Method of adaptive Barker-like protection, coding and data transmission⋆

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Abstract

To remotely control the movement of mobile robotic platforms, an important problem is to ensure reliable communication between such platforms and the remote control center, providing an appropriate level of cryptographic protection and noise immunity while reducing the weight, size, power consumption, and cost of their implementation. Ensuring high noise immunity and secrecy of data transmission can be achieved by using barker-like codes and means of adapting their bit depth to the noise value. The aim of the study is to develop adaptive barker-like coding and data transmission with high technical and operational parameters. An improved method for synthesizing barker-like codes is presented and an adaptive barker-like coding/decoding method is developed, which, taking into account the signal-to-noise ratio, provides high noise immunity and reduces data transmission time. The synthesis of a barker-like code sequence is carried out using the unique properties of "ideal ring bundles". The use of the developed method of adaptive barker-like coding/decoding ensures the creation of the main components of the data protection and transmission system with high technical and operational parameters.

Keywords

Adaptive data encoding and decoding, Barker-like code, ideal ring bundles.

1. Introduction

Relevance of the problem. When remotely controlling mobile robotic platforms, one of the key tasks is to ensure a stable and secure communication channel between the platforms and the control point. To achieve the required level of cryptographic protection and interference immunity, it is necessary to develop mobile onboard encryption systems that combine high resistance to interference with excellent technical and economic characteristics. This requires the introduction of a modern component base, as well as the creation of new methods, algorithms and structures that ensure effective software and hardware implementation of the processes of encryption, decryption, encoding and decoding of information. A significant increase in the reliability and confidentiality of data transmission can be achieved by using Barker codes with adaptation of their bit depth to the level of interference. In this regard, the task of creating a data encoding and transmission system based on the use of Barker codes, which combines high technical and operational performance, is of particular relevance [1, 2].

The study proposed the creation of an adaptive coding system based on Barker-like codes to organize reliable information transmission with increased technical and operational performance.

To achieve this goal, it is necessary to solve the following key tasks:

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- analysis of recent research and publications;
- selection of the approach and principles for developing a Barker-type coding and data transmission system;
- development of the design of fixed and movable parts of the Barker-type coding and data transmission system;
- software implementation of components of the Barker-type coding and data transmission system;
- development of hardware for the Barker-type coding and data transmission system;
- testing and evaluation of the parameters of the developed components.

The object of research are information processes related to encryption and decryption based on the use of Barker-like codes, as well as the procedure for encoding, decoding and transmitting data.

Subject of study covers the structural organization of the information encoding and transmission system using Barker-like codes, as well as approaches, algorithmic solutions and technical means of implementing its main functional elements. The scientific novelty of the study is:

- an improved method for synthesizing barker-like code;
- the developed adaptive method of Barker-like coding/decoding, which, taking into account the signal-to-noise ratio, provides high resistance to interference and reduces the data transmission time.

The practical significance of the obtained results of using the developed method of adaptive barker-like coding/decoding ensures the creation of the main components of the data protection and transmission system with high technical and operational parameters.

Ensuring a high level of information security is important in various cyber-physical systems [3, 4] and in the application of wireless sensor networks for intelligent systems [5]. Many different methods are used to protect information, but given the rapid spread of unauthorized access to confidential information, improving information security methods is extremely important [6, 7].

The creation of mobile onboard cryptographic protection and interference-resistant coding with high technical and economic performance requires the widespread use of a modern component base, the development of new methods, algorithms and structures aimed at the efficient software and hardware implementation of encryption-decryption and data encoding-decoding algorithms.

Achieving high resistance to interference and confidentiality of data transmission is possible through the use of Barker-type codes and methods of adapting their bit depth to the magnitude of interference. In this context, the problem of developing a system for encoding and transmitting data based on a barker-like coding system characterized by high technical and operational parameters becomes particularly relevant.

The aim of the study is to develop an adaptive barker-like coding and data transmission system with high technical and operational parameters.

