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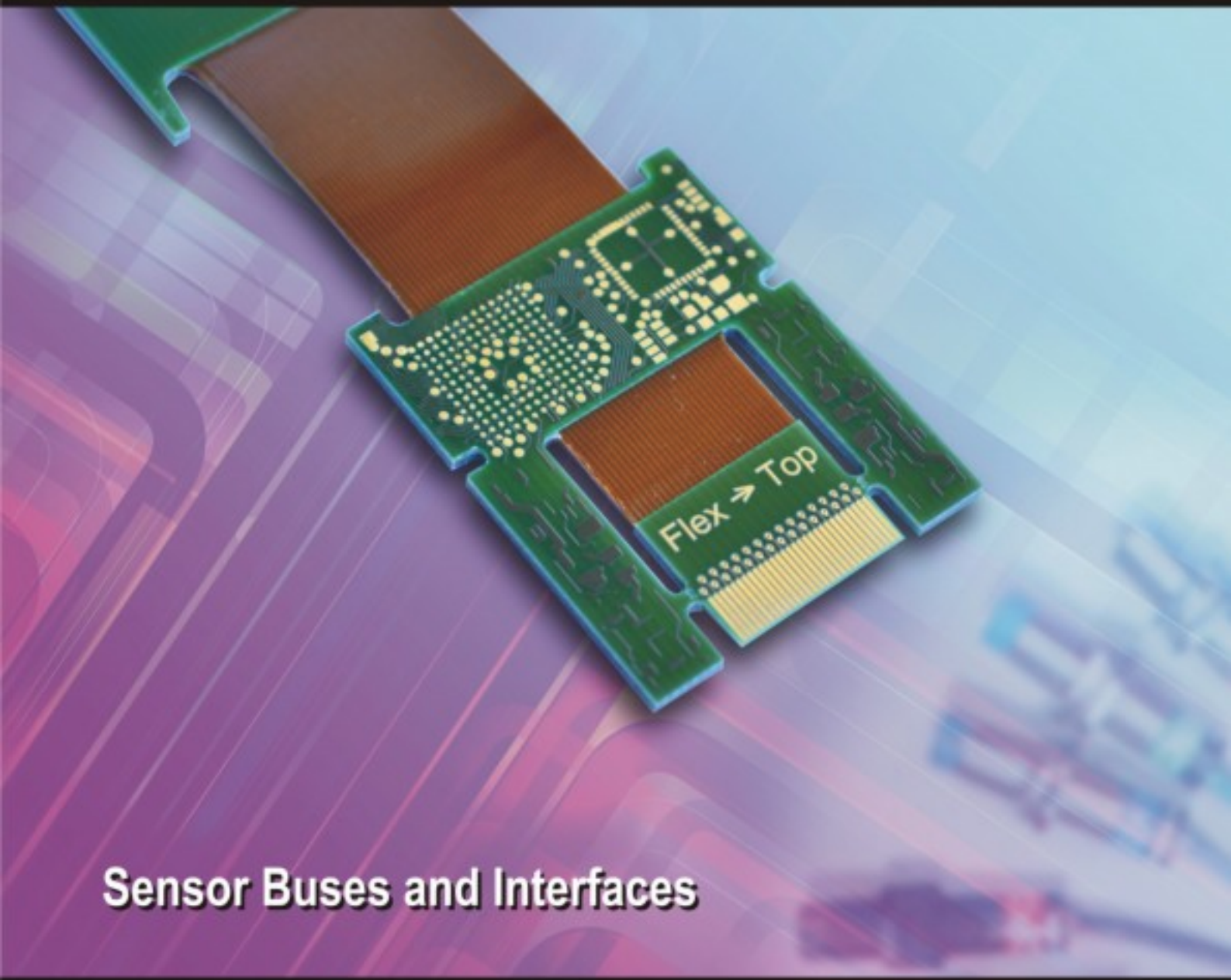

