.$$
$$\left.+\left(\sum_{j=0}^{i} d_{nw}(j)\right)\prod_{j=0}^{i}\big(1-\ell_v(j)\big)\right)\ell_w(i+1) \tag{4}$$

In (4), $N$ is the total number of bit-planes in the embedded bitstream, $d_w(j)$ and $d_{nw}(j)$ denote the distortion reduction (i.e., the amount by which the distortion of the received and reconstructed image will decrease with the successful decoding of the source bits contained in the segment) for the $j$th WM data segment (with watermark information) and the $j$th NW data segment (without watermark information), respectively. The distortion reduction of each segment can be measured by calculating the decoded image quality improvement in a way similar to [13, 15, 19, 21, 22]. $\ell_w(j)$ and $\ell_{nw}(j)$ denote the corresponding data loss ratio of the $j$th WM data (data with watermark information) and NWM data (data without watermark information) segment, respectively. Let $E[\cdot]$ denote the mathematical expectation. $E[Q_d]$ is the expectation of total decoded watermarked image frame distortion reduction, and can be expressed as (4). $\ell_w(i+1) = 1$ denotes the end of embedded bitstream. The expected distortion reductions of WM data segments are expressed as the summation of the weight $\sum_{j=0}^{i} d_w(j)$ with the corresponding probability $\prod_{j=0}^{i}(1-\ell_w(j))$ for successful decoding of each WM data segment. Distortion reduction expectation of all NWM data segments is similar.

The proposed optimal watermark can be described as how to select the optimal threshold $\{T_1^{\text{opt}}, T_2^{\text{opt}}\}$ and transmission strategy to maximize the watermark quality (i.e., maximize the authentication performance). The optimization constraints are for the watermarked image distortion to be lower-bounded and for the energy efficiency to be lower-bounded.

$$\left\{\left(T_1^{\text{opt}}, T_2^{\text{opt}}\right), \left(r_w(i), r_{nw}(i)\right)\right\}_{i=1,2,\ldots,N-1} = \underset{\{(T_1,T_2),(r_w(i),r_{nw}(i))\}}{\arg\max} \left[\mu(Q_w)\right] \\ St. \begin{matrix} u(Q_d) > Q_d^T; \\ e \leq e_{bound} \end{matrix} \tag{5}$$

*e* represents the total energy consumption. It is derived by our previous work [14–16]. In the previous work, the average total energy consumption can be expressed as a function of desirable BER requirement (*BER*), frame length ($L_{\text{DATA}}$), control packet transmission rate ($R_{\text{CTRL}}$), data packet transmission rate ($R_{\text{DATA}}$), transmission power ($P_{\text{DATA}}$) and retransmission limit ($RT_{\max}$). We could allocate these resources optimally to improve the watermark transmission quality when the channel condition is determined. An optimization study could be referred to our previous work in [14–16]. This optimization problem can be solved by effective genetic algorithm in an iterative way. Other optimization methods [24–27] could also be available for the consideration in the application. It searches for the optimal target set for one packet at a certain iteration, keeping the other packets' target set unchanged until the cost function converges. The detailed optimization algorithm is described in Algorithm 2 table.

**Algorithm 2**: Adaptive watermarking optimization algorithm with resource allocation

1: Define algorithm I/O. Input: Multimedia distortion reduction $d_w$ and $d_{nw}$ of each WM data and NWM data segment, length $L$ of each segment, channel state factor $A$ and energy budget $e_{\max}$.
*Output:* Optimal Watermark Threshold and Resource allocation $\{(T_1^{\text{opt}}, T_2^{\text{opt}}), (r_w(i), r_{nw}(i))\}_{i=1,2,\ldots,N-1}$
2: Binary coding and decoding for each chromosome:
Each possible solution $\{T_1, T_2, r_w, r_{nw}\}$ is coded as a chromosome and each element $r_m$ and $r_{nw}$ in the chromosome is coded as a gene. Initialize the size $S_{\text{pop}}$ of population and the maximal evolution iterations, and the watermark threshold $T_1 = T_0 + \Delta_1$, $T_2 = T_0 + \Delta_2$
3: Loop the following steps (3–5) for evolution.
4: Evaluate the fitness of each chromosome in the current generation $g$ which makes the fitness evaluation more effective.
Loop $i = 0; i \leq S_{\text{pop}} - 1; i++$
{
For each threshold $T_1 = T_1 + \Delta_1$, and $T_2 = T_2 + \Delta_2$
Calculate the total energy consumption expectation $u[e(i)]$ and the expected distortion reduction $\mu[Q_w(i)]$ using the current $\{r_w(g,i), r_{nw}(g,i)\}$.
The fitness $f$ of each chromosome can be evaluated using $f(i) = \mu[Q_w(i)]$.
}
5: In the current generation $g$, sort the chromosome in descending order according to the fitness value $f$.
6: Output the best chromosome in the current population with the largest $f$ value, while the energy consumption is within the budget constraint $e_{bound}$.
7: Decided if we are going to add a logo in to the current frame (frame $n + r$) based on the QSWT location we calculated from frame $n$.