2. Related works

In general, cyber-physical systems are closely related to Internet of Things (IoT) systems. The rapid evolution of cyber-physical systems is expanding the range of services and applications for people in various fields, including smart homes, e-health, e-commerce, etc. The Internet of Medical Things (IoMT) is being used to ensure the reliability and efficiency of healthcare operations to respond to patient needs efficiently and effectively. However, various issues and challenges, such as lack of security and privacy measures, require the implementation of appropriate security measures to increase the resilience of the IoMT to cyber-attacks. Such security measures for IoMT should provide a trade-off between security and system performance. In paper [8] proposes a security solution to detect, prevent attacks, and mitigate or remediate the damage from such attacks in order to preserve

patient privacy. The interconnection of the cyber and physical worlds requires reliable means of information security. Therefore, it is important to use appropriate technologies, applications and standards. Vulnerabilities, threats and security attacks on cyber-physical systems require the use of appropriate security measures [9].

Trends in the development of embedded cryptographic systems for mobile platforms indicate a growing interest in specialized encryption and decryption algorithms [10, 11]. Some studies [12, 13] indicate that existing approaches are not designed for use in the context of creating autonomous onboard cryptographic complexes.

Analysis of publications [14, 15] shows that existing cryptographic protection methods are not oriented towards their use in building on-board systems for cryptographic protection of information for mobile devices.

Papers [16, 17] consider methods for synthesizing Barker-type sequences and interference-resistant encoding/decoding algorithms using Barker-type codes. The disadvantage of the considered methods is the inability to adapt the bit depth of Barker-type codes to the size of the interference [18].

The key problem in building embedded systems is the choice of a noise-resistant coding method for secure data transmission and reception [19]. Barker codes allow for the practical implementation of secure data reception/transmission, but the length of Barker codes is limited to 13. Therefore, a relevant scientific problem is to find and build Barker-like codes with a length greater than 13 with characteristics close to Barker codes.

Taking into account the intensive increase in the number of users of embedded systems, the problem of finding Barker-like codes of different lengths with the ability to adapt to the number of errors found and corrected arises. And this is problematic, since at present there are no regular methods for building Barker-like codes [20].

3. Main results of the study

3.1. Development of the architecture of the Barker-like coding and data transmission system.

Choosing an approach and development principles. The creation of a hardware-software complex for encoding and transmitting data between a remote-control center and a mobile platform should be based on an integrated approach that includes:

- formalization of cryptographic principles of encryption/decryption;
- modeling and development of flexible coding structures with adaptation to Barker-like codes;
- formation of new algorithms for constructing Barker-like codes with cryptographic functionality.

The aim of the work is to develop hardware and software for a data encoding and transmission system between a remote control center and a mobile robotic platform, using the following principles:

- platform based on variable hardware architecture with a processor core and modular expandability;
- structural modularity, which involves separate implementation of each functional block of the system;
- use of open source programs focused on scalability and support of standard software;
- full adaptation of the software and hardware part to the specifics of encoding/decoding algorithms;
- the ability to change the length of the Barker-like code programmatically.

The efficiency of using methods based on barker-like codes is closely related to the chosen form of implementation.

Software implementation involves the use of microprocessor or microcontroller platforms. In this case, the computational processes are distributed in time and require intensive exchange between RAM and executive elements. The use of flexible software tools allows you to optimize the execution speed and code volume, while maintaining control over accuracy.

Hardware implementation, in turn, provides the implementation of parallel calculations in space and time without the need for a large amount of intermediate exchange. This simplifies the control logic and improves system performance.

A combined approach, where computational cores are supplemented with configurable logical blocks, turns out to be the most practical for implementing systems based on Barker codes.

It is worth emphasizing that exclusively software or purely hardware implementation of encoding and decoding algorithms based on Barker-like sequences is rarely found in practice. Typically, the implementation of such algorithms is carried out using a processor core, which functions in combination with hardware modules, in particular configurable logical devices [21].

Development of the structure of the fixed part of the Barker-like coding and data transmission system. The main task of designing an encoding system based on Barker-like codes, which should provide high technical and operational characteristics, is to reduce the cost of equipment while simultaneously meeting the established requirements and technical limitations [22].

The construction of an encoding and information transmission system based on the principles of using Barker-like codes involves the presence of two components: a stationary module - a remote control center, and a mobile node integrated into the robotic platform.

The scheme of constructing a stationary block of the encoding and data transmission system using Barker-like codes is shown in Fig. 1.

