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METHOD FOR DIAGNOSING DATA ERRORS OF A COMPUTER SYSTEM FUNCTIONING IN THE SYSTEM OF RESIDUAL CLASSES

Abstract. The **subject** of the article is the development of a method for diagnosing data errors of a computer system functioning in the residue number system (RNS). This method is based on the tabular principle of data diagnostics operation implementation. The **purpose** of the article is to reduce the time of performing the operation of diagnosing the data of a computer system that functions in the RNS in the dynamics of the computational process. **Tasks**: to analyze the possible application of RNS as a number system in computer data processing systems; to investigate existing methods of data diagnostics and identify possible shortcomings in data diagnostics in the dynamics of the computational process with the introduction of minimal information redundancy; to develop a method for diagnosing the data presented in the RNS, which is based on the tabular principle of the implementation of the diagnostic operation. **Research methods**: methods of analysis and synthesis of computer systems, number theory, coding theory in RNS. The following **results** were obtained. The work shows that the data diagnostics is carried out after the control operation has been performed. To carry out the operation of diagnosing data in the RNS, when one-time errors occur, methods for determining an alternative set (AS) of numbers are used. In this case, the main disadvantage of the considered methods is the considerable time required to determine the AS. To reduce the time for determining the AC numbers in the work, the method for diagnosing data in the RNS has been improved. Improvement of the method involves the compilation of a table (the first stage) of correspondence to each correct number of a possible set of incorrect numbers when one-time errors occur in the data. Based on the analysis of the contents of the table of the first stage, a table (of the second stage) is drawn up of the correspondence of each incorrect number to the possible values of the correct numbers. **Conclusions**. The use of the improved method increases the efficiency of diagnostics of the data presented in the RNS by reducing the time for determining the AC numbers. This is achieved by quickly fetching pre-calculated AC table values.

Keywords: number system; residue number system; computer system; data diagnostics; table implementation.

Introduction

The modern life stage of science and technology development involves perplexing tasks, which require prompt resolving. However, the complexity of these tasks outstrips the pace of computational power ascension of the universal computers. In this, the principal directions of computational system enhancement of real-time data processing are its performance maximization. It's known that one of the possible directions of high-performance computational systems development is to parallelize tasks and algorithms on the level of arithmetical microoperations. One of the ways of parallel task solving is to make a transition to the nonconventional machine arithmetic with alternative operands representation. If to choose out of numerous nonconventional arithmetic the most practical use in computational systems belongs to the non-positional numeral system in residue classes – residue number system (RNS) [1-3].

The set of RNS beneficial properties defines the following classes of tasks, where it's significantly more efficient than a positional arithmetic: cryptographic and modular transformations (implementation of cryptographic transformations in a group of elliptic curve dots, as well as algorithm realization for hashing and random numbers generations [4-7]), signal processing, image processing (compression), real-time large number of bits (hundreds of bits) integer data processing, vector and matrix informational array processing in bulk, neural computer information processing, FFT and DFT algorithm realization and optoelectronic table information processing [8-11].

In fact, its required to determine the alternative set (AS) in RNS $W(\tilde{A})=\left\{m_{l_1}, m_{l_2}, ..., m_{l_\rho}\right\}$ of the incorrect $\tilde{A}=(a_1, a_2, ..., a_{i-1}, a_i, a_{i+1}, ..., a_n)$ numbers. By the AS $W(\tilde{A})=\left\{m_{l_1}, m_{l_2}, ..., m_{l_\rho}\right\}$ of the incorrect (corrupted) number $\tilde{A}=(a_1, a_2, ..., a_{i-1}, a_i, a_{i+1}, ..., a_n)$ meant the set $\left\{m_{l_\kappa}\right\}$ $(\kappa=\overline{1,\rho})$ of ρ RNS bases, upon which the correct (not corrupted) number (codeword) $A=(a_1, a_2, ..., a_{i-1}, a_i, a_{i+1}, ..., a_n)$ may differ from the given set $\{\tilde{A}\}$ of possible derived incorrect numbers. This also suggests, that only a single (by one of the residues m_i $(i=\overline{1, n+1})$ of the number $A=$ $=(a_1, a_2, ..., a_{i-1}, a_i, a_{i+1}, ..., a_n)$) error (corruption of one of $(n+1)$ residues) may occur in the correct number A.