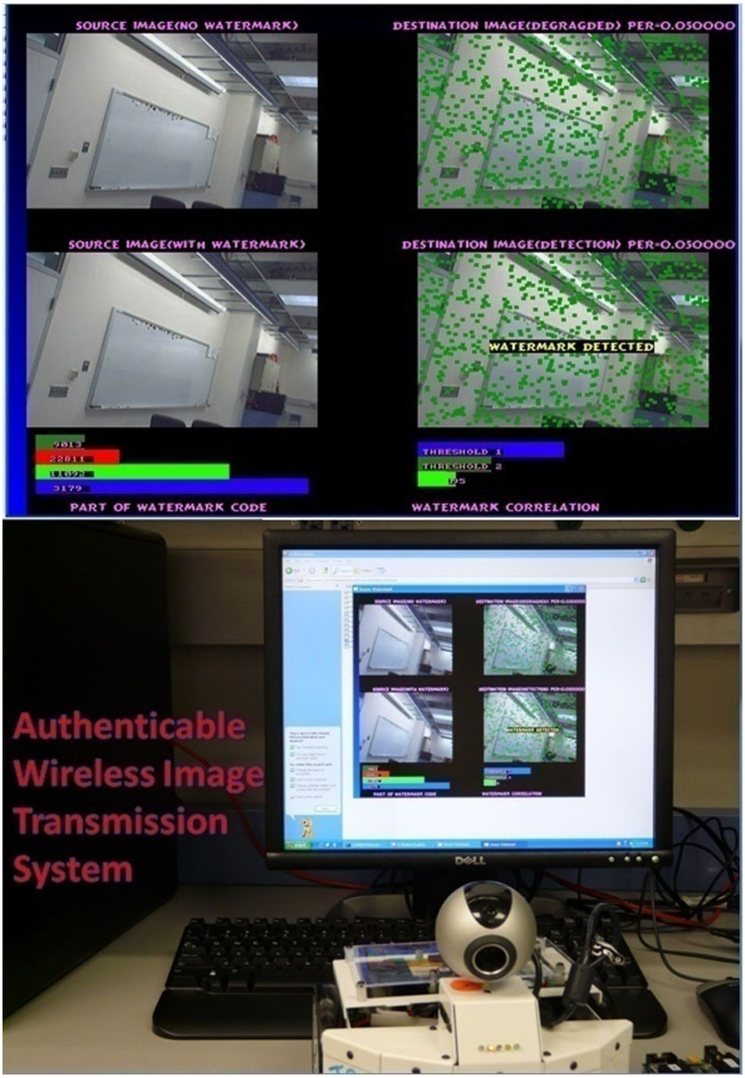



**Fig. 3** GUI for watermarking implementation over WMSNs

## 4 Experiment and evaluation

A similar observation was also made based on a real implementation of a pseudo sequence-based watermarking system in stargate based image sensor networks by the author in the Wise-COM lab. In this system, the stargate image sensors are carried by the Gacial robots that provide the mobile wireless environments. The system is developed based on the Linux platform of stargate using the C and C++ language. The real experimental results as shown in Fig. 3 demonstrated similar results as presented in Fig. 1: the authentication results (extracted watermark quality) can be significantly impacted when the quality of image transmissions is degraded.