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A New Ultra-Lightweight Authentication Protocol for Low Cost RFID Tags

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Abstract: The Radio Frequency Identification (RFID) system has been widely used in almost every aspects of the society. At present, the problem of security and privacy become a key factor of severely blocking the widespread of its usage. However, due to restraints on RFID tag's manufacturing cost, the traditional methods of encryption are not good candidate to defend the security of wireless communication channel between reader and tag. Designing lightweight or ultra-lightweight RFID authentication protocol has become a hot research topic recently. This paper proposes a new ultra-lightweight RFID authentication protocol with high robustness and execution efficiency. The proposed protocol requires only simple bit-wise operations, it has the characteristics of low storage requirement and communication cost. At the same time, through elaborate mechanism design, avoid the vulnerability of the existing ultra-lightweight authentication protocols. *Copyright © 2013 IFSA.*

Keywords: RFID, Security, Privacy, Ultra-lightweight, Authentication.

1. Introduction

Compare with bar-code, Radio Frequency Identification (RFID) has mesh points of non-contact recognition, batch read and remote access, identification of high speed moving object. It was widely used in supply chain management, access control, payment, retail inventory control or product tracking. With popularization and application of large-scale RFID system, the cost of RFID tag is one of the key factors that limit its development. However, the cost is too low is bound to bring about lower the tag's computational capabilities, storage capacity. Consequently, the traditional encryption schemes are no longer suitable for low-cost RFID tag, conduct correlation researches of lightweight or ultra-lightweight security mechanisms have become a hot research topic recently.

Recently, many ultra-lightweight protocols for RFID system have been proposed. However, they have varies of flaws and weaknesses more or less. In 2006, Peris-Lopez et al. proposed a family of ultra-lightweight mutual authentication protocol, namely, UMAP protocol family [1-3], creates an interesting research direction. In UMAP, only simple bit-wise operations were adopted. Hence, the computational cost were very little suitable for low-cost tags. However, these protocols were demonstrated very vulnerable to de-synchronization attack, disclosed attack [4]. Chien et al. [5] proposed a new ultra-lightweight authentication protocol (SASI protocol) [5], this protocol introduced ROT operation and new and old dynamic identification provide greater security than UMAP. However, it is still vulnerable to trace attack, de-synchronization attack and full-disclosed attack [6, 7]. Gildas Avoine proposed a passive full-disclosure attack on SASI that works with any definition of the rotation [8]. P. D'Arco proposed de-synchronization attack and disclosed attack to SASI [9], only need 48.5 times to form

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success de-synchronization attack on average. In addition, design the full-disclosed attack can disclose all the secret data. Pedro Peris-Lopez et al. (2009) put forward another ultra-lightweight authentication protocol, namely, Gossamer protocol [10]. The protocol introduced Double-Rot and *mixbits* algorithm which can better resistance to all sorts of common attacks. Thus, attackers can hardly get any useful information from tags. However, Tagra et al. proved that the protocol was insecure to de-synchronization attack [11]. Yun Tian (2012) proposed a new ultra-lightweight mutual protocol with permutation(RAPP protocol) [12], where the protocol adopted Per operation to break the orders of bits, compare with SASI protocol reached better encrypted and authentication effect. Unfortunately, Due to the design flaws, Wang Shao-Hui and Zahra Ahmadian, respectively, proposed effective de-synchronization attack and full-disclosed attack to RAPP protocol [13, 14].

In this paper, we propose a new ultra-lightweight RFID authentication protocol for low-cost RFID system. The proposed protocol can provide a security, stable and efficient channel for the legal tags and readers. The rest of this paper is organized as follows: Section 2, a new security protocol is proposed and description in details. Section 3, informal security analysis of the proposed protocol's ability against the attack modes, these attacks form great threats to existing RFID security protocols. Section 4, provide corresponding performance evaluation for the designed protocol. Finally, concludes are given in Section 5.