Noting that AS is considered when a minimal information redundancy is introduced to RNS, by applying a single ($k=1$) additional (check) RNS base m_{n+1} to n informational basis, given that $m_i < m_{n+1}$, $i=\overline{1, n}$. In this case the total amount N_{TA} of RNS codewords is $N_{TA}=\prod_{i=1}^{n+1} m_i$. The amount of N_{CC} correct codewords is $N_{CC}=\prod_{i=1}^{n} m_i$, as the amount of N_{IC} incorrect (corrupted) codewords is equal to $N_{IC}=N_{TC}-N_{CC}=N_{CC}\cdot(m_{n+1}-1)$.

Importance of the AS determining can occur in the following principal cases. Firstly, if the error verification, diagnosing and correction of data in RNS is required.

Secondly, when performing error verification, diagnose and correction of data in RNS in a process of task solving in computational process dynamics (CPD) (in real-time, i.e. without pausing computations) given the minimum information redundancy [2]. One of the main requirements of the AS determining procedure in RNS is the requirement to decrease a time for a given bases set determination. This requirement is especially crucial for the second case – in a process of task solving in CPD [12-15].

As can be seen, pending and important task is to develop new and improve existing methods of prompt AS numbers $W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$ determining in RNS.

The purpose of the article is to reduce the time of performing the operation of diagnosing the data of a computer system that functions in the RNS in the dynamics of the computational process.

Method for diagnosing data in a in residue number system

All existing methods of AS numbers determining are based on the sequential determining procedure of the sought bases of AS numbers in RNS [1].

As an example (first method), the AS $W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$ of the incorrect number

$$\tilde{A}=(a_1,a_2,...,a_{i-1},a_i,a_{i+1},...,a_n) \quad (1)$$

can be determined by a sequential checking of each of the RNS bases m_i, $i=\overline{1,n}$) as following. The number set having the same value of the residues over each of RNS bases, as well as the number $\tilde{A}$, is being determined, except of a one certain base, and being different only via the values of possible residues over given base. Amongst this set of number there may be no correct number, or a single correct number can be present only. In this latter case the determined number is included into the AS of the incorrect number being checked $\tilde{A}$. The considered method suggests the sequential alike verifications for each of the informational RNS bases (check bases are always contained in the AS bases). The result of such sequential verifications fully determines the AS

$$W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}. \quad (2)$$

The downsides of this method of the AS determining are high computational complexity and significant time consumption.

The second method for the AS determining is based on the subtraction of each of the possible projections

$$\tilde{A}_i=(a_1,a_2,...,a_{i-1},a_{i+1},...,a_n) \quad (3)$$

of the incorrect number $\tilde{A}$, and their following comparison to the value of the RNS defined informational range. As it proved [2], the necessary and sufficient condition for RNS base appearance in the AS $W(\tilde{A})$ of the number $\tilde{A}$ is its projections $\tilde{A}_i$ are being correct. The second method application slightly improves the AS determining process $W(\tilde{A})$ of the number

$$A=(a_1,a_2,...,a_{i-1},a_i,a_{i+1},...,a_n), \quad (4)$$

because of the ability of simultaneous determining of the possible projections $\tilde{A}_j$ of the incorrect number. Given circumstance decreases the time factor difficultness of the AS determining. However, the AS number determining procedure contains following basic operations: number A conversion from RNS to PNS; projections $\tilde{A}_i$ conversion of the incorrect number A from RNS to PNS and the comparison procedure of numbers. Listed operations in RNS are referring to as non-positional operations, which require significant time and hardware investments for implementation. The downsides of the mentioned method of the AS determining are the same as in the first method: significant computational complexity and significant time consumption. Therefor there remains the task to improve the second viewed method in terms of reducing time of the AS determining.