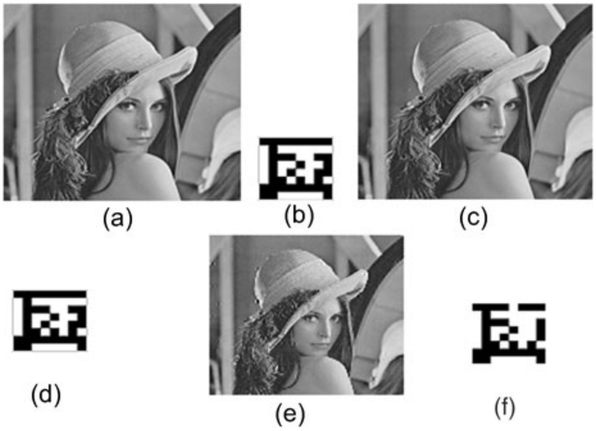



**Fig. 4** We use the Lena image as the test image shown in (**a**). The logo we inserted is (**b**), and (**c**) is the outcome of the watermarked image. (**d**) is the recovered logo using watermark detector. Image (**e**) is the outcome of the recovered of image (**c**) after JPEG compression, using quality parameter 90. (**f**) is the recovered logo of image (**d**). Notice that there is some information loss due to the JPEG compression

In the experiment results, Fig. 4 shows the watermark logo and recovered logo based on the test image frame and the proposed scheme. The results show the proposed watermark system can resist the traditional image compression although there is loss of information after JPEG compression. The wavelet based watermarking process achieves a good performance of invisibility.

We use the normalized correlation (NC) [17] coefficient to measure the similarity of original watermarks and extracted watermark, which is defined as follows:

$$NC = \frac{\sum_{i=1}^{w}\sum_{j=1}^{m} w(i,j)w^*(i,j)}{\sum_{i=1}^{w}\sum_{j=1}^{m} [w(i,j)]^2}$$

where $w^*(i, j)$ denotes the extracted watermark and the $w(i, j)$ denotes the referenced watermark. Figure 5 shows the proposed watermarking scheme against the image compression. Figure 5(a) shows the original image and watermarked image under JPEG Quality of Factor 75. The quality of watermarked image is still good and it is impossible to distinguish the difference visually. Figure 5(b) tables the extracted watermark from JPEG-compressed version of the watermark image with different Quality Factors, 61.5, 58.5, 35, 25. The left two columns contain the original multimedia. Under Quality Factor 61.5, the quality of watermarked image is still good. Even for the Quality Factor 25, the PSNR is still around 36 dB and the extracted watermark is still visually recognizable. The result indicates that the proposed system has achieved very good invisibility and can be against JPEG lossy compression.

We use T-MAC protocol parameters in the transmission energy optimization. For T-MAC data packets in TinyOS, the MAC header is 11 bytes and the payload is 36 bytes. For the control packet such as RTS, ACK, the length is 13 bytes. Preamble length is 18 bytes. CTS packet is 15 bytes. The transmission of the control packets uses the basic modulation scheme, while the transmission of DATA packets utilizes the scaled modulation schemes. The energy model proposed by our previous works in [14–16] is used to calculate the optimal energy consumption under certain channel conditions.

Our experiment study also show that with the increase of thresholds $T_1$ and $T_2$, the watermarked image distortion (measured by PSNR) is decreased at the source code


(a)

The table below shows the detected watermark after compression

| (O) Image | (W) Image | 61.5 | 58.5 | 35 | 25 |
|---|---|---|---|---|---|
| | | PSNR 59.2049 NC 1.0952 | PSN R 53.4859 NC 0.9851 | PSNR 48.2817 NC 0.9846 | PSNR 34.9873 NC 1.0482 |
| | | PSNR 53.9056 NC 0.6329 | PSNR 51.7590 NC 0.6383 | PSNR 41.0551 NC 0.6791 | PSNR 38.4015 NC 0.7002 |
| | | PSNR 57.1768 NC 1.0422 | PSNR 54.5142 NC 0.9802 | PSNR 43.4496 NC 1.0025 | PSNR 40.0649 NC 0.9132 |
| | | PSNR 55.7889 NC 0.6711 | PSNR 53.8901 NC 0.6591 | PSNR 44.6403 NC 0.6622 | PSNR 43.0239 NC 0.6838 |
| | | PSNR 54.1793 NC 0.9880 | PSNR 51.3637 NC 1.0271 | PSNR 39.3811 NC 0.9936 | PSNR 34.6282 NC 0.6000 |
| | | PSNR 53.7199 NC 0.9689 | PSNR 48.5615 NC 0.9729 | PSNR 39.9245 NC 1.1760 | PSNR 36.7794 NC 0.8625 |
| Average PSNR Average NC | | 55.5625 0.8997 | 52.2629 0.8771 | 42.7896 0.8273 | 37.9868 0.8013 |

