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(54) **System for transmitting television picture information using transform coding of subpictures.**

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EP 0 083 127 B1

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Description

The invention relates to a system for transmitting information of a television picture over a medium, said television picture being organized in television lines and pixels within each line, and being distributed over a plurality of subpictures of uniform dimensions, said system comprising a transformation device for receiving the information of a subpicture for transform into a series of *a* coefficient bits of respective transformation functions, and comprising an encoder for encoding a subset of *k* bits of said *a* coefficient bits into a larger group of *n* bits by means of a code having at least single error correction capability for said *k* bits, said *k* bits containing at least one bit associated to at least one lowest frequency transformation function as most significant bit of the associated coefficient, an output of said transformation device being connected to an input of said medium, said system furthermore comprising a display apparatus which is connected to said medium and which comprises a decoder for receiving said encoded coefficient bits and for therefrom reconstructing the information of the associated subpicture. Such a system is known from the article by T. Ohira et al., Orthogonal Transform Coding Systems for NTSC Colour Television Signals, IEEE Transactions Communications, Vol. COM-26, No. 10, October 1978, pages 1545—63. The transmission medium may be a transport medium, for example, a bundle of telephone lines, or a storage medium, for example, a magnetic tape within a video cassette recorder. The encoding serves to limit the redundancy of the picture information so that the bit rate of the information to be stored or transferred is diminished. The reduction may for example be by a factor of four without lessening the subjective display quality. Suitable transformation function are Hotelling, Fourier, Hadamard or Haar functions, hereinafter only the use of Hadamard functions is treated by way of example. The reduction of the redundancy leads to a higher susceptibility to errors. The citation protects eleven bits by a single error correction code having a minimum Hamming-distance of three.

It has been found that under certain circumstances single bit error correction is insufficient. On the other hand, protection of all *k* coefficient bits by a code of increased correction capability would raise the number of bits by a too large amount. It is an object of the invention to provide improved error protection for certain coefficient bits while leaving the protection of other coefficient bits at their earlier levels. The object of the invention is realized in that it is characterized in that said code has a minimum Hamming-distance of four to allow for at least single error correction, double error detection within said *k* bits, in that said code has a second, larger, minimum Hamming-distance of at least five to allow for at least double error correction within a subset of at least two bits of said *k* bits.

In itself an extended error protection system is disclosed in US—A—3,949,208. This document, however, relates to a memory for general use and therefore the particular relevance of each stored bit is not known beforehand. Therefore, according to this citation all bits have to be equally well protected.

Coefficient bits are to be understood to mean herein the bits which are applied to the encoder of the error correction code in order to be encoded. Code bits are to be understood to mean herein the bits which form the output result of the encoder or the information supplied for the decoder. The bits which result from the analog-to-digital conversion of the picture information before it is applied to the transformation device will not be considered, and the bits which are formed after the implementation of the error correction code in order to adapt the signal to be transmitted to the specific properties of the transmission medium (modulation bits) will not be considered either.

In a particular embodiment of a system of the kind described in the preamble, it is proposed to activate the encoder selectively, under the control of subpicturewise received television picture information, to operate in one of a plurality of transformation modes, each mode having a respective set of coefficient bits applied to the medium plus a mode signalling bit group to indicate the transformation mode thus activated. This is described in the prior unpublished Netherlands Patent Application 8003873. The earlier system has a normal mode in which information is transported only as a small number of bits, for example, as a 0 bit or a 1 bit. In incidental cases this is not sufficient and for one (or some) blocks a change-over is made to such an incident mode. For some transformation functions the number of coefficient bits is then increased at the expense of other transformation functions. It is attractive to include said signalling bit group in the error protection code so that the selection of the incident modes is protected.