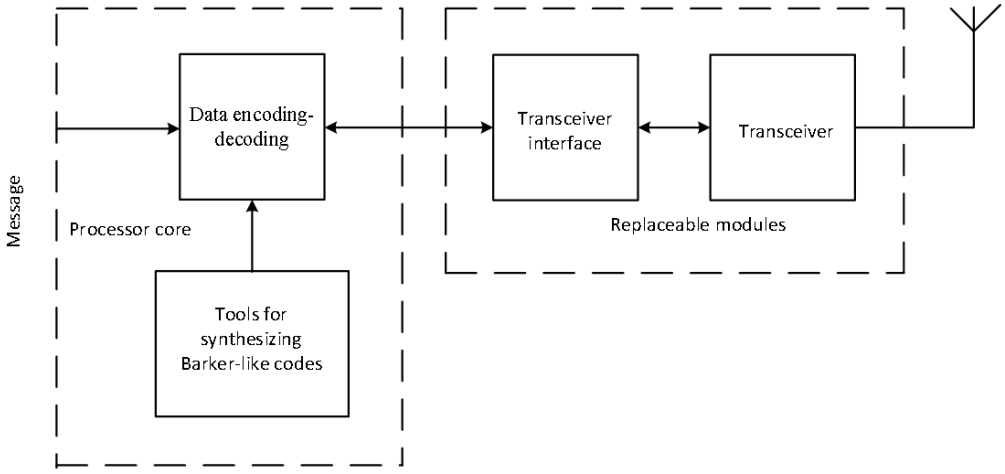

Figure 1: Structure of the stationary part of the Barker-like coding and data transmission system.

The control center is based on a personal computer using the Intel IA-64 processor architecture. Some of the interface solutions are implemented in the form of software components that provide interaction with the operator to transmit control signals to the object. The received commands and information undergo a decryption stage and are transmitted to the mobile module of the data protection and transmission system, which operates on the basis of principles similar to barker-like codes. The transmitter is responsible for the physical transmission of encrypted messages via a radio channel. It is connected to the computing core using standard interface means and is under the control of a microcontroller.

Development of a mobile structure for a Barker-like coding and data transmission system. The mobile module of the system for encoding and transmitting information based on Barker-like codes is implemented using a processor core, which can be supplemented with specialized hardware or

software if necessary. The architectural basis of this processor core is a modern microcomputer that provides the necessary performance and flexibility.

The block diagram of the mobile part of the system, which provides encoding and transmitting data based on Barker-like codes, is shown in Fig. 2.

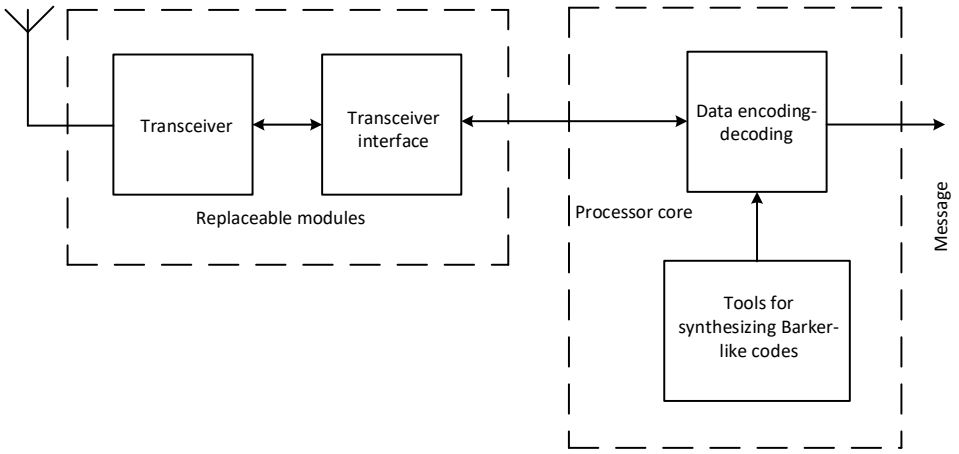

Figure 2: Structure of the mobile part of the Barker-like coding and data transmission system.

The main elements of the mobile unit of the data transmission and encoding system, which operates on the basis of Barker-like codes, include: a radio receiver, an interface for interaction with the receiver, modules for generating Barker-like codes, as well as devices for encoding and decoding information [23, 24].

The implementation of the mobile part is carried out on the basis of modern microcomputer and microcontroller platforms using a combination of universal solutions and highly specialized technologies - both hardware and software. This approach ensures that the system meets the requirements for dimensions, weight characteristics and energy efficiency.