2. An Ultra-Lightweight RFID Protocol for Low Cost RFID Tags

2.1. Preliminaries and Notations

The RFID system mainly includes backend server, reader and tag. Due to working in Wireless network environment, the channel between reader and tag is vulnerable to a variety of severe attack modes. At the same time, due to backend server and reader have adequate computer power, storage space. The channel between them can adopt traditional encryption technology, the interactive operation between backend server and reader can be considered to be secure. To simplify the analysis, we only need design and analysis security certificate mechanism between reader and tag.

The notations used in the paper are denoted as follows:

$\oplus$: Bit-wise XOR n_1 : Random number

$+$: Addition mod 2 m, m=96

ID : Static identification of the tag

IDS_{old} / IDS_{new} : Tag's old/potential next dynamic identification

K_{old} / K_{next} : Tag's old/ potential next dynamic key

$Rot(x, y)$: An $w(y)$ -bit left rotation on x , defined as follows:

$$\begin{aligned} &\mathrm{z} \leftarrow x \\ &\{\mathrm{z}=\mathrm{z} << w(y);\} \\ &return\ z; \end{aligned} \tag{1}$$

where $w(y)$ denotes the Hamming weight of y .

$mixbits(x, y)$: Defined as fol1ows:

$$\begin{aligned} &\mathrm{z} \leftarrow x \\ &for\ (i=1;\ i<32;\ i++) \\ &\{\mathrm{z}=(\mathrm{z} >> 1)+\mathrm{z}+\mathrm{z}+\mathrm{y};\} \\ &return\ z; \end{aligned} \tag{2}$$

$Per(A, B)$: Let A and B are two L-bit word, where a_i and b_i is the i^{th} bit of A and B, such as: $A = a_1 a_2 ... a_i ... a_L \quad B = b_1 b_2 ... b_j ... b_L$, where $w(A) = w(B) = m$, and $b_{k_1} = b_{k_2} = ... = b_{k_m} = 1,\ b_{k_{m+1}} = b_{k_{m+2}} = ... b_{k_L} = 0$, $Per(A, B)$ denoted as:

$$Per(A, B) = a_{k_1} a_{k_2} ... a_{k_m} a_{k_L} a_{k_{L-1}} ... a_{k_{m+2}} a_{k_{m+1}} \tag{3}$$

The shared secret values include ID , K_{old} / K_{next} between reader and tag. To solve the problem of traceability, the dynamic identity IDS and secret key K are updated after each authentication session to resist traceability. Meanwhile, to resist de-synchronization attack, after each session ends, old and potential next dynamic identification and key were shared by reader and tag.

2.2. Protocol Description

The Protocol's thumbnail as shown in Fig. 1, it can be divided into two stages include: identification and authentication stage, update stage. The protocol detail is described in the following:

Phase 1: Identification and authentication

Step 1. Reader $\rightarrow$ Tag: $Hello$

The reader transmits handshake information "$Hello$" to tag

Step 2. Tag $\rightarrow$ Reader: IDS

After receiving the reader's handshake information, the tag transmits its dynamic identity IDS to the reader.