In a further particular embodiment of a system of the kind described in the preamble it is proposed, for use with colour television picture information which is sampled in the converter with a sample frequency fs which equal twice the color subcarrier frequency fsc at instants which coincide with the phase positions

$$\pm\frac{\pi}{4}+M\pi,$$

in which M=0, 1, 2,..., of the colour information signal u(t) in the line signal, that the transformation functions are Hadamard functions. This is described in the prior unpublished Netherlands Patent Application 8004521. According to the earlier system, the colour difference signal is embodied in only a very small number of coefficients, for example, in only two coefficients. In that case it is attractive to include the most significant coefficient bit of each of the two transformation functions representing the colour difference information in the error correction code.

Preferably, said extra-protected coefficient bits comprise the most significant coefficient bits of the transformation function which indicate the mean luminance of the relevant subpicture. It has been found that the protection of these most significant bits offers a good subjective result. The number of bit errors to be corrected preferably equals the number of bits forming the third number of coefficient bits.

The invention also relates to a picture converting device for use in a system of the described kind in which the encoder forms a non-systematic code. It has been found that, contrary to many other cases, the non-systematic code then offers an attractive compromise between means and results. Preferably, the number of data bits protected by the error correction code amounts to six and said second number preferably also amounts to six. This results in a simple implementation with usually adequate correction possibilities.

The invention also relates to a display apparatus for use in a system of the described kind in which the decoder forms a feasible series of data bits on the basis of at least one series of a number of code bits which has been found to be incorrect but not correctable. Sometimes the correction is then correctly performed but sometimes also incorrectly. However, it has been found that in many cases the extra-protected coefficient bits can still be correctly recovered.

The invention also relates to a decoder for use in a system or a display apparatus of the described which is constructed as a switching module. It may be a single integrated circuit or, for example, a module consisting of several integrated circuits.

Brief description of the figures.

The invention will be described in detail hereinafter with reference to some Figures.

Figure 1 diagrammatically shows a system in which the invention can be incorporated,

Figure 2 shows, as background information, some possibilities for the coding of a subpicture by means of Hadamard functions,

Figure 3 shows more relevant information for a subpicture consisting of 4×4 pixels,

Figure 4 shows some configurations of subpictures comprising 4×4 pixels,

Figure 5 shows five possibilities for the numbers of coefficient bits used for the elements of the series of transformation functions,

Figure 6 shows the generator matrix of a specimen code,

Figure 7 shows the set of code words formed for this code,

Figure 8 shows an encoder for this code,

Figure 9 shows the parity check matrix for the specimen code,

Figure 10 shows a table with the syndrome words which can be formed,

Figure 11 shows a block diagram of a decoder for the specimen code,

Figure 12 shows a detail of the decoder,

Figure 13 shows a table with syndrome words and associated error indication bits,

Figure 14 shows a detail of the decoder,

Figure 15 shows a table with feasible (n, k) code, and

Figure 16 shows the generator matrix of a (12, 4) code.

Figure 17 shows the relationship between code bits and (guessed) data bits for the Figures 6, 9.

Brief description of the system

Figure 1 diagrammatically shows a system in which the invention can be incorporated. Element 120 is a camera tube. The signal which is scanned line-wise is converted into a digital representation in element 122. Transformation device 146 first of all comprises a Hadamard transformation device 124 and an encoder 126 for an error correction code as will be described hereinafter. Block 128 represents an interleaving device for spreading over a larger time interval faults cause by burst errors. Block 130 represents a modulator for converting the series of code bits received into channel symbols: this series is thus adapted to the properties of the transmission medium. For example, given lower limits are implemented as regards the length of intervals without transitions (run length limitation). Line 144 represents the transmission medium which may be a storage medium or, for example, a communication channel. The elements 120 to 130 may together form part of a picture converting device, for example, a camera. Block 132 represents a demodulator for recovering the code bits from the series of channel symbols regenerated. Element 134 represents the opposite member of the block 128 and serves for de-interleaving. Element 136 represents the decoder for reconstructing or choosing the data bits from the code bits. Element 138 forms the opposite member of the block 124 for cancelling the Hadamard transformation and for recovering a binary coded amplitude signal per pixel. Element 140 represents a digital-to-analog converter. Element 142 represents the display element which is in this case constructed as a cathode ray tube. The elements 132 to 142 may form part of a display apparatus.