3.2. Improvement of the adaptive Barker-like data encoding/decoding method.

The formation of Barker-like code sequences is carried out due to the unique characteristics of "ideal ring bundles" (IRBs) - these are sequences of integers with a cyclic structure, in which all n numbers, including the sums of adjacent elements, cover the set of natural numbers *R* times [25, 26]. Such a multi-position code sequence, resistant to interference and built on the basis of IRBs, is called a Barker-like code. To create a Barker-like code of length S_n using IKV, you need to select a line with S_n, number the positions of the one-dimensional array, assign ones to those positions whose indices match the numbers *xj*, and fill the rest with zeros. The code positions corresponding to the number *xj* are determined as follows:

$$x_j - 1 \equiv \sum_{i=1}^{j} k_i (mod(S_n), \mathrm{j} = 1,2 \dots \mathrm{n}, \tag{1}$$

$$S_n = n\frac{(n-1)}{R} + 1, \tag{2}$$

where k_i – *i*-th element of the IRB; *n, R* – parameters of the IRB.

The resulting sequence of binary symbols is a combination that forms a code sequence, otherwise $S_n - 1$ code sequences are created by cyclic shifting, where the code distance:

$$d_{min} = 2(n - R). \tag{3}$$

Using this Barker-like code sequence, which depends on the parameters *n* and *R*, allows finding the following number of errors:

$$t_1 \leq 2(n-R)-1. \quad (4)$$

Depending on the parameters *n* and *R* of this Barker-like code sequence, it is possible to correct the following number of errors:

$$t_2 \leq n-R-1. \quad (5)$$

Using formulas (1) and (2), a Barker-like code sequence is synthesized, which is used for data encoding [27, 28]. For the encoding and decoding processes using Barker-like codes, a method has been developed that allows adapting the code length to the level of noise interference.

The encoding and decoding procedure using this method consists of the following steps:

1. Determining the length m and selecting the type of Barker-like code for encoding information.
2. Performing element-by-element encoding of the number, starting from the most significant bit: if the i-th bit of the number is equal to logical 0, the Barker-like code is transmitted; if the i-th bit is equal to logical 1, the inversion of the Barker-like code is sent.
3. Transmitting the i-th bit in the form of an m-bit Barker-like code.
4. Setting the selected Barker-like code of length m for further decoding.
5. Receiving the i-th bit encoded with an m-bit Barker-like code.
6. Applying the logical operation XOR (exclusive OR) between the given m-bit Barker-like code and the obtained m-bit value of the i-th encoded bit.
7. Formation of the result of the XOR operation: (exclusive OR) logical 0 means the same values at the inputs, logical 1 means different values.
8. Summing m results of the execution of the logical operation *Exclusive* OR and obtaining the *sum* Cm_{ExOR}.
9. Comparison of the calculated amount Cm with meaning (*m*+1)/2 and formation of the decoded i_{∂}-th to discharge according to the formula:

$$i_d = \begin{cases} 0, \ if & Cm_{ExOR} < (m+1)/2 \\ 1, \ if & Cm_{ExOR} \geq (m+1)/2 \end{cases}. \quad (6)$$

10. Determining the number of digits k_{err}, which are with errors by the following formula:

$$k_{err} = \begin{cases} m - Cm_{ExOR}, \ if & i_d = 1 \\ Cm_{ExOR}, & if \quad i_d = 0 \end{cases}. \quad (7)$$

11. Analysis k_{err} and the choice of reducing or increasing the length of the Barker-like code.

3.3. Implementation of basic components of a Barker-like coding and data transmission system.

Dependence of the number of corrected errors k_{err} on the code length S_n is shown in Fig. 3. This figure shows a graph for the 27 values of S_n shown on the right of the figure. From the figure, we can see that at first there is a rapid increase in the value of k_{err}, and then there is a smooth change with a gradual reaching of an almost constant value of k_{err}.

The use of this developed method provides high immunity to interference and reduces data transmission time.

An important stage is the proper software implementation of the main components of the Barker code-based coding and data transmission system. The software implementation of the components of the Barker code-based coding and data transmission system involves the use of computing resources of all processor cores. The system modules are written in the high-level C++ language, which ensures software compatibility of both stationary and mobile parts, as they are designed for different hardware platforms.