Step 3. Reader $\rightarrow$ Tag: A and B

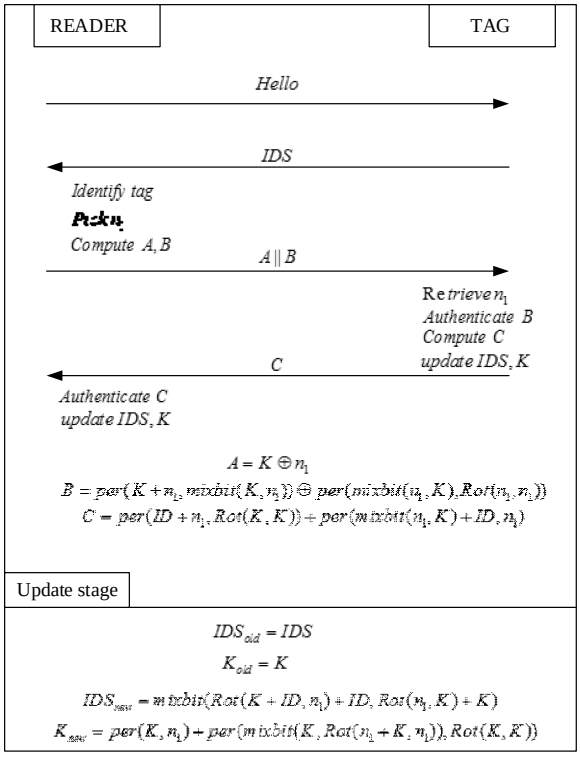

Fig. 1. An ultra-lightweight RFID protocol for low cost RFID Tags.

After receiving the tag's IDS , If the corresponding IDS_{new} cannot be found in the backend database, the reader will regenerate handshake information "$Hello$" to the tag. By this time, the tag will set $IDS = IDS_{old}$ and retransmits it to the reader. Or else, the reader adopts Pseudo-random number generator (PRNG) generates a random number n_1 , computer A and B as following:

$$A = K \oplus n_1$$

$$B = per(K + n_1, mixbit(K, n_1)) \oplus per(mixbit(n_1, K), Rot(n_1, n_1)) \quad (4)$$

Step 4. Tag $\rightarrow$ Reader: C

Upon receiving the reader's message $A||B$, the tag derives n_1 from the equation :

$$n_1' = A \oplus K . \quad (5)$$

Then the tag computer B' with n_1' and K by the following equation:

$$B' = per(K + n_1', mixbit(K, n_1')) \oplus per(mixbit(n_1', K), Rot(n_1, n_1')) \quad (6)$$

If $B' = B$, the authentication gets through, the reader can be seen as legal. Then the tag computer C as following equation:

$$C = per(ID + n_1, Rot(K, K)) + per(mixbit(n_1, K) + ID, n_1) \quad (7)$$

The tag sends C to the reader. When the C is received, then the reader computer corresponding C' with local value in the backend server, if $C' = C$, the mutual authentication gets through, the protocol step into next phase, or else, the authentication protocol is failed.

Phase 2: Key updating

When the identification and authentication Phase between the reader and the tag is gets though, they update their Key and IDS each other in themselves as following equations:

$$IDS_{old} = IDS \quad (8)$$

$$K_{old} = K \quad (9)$$

$$IDS_{new} = mixbit(Rot(K + ID, n_1) + ID, Rot(n_1, K) + K) \quad (10)$$

$$K_{new} = per(K, n_1) + per(mixbit(K, Rot(n_1 + K, n_1)), Rot(K, K)) \quad (11)$$

Then both of them will update and save their $K_{old}, K_{new}, IDS_{old}, IDS_{new}$ in themselves, and update stage is finished.

3. Protocol Security Analysis

Currently, these attacks to break existing RFID authentication protocol mostly include as following: For one thing, attackers try to destroy the mutual message's confidentiality, integrity, availability; For another thing, an attacker could mount attacks by protocol's weaknesses, such as: de-synchronization attack, replay attack, disclosure attack and so on. We discuss our protocol's security as following:

Mutual authentication and Data confidentiality: Because of only genuine reader and genuine tag share secret values K, IDT , the mutual authentication between the tag and the reader can be go through by the messages A, B, C which are generated by the mixed operation of K, IDT, n_1. At the same time, without knowledge of K , it is difficult to an attacker deduce the random number n_1 from $A || B || C$.

Thus, under the random number's protection, ensure the confidentiality and integrity of the static identification IDT and secret value K.

Tag anonymity and un-traceability: After every time success mutual authentication, the update of shared secret K and tag's dynamic identification IDS involve random number n_1. Meanwhile, the introduced of $mixbits(x, y)$ operation overcome the weakness of hamming weight-invariant of RAPP protocol. Thus, the adversary cannot trace the same tag by the invariance of IDS.