Description of the transformation functions

For background information Figure 2 shows some possibilities for the encoding of a subpicture by means of so-called Hadamard functions. The first eight Hadamard functions are shown over a unit time interval at the left of the Figure with bivalent amplitude (0, 1). This row of functions can be indefinitely continued. It can be demonstrated that an arbitrary function can be approximated with any desired accuracy over the unit interval by means of a series of Hadamard functions with adapted amplitude. The same is applicable to a two-dimensional subpicture, four of which are denoted by the reference numerals

20, 22, 24, 26, with bivalent density (white and shaded). Block 20 has an intensity which varies in the horizontal direction according to the function 38 and in the vertical direction according to the function 30: code 3830. The other blocks have the following codes 22: 4034; 24: 3236; 26: 4242. In the approximation of an arbitrary monochrome intensity distribution in the subpicture, the coefficients of the higher order Hadamard functions are almost always relatively small. Such a code can also be used for a polychrome picture (generally trichrome in the case of television pictures). In addition to the luminance signal two colour difference signals are applicable (for red and for blue). The variation of these colour difference signals can also be approximated by means of a series of Hadamard functions with suitable coefficients.

As a continuation Figure 3 shows the sixteen feasible Hadamard functions for approximating a subpicture comprising 4×4 pixels. It is to be noted that this can also be done with subpictures which are not square. However, hereinafter only subpictures comprising 4×4 pixels will be considered. Generally, the number of picture lines and the number of pixels per picture line preferably equals a power of the number two. The number of feasible Hadamard functions for a one-dimensional interval of p pixels (or lines) equals p. Figure 4 shows four feasible dispositions of a subpicture of 4×4 pixels, a shift of one half pixel period being allowed between the pixels of two successive picture lines. Figure 4, example 44, shows an attractive configuration of a subpicture for a PAL system and identical configurations of the subpictures; it has been found that the colour difference signals are then embodied in the functions C6 and C7 of Figure 3 (Figure 3 does not show the shift of the picture lines; furthermore, the subpicture concerns only a single frame). Figure 4, block 46, shows an attractive configuration of a subpicture for an NTSC system and identical configurations of the subpictures; it has been found that the colour difference signals are then embodied in the functions C5 and C7 of Figure 3.

By combinations of the subpictures shown in Figure 4 and possibly of their mirror images, a picture can be divided in many ways; within one picture, subpictures of mutually different configuration may also occur. For further details, reference is made to the cited Netherlands Patent Application 8004521.

The information of each subpicture is transformed by means of the set of Hadamard functions which is symbolized in Figure 3, the coefficients being represented by a bit group. Figure 5 shows five examples for the assignment of a given number of bits to each of these coefficients. The digits in the column 62 correspond to the order of the Hadamard function in Figure 2. The total number of bits in each column (being the sum of the numbers in the column) always equals 38 in Figure 5. This means that the same total dynamics can be realized for the luminance of a subpicture, because each Hadamard function has the same mean value, that is to say half the luminance "white" in Figure 3. The combination of column 60 of Figure 5 and the subpicture configuration 44 shown in Figure 4 represents an attractive realization for a PAL system in which the colour difference signals are embodied in the coefficients of the Hadamard functions C6 and C7 of Figure 3. The five columns 52 through 60 shown in Figure 5 represent the numbers of transformation modes in which the picture can be represented. Notably the first four columns represent as many selectable cases. Column 52 represents a "normal" situation with an "average" picture, and the other columns represent cases in which a coefficient which is normally small is "large" in a special case. Such a coefficient can then be represented bar a larger number of bits so that it is emphasized.

Column 54 emphasizes C5, C9, C13
Column 56 emphasizes C5, C9, C13,
Column 58 emphasizes C5, C6, C13, C9,
the emphasis being at the expense of mainly C0.