(b)

**Fig. 5** Against the image compression in the proposed watermarking scheme

site. This is because that using higher thresholds can only identify fewer QSWT trees where logo is embedded and then fewer redundancies could be added with less distortion. Lower thresholds can provide much more QSWT trees, and the redundant pixels of watermark logo can be embedded in these redundant QSWT trees. Therefore, the higher thresholds lead to good watermarked image quality at the source coding site, but could produce the poor watermarked image quality at the receiver site. Since us-

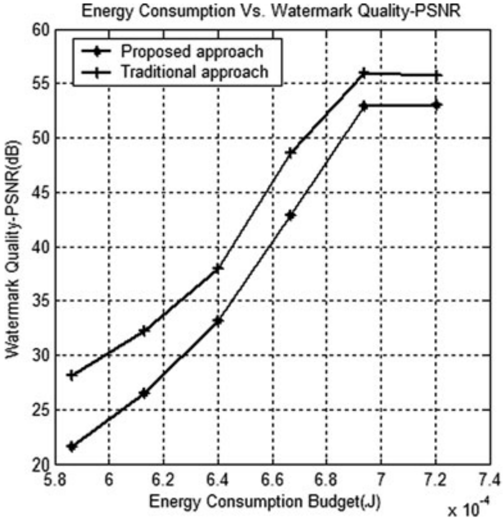



**Fig. 6** Energy consumption vs. watermark quality

ing the higher threshold gives us more QSWT trees, the watermark logo redundancies can be embedded into more QSWT trees. Even some packets (includes QSWT trees) are lost, the extracted watermark could still retain higher quality. We also studied the relationship between the numbers of QSWT trees and WAS probability under different loss ratios. It is clear that with the increasing number of QSWT trees where the watermark redundancies are embedded, the proposed watermark scheme achieves higher authentication probability.

In Fig. 6, we also compare the proposed approach with the traditional wavelet based watermark approach. The traditional approach is defined as the one that does not perform UEP on the WM packet and has no energy optimization scheme at the link level. The threshold is not adaptive and instead fixed. We use the lowest thresholds that could find least required QSWT trees where the watermark can be embedded. The proposed resource aware watermark scheme is especially favorable for strict energy budget constraints. In Fig. 6, the distortion reductions are very close between both approaches with 0.7 J energy budget constraint. For 0.58 J energy budget constraint, the proposed approach can achieve around 5.5 dB watermark distortion reduction gain over traditional approach. The reason is that with strict energy budget constraints, the proposed approach can allocate the scarce resources on WM packets more than on NWM packets. These results demonstrate that the proposed approach could achieve the better watermark quality under the same energy consumption budget. Thus, the corresponding authentication performance (indicated as the watermark quality) is improved.

## 5 Conclusion

In this paper, we studied how an adaptive energy-aware watermark scheme in WMSN can work against the transmission channel error and achieve high image authentication performance. We found that our proposed resource-aware approach based on adaptive watermark thresholds can guarantee the watermarked image and in general any image transmission quality as well as achieve high authentication performance (i.e., improving the watermark quality) and energy efficiency. The simulation demonstrated that the proposed watermarking scheme achieves considerable energy efficiency and enhances security and image transmission quality in multimedia-sensor-based WMSN.