Resistance to replay attack: Due to the generation of message $A \| B \| C$ involved new random number n_1 in each session, the attacker try to replay the message will not be approved. Moreover, the attacker could intercept the transmission of message C lead to the reader didn't update inter secret values. Meanwhile, send last time $A \| B$ to the tag. However, the attacker cannot get any secret information and tag's internal states keep the same as the last session. It makes absolutely no sense to attacker.

Resistance to de-synchronization attack: Due to the use of radio link between the reader and the tag, the messages transmission can be interrupt easily by the malicious attacker or various natural factors. Hence, accidental transmission can result in de-synchronization between genuine reader and genuine tag. However, the protocol keeps the old and new key and dynamic identification, namely, $(K_{old}, K_{new}, IDS_{old,} IDS_{new})$. Hence, even if the message C transmission failed, the reader and the tag can make authenticate each other by the old key and dynamic identification. Thus, the protocol can return to the synchronization state.

In addition, the attacker make de- synchronization attack by change one or small bits in A, then obtain coordinated correctness pair (A', B', C') by change some bits on B or C. However, it is impossible to this way of attack, because of any slight changes can make the B and C almost change into a totally different number in our protocol.

Resistance to disclosure attack: The attacker may though change one or some bits in A and modified some bits on B and transmission them to the tag to verified the correctness of forged (A', B'), then infer some useful information from the response of the tag. However, constructed such (A', B') is almost impossible in our protocol, due to any slight modification in A will result to B varies greatly. Hence, the attacker cannot get any useful information for deduce secret information.

In addition, the introduce of $mixbits$ operation overcome the vulnerability of RAPP protocol proposed in [13].

In RAPP protocol, due to the improper use $ROT(x, x)$, lead to the problem as following:

When $[x]_i \neq [x]_{i+1}$, at the same time, denote $[x]_i$ stand for the bit at i position in x, $\overline{x}_{i,i+1}$ stand for the string with the same bit as x other than the bit of i and $i+1$:

$$\begin{cases} per(y, ROT(\overline{x}_{i,i+1}, \overline{x}_{i,i+1})) \\ \quad = per(y, ROT(x, x)) \\ per(y, ROT(\overline{x}_{i,i+1}, \overline{x}_{i,i+1})) \\ \quad \oplus per(y, ROT(x, x)) = \overline{0}_{s,t} \end{cases} \tag{12}$$

The attack may adopt this vulnerability obtain the bit adjacent relation in x bit by bit.

In our protocol, the mechanism of $per(mixbit(n_1, K), Rot(n_1, n_1))$ effectively inhibited this way of attack, when $[n]_i \neq [n]_{i+1}$, $per(misbits(\overline{n}_{i,i+1}, K), ROT(\overline{n}_{i,i+1}, \overline{n}_{i,i+1}))$ and $per(misbits(n, K), ROT(n, n))$ have nothing relationship.

4. Protocol Performance Evaluation

Under the premise in security, computational cost, communication cost, storage requirement are metrics for evaluating whether a protocol's performance is fine. Table 1 compares the performance of our protocol with some common ultra-lightweight authentication protocols proposed recently. The protocol proposed in this paper has good performances base on ensure security.

Computational cost: The protocol only adopts simple bit-wise operation, such as XOR operation, modulo addition operation. In addition, we adopt non-triangular operations, such as ROT operation, $mixbits$ and per operation. The $mixbits$ operation only requires some right shift operation and modulo addition operation, the per operation only requires some simple permutation operation. Hence, even if to low-cost tag, these operations are easy to implement. At the same time, compare with SASI and RAPP protocol, our protocol only use one time pseudo random number generator in an interaction session, so save the computational cost and time.