The improvement of the acquainted second method is to reduce the time needed to determine the AS. The mission of the introduced method in this article of the AS number determining in RNS is to perform the preliminary corresponding M tables compiling (first stage tables) $A=\Phi_1(\tilde{A})$ for each correct A number (contained in the numerical range $0\div M-1$), of the possible set $\left\{\tilde{A}\right\}$ of the incorrect numbers (contained in the numerical range $M\div M_0-1$) with single error (in one of the residue) occurring in the number A. Based on the analysis of the first stage tables the second stage table is being compiled, which contains the correspondence $\tilde{A}=\Phi_2(A)$ of each incorrect $\tilde{A}$ number out of the numerical range $M\div M_0-1$ to the possible values of the corrected (non-corrupted) A numbers.

The amount of the correct A numbers corresponds to the amount of the RNS basis, that are contained in the AS $W(\tilde{A})$ of the A number. The stages of implementation of the improved method for determining the AS in the RNS are shown in Fig. 1.

It's appropriate to consider the application of the introduced method of the AS determining for a particular RNS, that is defined by the informational $m_1=2$, $m_2=3$ and check $m_k=m_3=m_{n+1}=5$ basis ($M=2\cdot3=6$; $M_0=30$).

By each of the correct codewords 0-5 following fist stage $A=\Phi_1(\tilde{A})$ corresponding tables are compiled (Tables 1).

Table 2 shows the algorithm for the AS $W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$ numbers determining in RNS.

According to these tables the second stage $\tilde{A}=\Phi_2(A)$ Table 7 is being compiled. Table 7 shows the correspondence $\tilde{A}=\Phi_2(A)$ of each incorrect $\tilde{A}$ number out of numerical range 6-29 to a possible values of the corrected (non-corrupted) A numbers.

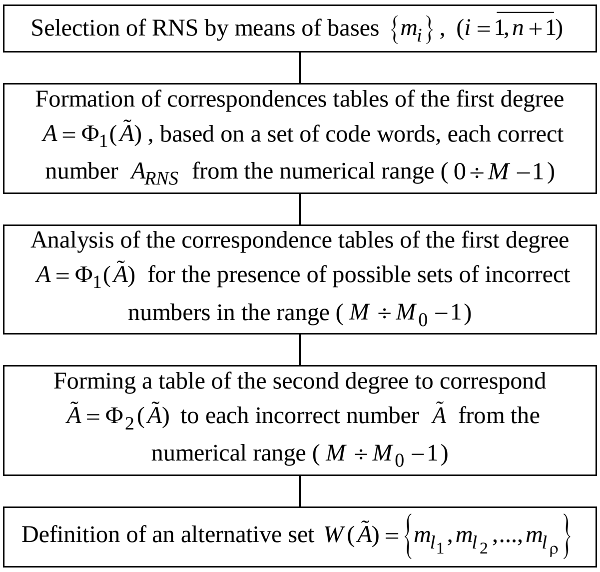

Fig. 1. An improved method
for determining the alternative set in the RNS

Table 1 – **First stage correspondence table**

0	0	0	0	1	1	1	1
15	1	0	0	16	0	1	1
10	0	1	0	21	1	0	1
20	0	2	0	11	1	2	1
6	0	0	1	25	1	1	0
12	0	0	2	7	1	1	2
18	0	0	3	13	1	1	3
24	0	0	4	19	1	1	4
2	0	2	2	3	1	0	3
17	1	2	2	18	0	0	3
12	0	0	2	13	1	1	3
22	0	1	2	23	1	2	3
20	0	2	0	15	1	0	0
26	0	2	1	21	1	0	1
8	0	2	3	27	1	0	2
14	0	2	4	9	1	0	4
4	0	1	4	5	1	2	0
19	1	1	4	20	0	2	0
24	0	0	4	15	1	0	0
14	0	2	4	25	1	1	0
10	0	1	0	11	1	2	1
16	0	1	1	17	1	2	2
22	0	1	2	23	1	2	3
28	0	1	3	29	1	2	4