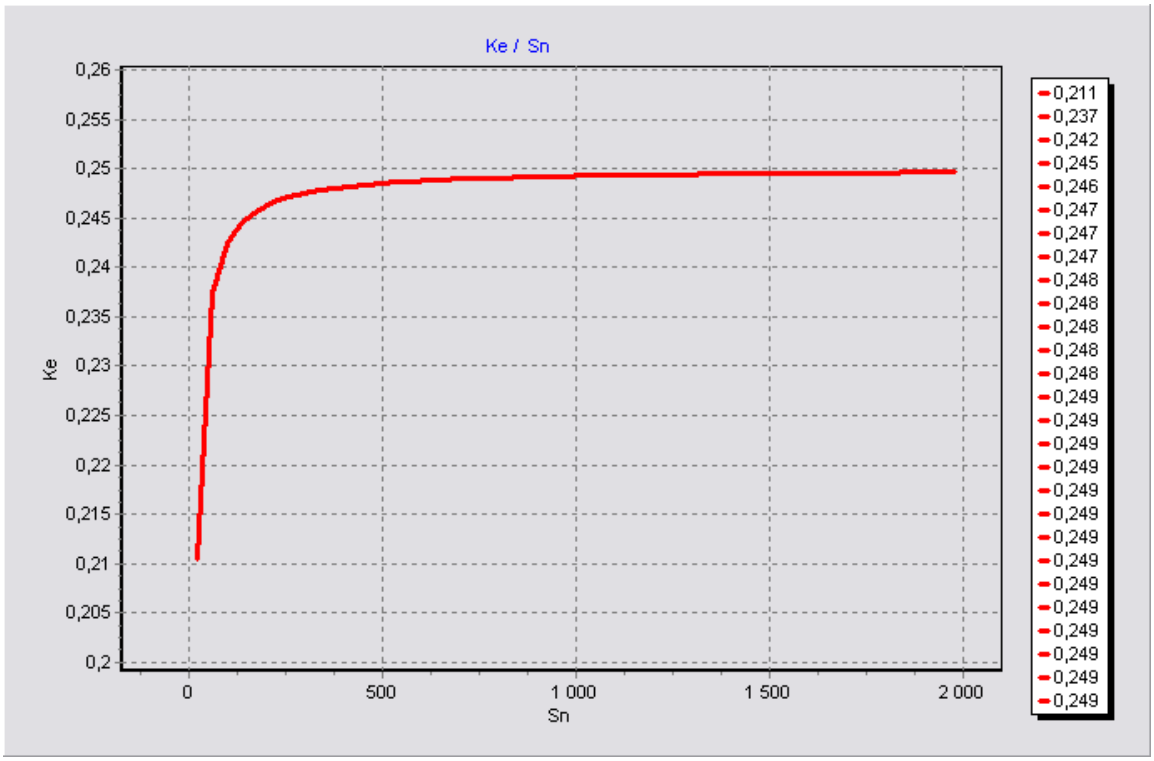

Figure 3: Dependence of the number of corrected errors k_{err} on the code length S_n.

This approach makes it possible to create, debug and improve software using a computer, as well as to modify modules of mobile devices based on microcomputers [29].

The debugging of the developed modules, their objective testing, detection and elimination of errors were performed autonomously. After that, the ready and tested software components were integrated into a single complex that provides the performance of the tasks of encoding (decoding) and data transmission using Barker codes.

The software complex of the Barker-like code-based encoding, decoding and data transmission system includes the following main components: an encoder based on Barker-like codes, a decoder with a similar approach and a Barker-like code synthesis module. These software components are implemented on an open source basis, which allows them to be expanded and debugged independently of each other [29].

The research results have practical applications for embedded smart systems with wireless control. The noise-resistant Barker-like code allows for reliable wireless data reception/transmission with error detection and correction for embedded smart systems [29, 30].

Conclusion

It is proposed to create a data encoding and transmission system using the Barker code method, which is characterized by high technical and operational indicators. For this purpose, a comprehensive approach is used, which includes: research and development of theoretical foundations of cryptographic encryption and decryption of data based on the Barker-like code method, as well as the study and development of theoretical foundations of the synthesis of Barker-like codes of the type and methods of encoding/decoding information.

The method of data encryption and decryption using Barker-like coding has been improved, which, due to the parallelization of the process, provides a significant reduction in the encoding/decoding time for a software solution.

An adaptive encoding/decoding method based on Barker-like codes has been developed, which, taking into account the signal/noise ratio, guarantees high resistance to interference and reduces data transmission time.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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