Communication cost: The interaction messages transmitted between the tag and the reader mainly include $IDS \| A \| B \| C$. The whole transmitted message demand 384 bits. Due to the fewer bytes in the transmission channel, the data transport time effective is cut.

Table 1. Comparison of Ultra-lightweight Authentication Protocols.

Protocols	U-MAP family	SASI	GOSSAMER	RAPP	Ours
Protect user privacy	NO	YES	YES	YES	YES
Resistance to Desynchronization attacks	NO	NO	NO	NO	YES
Resistance to Disclosure attacks	NO	NO	YES	NO	YES
Mutual Authentication	YES	YES	YES	YES	YES
Total messages for mutual authentications	4-5 L	5L	5L	6L	4L
Mesmory size on tag	6L	7L	7L	5L	5L
Mesmory size for each tag server	6L	4L	4L	9L	5L
Operations in the tag	$\oplus, \wedge, \vee, +$	$\oplus, \wedge, \vee, +, ROT$	$\oplus, +, ROT^2$, $MIXBITS$	$\oplus, ROT$, Per	$\oplus, +, ROT$, $mixbits, Per$

L designates the bit length of variables used

Storage requirement: Each tag require 96 bytes read-only memory to preserve the static identification of tag, at the same time, needs 384 bytes erasable memory for the update of $(IDS_{old}, IDS_{new}, K_{old}, K_{new})$ in each session. Hence, the protocol needs little storage requirement and meet the requirement of low-cost RFID tag.

5. Conclusion

Privacy and security issues have become enormous challenges to the current RFID domain. It is one of the key problems to be solved that design high performance, strong security ultra-lightweight RFID authentication protocol for ensure the security of the channel between the reader and the tag. In this paper, we proposed a novel new ultra-lightweight RFID authentication protocol, the protocol require only simple bit-wise operation, meanwhile, ingenious adopt two non-triangular proposed recently: $mixbits$ and per operation. Through the elaborate design, the protocol achieves better encryption and authentication effects. In addition, overcome the problem of pure to adopt per per operation which result in de-synchronization attack and full-disclose attack. The informal analysis indicated that the protocol resistance to common attacks in wireless transmission network. At the same time, compare with many existing ultra-lightweight authentication protocols, the protocol have characteristics of low computational cost, communication cost and storage requirement. Hence, the protocol proposed in this paper is highly efficient for low-cost RFID tags.

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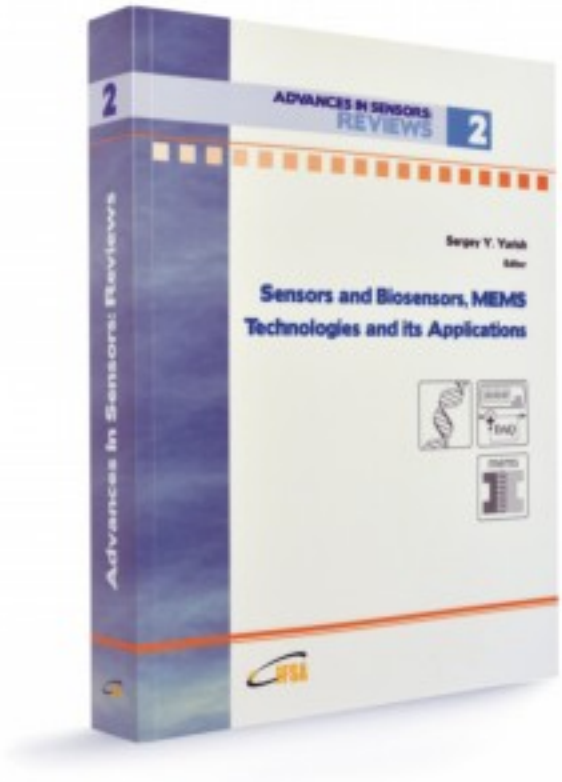
Sergey Y. Yurish
Editor

Sensors and Biosensors, MEMS Technologies and its Applications



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