Table 7 – **Second stage correspondence table**

Incorrect $\tilde{A}$ number	Correct A number	AS value $W(\tilde{A})$
$\tilde{A}_6=(0\|\|0\|\|1)$	$A_0=(0\|\|0\|\|0)$	$W(\tilde{A}_6)=\{m_3\}$
$\tilde{A}_7=(1\|\|1\|\|2)$	$A_1=(1\|\|1\|\|1)$	$W(\tilde{A}_7)=\{m_3\}$
$\tilde{A}_8=(0\|\|2\|\|3)$	$A_2=(0\|\|2\|\|3)$	$W(\tilde{A}_8)=\{m_3\}$
$\tilde{A}_9=(1\|\|0\|\|4)$	$A_3=(1\|\|0\|\|3)$	$W(\tilde{A}_9)=\{m_3\}$
$\tilde{A}_{10}=(0\|\|1\|\|0)$	$A_0=(0\|\|0\|\|0)$ $A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{10})=\{m_2,m_3\}$
$\tilde{A}_{11}=(1\|\|2\|\|1)$	$A_1=(1\|\|1\|\|1)$	$W(\tilde{A}_{11})=\{m_2,m_3\}$
	$A_5=(1\|\|2\|\|0)$	

Закінчення табл. 1

Incorrect $\tilde{A}$ number	Correct A number	AS value $W(\tilde{A})$
$\tilde{A}_{12}=(0\|\|0\|\|2)$	$A_0=(0\|\|0\|\|0)$ $A_2=(0\|\|2\|\|2)$	$W(\tilde{A}_{12})=\{m_2,m_3\}$
$\tilde{A}_{13}=(1\|\|1\|\|3)$	$A_1=(1\|\|1\|\|1)$ $A_3=(1\|\|0\|\|3)$	$W(\tilde{A}_{13})=\{m_2,m_3\}$
$\tilde{A}_{14}=(0\|\|2\|\|4)$	$A_2=(0\|\|2\|\|2)$ $A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{14})=\{m_2,m_3\}$
$\tilde{A}_{15}=(1\|\|0\|\|0)$	$A_0=(0\|\|0\|\|0)$ $A_3=(1\|\|0\|\|3)$ $A_5=(1\|\|2\|\|0)$	$W(\tilde{A}_{15})=\{m_1, m_2, m_3\}$
$\tilde{A}_{16}=(0\|\|1\|\|1)$	$A_1=(1\|\|1\|\|1)$ $A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{16})=\{m_1,m_3\}$
$\tilde{A}_{17}=(1\|\|2\|\|2)$	$A_2=(0\|\|2\|\|2)$ $A_5=(1\|\|2\|\|0)$	$W(\tilde{A}_{17})=\{m_1,m_3\}$
$\tilde{A}_{18}=(0\|\|0\|\|3)$	$A_0=(0\|\|0\|\|0)$ $A_3=(1\|\|0\|\|3)$	$W(\tilde{A}_{18})=\{m_1,m_3\}$
$\tilde{A}_{19}=(1\|\|1\|\|4)$	$A_1=(1\|\|1\|\|1)$ $A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{19})=\{m_1,m_3\}$
$\tilde{A}_{20}=(0\|\|2\|\|0)$	$A_0=(0\|\|0\|\|0)$ $A_2=(0\|\|2\|\|2)$ $A_5=(1\|\|2\|\|0)$	$W(\tilde{A}_{20})=\{m_1, m_2, m_3\}$
$\tilde{A}_{21}=(1\|\|0\|\|1)$	$A_1=(1\|\|1\|\|1)$ $A_3=(1\|\|0\|\|3)$	$W(\tilde{A}_{21})=\{m_2,m_3\}$
$\tilde{A}_{22}=(0\|\|1\|\|2)$	$A_2=(0\|\|2\|\|2)$ $A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{22})=\{m_2,m_3\}$
$\tilde{A}_{23}=(1\|\|2\|\|3)$	$A_3=(1\|\|0\|\|3)$ $A_5=(1\|\|2\|\|0)$	$W(\tilde{A}_{23})=\{m_2,m_3\}$
$\tilde{A}_{24}=(0\|\|0\|\|4)$	$A_0=(0\|\|0\|\|0)$ $A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{24})=\{m_2,m_3\}$
$\tilde{A}_{25}=(1\|\|1\|\|0)$	$A_1=(1\|\|1\|\|1)$ $A_5=(1\|\|2\|\|0)$	$W(\tilde{A}_{25})=\{m_2,m_3\}$
$\tilde{A}_{26}=(0\|\|2\|\|1)$	$A_2=(0\|\|2\|\|2)$	$W(\tilde{A}_{26})=\{m_3\}$
$\tilde{A}_{27}=(1\|\|0\|\|2)$	$A_3=(1\|\|0\|\|3)$	$W(\tilde{A}_{27})=\{m_3\}$
$\tilde{A}_{28}=(0\|\|1\|\|3)$	$A_4=(0\|\|1\|\|4)$	$W(\tilde{A}_{28})=\{m_3\}$