## References


1. Hsieh M-S, Tseng D-C, Huang Y-H, (Oct 2001) Hiding digital watermarks using multiresolution wavelet transform. IEEE Trans Ind Electron 48(5)
2. Ntalianis KS, Doulamis AD, Doulamis ND, Kollias S (2002) An automatic scheme for stereoscopic video object-based watermarking using qualified significant wavelet trees. In: Proc IEEE international conference on image processing, vol 3. pp 24–28 June
3. van Schyndel RG, Tirkel AZ, Osborne CF (1994) A digital watermark. In: Proc IEEE int conf image processing, vol 2. pp 86–90
4. Mathai NJ, Heikholeslami A, Kundur D (2003) VLSI implementation of a real-time video watermark embedder and detector. In: Proc the 2003 international symposium on circuits and systems, vol 2, pp 25–28 May
5. Inoue H, Miyazaki A, Yamamoto A, Katsura T (1998) A digital watermark based on the wavelet transform and its robustness on image compression. In: Proc IEEE int conf image processing, vol 2, pp 391–395
6. Shapiro JM (Dec 1993) Embedded image coding using zerotrees of wavelet coefficients. IEEE Trans Signal Process 41:3445–3462
7. Kim Y-S, Kwon O-H, Park R-H (Mar 1999) Wavelet based watermarking method for digital images using human visual system. Electron Lett 35:466–468
8. Li Z, Sun Q, Lian Y, Chen CW (June 2007) Joint source-channel-authentication resource allocation and unequal authenticity protection for multimedia over wireless networks. IEEE Trans Multimedia 9(4)
9. Lin C-Y, Chang S-F (1998) A robust image authentication method surviving JPEG lossy compression. In: Proc SPIE storage and retrieval of image/video database, vol 3312, pp 296–307
10. Wu CW (Jun 2002) On the design of content-based multimedia authenticationsystems. IEEE Trans Multimedia 4(3):385–393
11. De Couto D, Aguayo D, Bicket J, Morris R A high-throughput path metric for multi-hop wireless routing. In: ACM MobiCom'03
12. Warrier A, Le L, Rhee I Cross-layer optimization made practical, www4.ncsu.edu/~acwarrie/publications/crossLayer.pdf
13. Wu Z, Bilgin A, Marcellin M (2005) Joint source/channel coding for multiple images. IEEE Trans Commun 53(10):1648–1654
14. Wang W, Peng D, Wang H, Sharif H, Chen H (2007) Energy efficient multirate interaction in distributed source coding and wireless sensor network. In: Proc IEEE wireless communications and networking conference (WCNC 2007), Mar, pp 4091–4095
15. Wang W, Peng D, Wang H, Sharif H, Chen HH (Oct. 2008) Energy-constrained distortion reduction optimization for image transmission in wireless sensor networks. IEEE Trans Multimedia 10(6)
16. Wang H, Peng D, Wang W, Sharif H, Chen HH (2007) Collaborative image transmissions based on region and path diversity in wireless sensor network. In: Proc IEEE global communications conference, Nov, pp 971–975
17. Hsu C-T, Wu J-L (Aug 1998) Multiresolution watermarking for digital images. IEEE Trans Consumer Electron 45:1097–101
18. Sun Q, Apostolopoulos J, Chen C-W, Chang S-F (Jan 2008) Quality-optimized and secure end-to-end authentication for media delivery. IEEE Proc 96(1):97–110
19. Wang W, Peng D, Wang H, Sharif H, Chen H-H (2008) Energy-distortion-authentication optimized resource allocation for secure wireless image streaming. In: Proc IEEE WCNC, pp 2810–2815
20. Zhang Z, Sun Q, Wong W, Apostolopoulos J, Wee S (Feb. 2007) An optimized content-aware authentication scheme for streaming JPEG-2000 images over lossy networks. IEEE Trans Multimedia 9(2):320–331

21. van der Schaar M, Turaga D (Jan. 2007) Cross-layer packetization and retransmission strategies for delay-sensitive wireless multimedia transmission. IEEE Trans Multimedia 9(1):185–197
22. Wu Z, Bilgin A, Marcellin M (Aug. 2005) Joint source/channel coding for image transmission with JPEG2000 over memoryless channels. IEEE Trans Image Process 14(8):1020–1032
23. Wang H, Peng D, Wang W, Sharif H, Chen H-H (2008) Energy-aware adaptive watermarking for real-time image delivery in wireless sensor networks. In: Proc ICC '08. IEEE international conference on communicaitons, 19–23 May, pp 1479–1483
24. Peng Y, Kou G, Shi Y, Chen Z (2008) A descriptive framework for the field of data mining and knowledge discovery. Int J Inform Technol Decis Making 7(4): 639–682
25. Chen J, Lin Q, Hu Q (March 2010) Application of novel clonal algorithm in multiobjective optimization. Int J Inform Technol Decis Making 9(2):239–266,
26. Zhao L, Jiang Y (December 2009) A game theoretic optimization model between project risk set and measure set. Int J Inform Technol Decis Making 8(4):769–786
27. Better M, Glover F, Kochenberger G, Wang H (2008) Simulation optimization: applications in risk management. Int J Inform Technol Decis Making 7(4):571–587