Let's review the example of the AS number determining in RNS using the introduced in this article table method. Given the incorrect number $\tilde{A}_{15}=(1\|\|0\|\|0)$ (Table 4).

Number's AS should be determined. Initially six correspondence tables are being compiled (Tables 1-6) of the first stage for each correct

$$A=(a_1, a_2, ..., a_{i-1}, a_i, a_{i+1}, ..., a_n)$$

number (out of numeral range 0-5) for the possible set of incorrect numbers (out of numeral range 6-29) when single errors (in one of the residues) occur in the number A. Based on the analysis of the first stage table content the second stage table is compiled, that contains the correspondence for each incorrect number out of numeral range 6-29 to the possible corrected (non-corrupted) values $A=(a_1,a_2,...,a_{i-1},a_i,a_{i+1},...,a_n)$ of numbers. The amount of correct A numbers corresponds to the amount of RNS bases, that are contained in the AS

$$W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$$

of the A number. Influenced by single errors occurrence the incorrect number $\tilde{A}_{15}=(1\|0\|0)$ can be formed by the following correct A numbers.

Firstly, the correct number $A_0=(0\|0\|0)$ (Table 5) might be corrupted in its first residue $a_1=0$ $(\tilde{a}_1=1)$.

Secondly, the correct number $A_3=(1\|0\|3)$ (Table 8) might be corrupted in ins third residue $a_3=3$ $(\tilde{a}_3=0)$. And, lastly, the incorrect number $A_5=(1\|2\|0)$ (Table 6) might be corrupted in its second residue $a_2=2$ $(\tilde{a}_2=0)$. In this case the AS

$$W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$$

of the incorrect number $\tilde{A}_{15}=(1\|0\|0)$ is equal to the value $W(\tilde{A}_{15})=\{m_1,m_2,m_3\}$ (Table 7).

Conclusions

The method of determining the alternative set of numbers, which is based on the implementation of correspondence functions of possible errors values, by forming correspondence tables of the correct number of possible set of incorrect numbers, which allows to increase the efficiency of error diagnosis in RNS.

This method usage as opposed to other existing methods, allows to significantly reduce time needed for the AS number determining. Firstly, this is achieved by decreasing the amount of RNS bases being checked, that indicate the possibility of the correct number's $A=(a_1,a_2,...,a_{i-1},a_i,a_{i+1},...,a_n)$ residues to be corrupted. And, secondly, due to introduction of the fast (table-based) selection of preliminary calculated AS $W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$ values.

Time reduction for AS number's $W(\tilde{A})=\left\{m_{l_1},m_{l_2},...,m_{l_\rho}\right\}$ determining may subsequently increase the performance of the error verification, diagnosing and correction of data in RNS. Also, this feature will increase the efficiency of using non-positional code structures when creating computer systems and components [16-18].

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Метод діагностики помилок даних комп'ютерної системи, що функціонує у системі залишкових класів

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Анотація. **Предметом** статті є розробка методу діагностики помилок даних комп'ютерної системи функціонує у системі залишкових класів (СЗК). Даний метод ґрунтується на табличному принципі реалізації операції діагностики даних. **Метою** статті є зменшення часу виконання операції діагностики даних комп'ютерної системи, яка функціонує у СЗК в динаміці обчислювального процесу. **Задачі**: провести аналіз можливого застосування СЗК як системи числення у комп'ютерних системах обробки даних; дослідити існуючі методи діагностики даних і виявити можливі недоліки при діагностиці даних у динаміці обчислювального процесу при введенні мінімальної інформаційної надмірності; розробити метод діагностики даних представлених у СЗК, який заснований на табличному принципі реалізації операції діагностики даних. **Методи** дослідження: методи аналізу і синтезу комп'ютерних систем, теорія чисел, теорія кодування у СЗК. Отримані наступні **результати**. В роботі показано, що діагностика даних проводиться після виконання операції контролю. Для проведення операції діагностики даних у СЗК, при виникненні однократних помилок, використовуються методи визначення альтернативної сукупності (АС) чисел. При цьому основним недоліком розглянутих методів є значний час, необхідний для визначення АС. Для зменшення часу визначення АС чисел в роботі удосконалено метод діагностики даних у СЗК. Удосконалення методу передбачає складання таблиці (першого ступеня) відповідності кожному правильну числу можливій сукупності неправильних чисел при виникненні у даних однократних помилок. На підставі аналізу вмісту таблиці першого ступеня, складається таблиця (другого ступеня) відповідності кожного неправильного числа можливим значенням правильних чисел. **Висновки**. Використання вдосконаленого методу підвищує ефективність діагностики даних, які представлені у СЗК, за рахунок зменшення часу визначення АС чисел. Це досягається за рахунок швидкої вибірки попередньо розрахованих табличних значень АС чисел.

Ключові слова: система числення; система залишкових класів; комп'ютерна система; діагностика даних; таблична реалізація.

Метод диагностики ошибок данных компьютерной системы, функционирующей в системе остаточных классов

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Аннотация. Предметом статьи является разработка метода диагностики ошибок данных компьютерной системы функционирующей в системе остаточных классов (СОК). Данный метод основывается на табличном принципе реализации операции диагностики данных. **Целью** статьи является уменьшение времени выполнения операции диагностики данных компьютерной системы, которая функционирует в СОК в динамике вычислительного процесса. **Задачи**: провести анализ возможного применения СОК как системы счисления в компьютерных системах обработки данных; исследовать существующие методы диагностики данных и выявить возможные недостатки при диагностике данных в динамике вычислительного процесса при введении минимальной информационной избыточности; разработать метод диагностики данных представленных в СОК, который основан на табличном принципе реализации операции диагностики. **Методы исследования**: методы анализа и синтеза компьютерных систем, теория чисел, теория кодирования в СОК. Получены следующие **результаты**. В работе показано, что диагностика данных проводится после выполнения операции контроля. Для проведения операции диагностики данных в СОК, при возникновении однократных ошибок, используются методы определения альтернативной совокупности (АС) чисел. При этом основным недостатком рассмотренных методов является значительное время, необходимое для определения АС. Для уменьшения времени определения АС чисел в работе усовершенствован метод диагностики данных в СОК. Усовершенствование метода предполагает составление таблицы (первой ступени) соответствия каждому правильному числу возможной совокупности неправильных чисел при возникновении в данных однократных ошибок. На основании анализа содержимого таблицы первой ступени, составляется таблица (второй ступени) соответствия каждого неправильного числа возможным значениям правильных чисел. **Выводы**. Использование усовершенствованного метода повышает эффективность диагностики данных, которые представлены в СОК за счет уменьшения времени определения АС чисел. Это достигается за счет быстрой выборки предварительно рассчитанных табличных значений АС чисел.

Ключевые слова: система счисления; система остаточных классов; компьютерная система; диагностика данных; табличная реализация.