It is to be noted that such different transformation modes can also be realized when the combination of the column 60 represents the normal mode. The selection from the four (or possibly another number) transformation modes is signalled by a signalling bit group (of two bits in the case of realization according to the columns 52... 58 of Figure 5). The subpicture of 16 pixels is thus coded by 40 data bits, 38 of which are coefficient bits; this means $2\frac{1}{2}$ bit per pixel. Other adaptive transformation methods are also known per se.

Description of the error protection code.

In the embodiment in accordance with the invention, six of said 40 data bits which represent the relevant subpicture information are protected by a non-systematic (n, k)=(12, 6) code, which means that the number of bits is increased by six; however, within the set of twelve bits all bits are code bits and an original data bit may not be recovered from one associated code bit. As regards the first four columns of Figure 5, these six data bits may represent the four most significant bits of the coefficient C0 plus the two bits of the signalling bit group. Alternatively, in the columns 54, 56 and 58, the three most significant bits of C0 plus the most significant bit of C8 may be selected. In column 60 of Figure 5, the six protected bits may be the four most significant bits of the coefficient of the transformation function C0 and the most significant bits of the functions C6, C7 which represent the colour difference signals.

Figure 6 shows the generator matrix of the specimen code used and Figure 7 shows the table with the 12-bit code words thus formed (column 64) on the basis of the relevant data words (column 66). Column 68 states the weight of the associated code word, i.e. the number of code bits having the value "1". Ignoring the code word which consists entirely of "0" bits, the minimum weight of a code word equals four. This means that the minimum Hamming distance of the code also equals four, so that at all times one error bit can be corrected in a code word and two error bits can be detected. Figure 8 shows an encoder for implementing the generator matrix of Figure 6. The six data bits arrive in parallel on the inputs 72; the twelve code bits are also outputted in parallel on the outputs 74. The matrix is implemented by means of EXCLUSIVE-OR elements such as the element 70. It is alternatively possible to perform the coding operation by means of a read-only memory which comprises (at least) six inputs and twelve outputs. The interleaving, modulation and parallel/series conversion mechanisms have been omitted in this Figure.

When a code word is received which comprises two incorrect bits, it can be detected as being an incorrect code word. In that case there are a number of code words which are situated from the relevant code at a Hamming distance which equals two. For the decoding of this incorrect code word it is not relevant to determine the correct code word from the feasible choices. However, it is important that the most likely correct data word is selected in the case of an incorrect code word. It appears that the table of Figure 7 can be divided into four subtables. All data words of each subtable have the same value for the two extreme left (most significant) bits. Each code word of a subtable then has a Hamming distance of at least 5 from each code word of each other subtable. For the code word which consists entirely of zeros, this can be verified most easily. Consequently, the two most significant data bits are protected by a code which corrects two bit errors. It also appears that when two bit errors occur in a code word, one in an even position and one in an odd position, correction is also feasible. This appears from the fact that there is no code word having the weight "4" with a "1" in an even bit position as well as in an odd bit position.

Figure 9 shows the parity check matrix [H] of the specimen code which satisfies $[G]\cdot[H]=0$. Multiplication of a twelve-bit word by the parity check matrix [H] produces a six-bit syndrome word. If the twelve-bit word is an error-free code word, the syndrome word consists exclusively of "0" bits. Figure 10 shows a table with the syndrome words. The first two columns state the digital and the binary representation of the syndrome words. The further column states the order of incorrect code bits (0—11) causing the relevant syndrome word. If there are several possibilities, they are separated by a semicolon. For all feasible 2^{12}=4k different incorrect words, only those comprising the lowest number of incorrect bits are indicated for each syndrome word. For example, the syndrome word "4" is caused by an error in code bit "10", the syndrome word "6" by an error in the code bits 3 and 8, the syndrome word "24" by two feasible combinations of two incorrect code bits, the syndrome word "16" by three of such feasible combinations, and the syndrome word "48" by a large number of feasible combinations of three incorrect code bits. Because the code is linear, the effect of disturbances may be summed. The error pattern (4, 8) and the error pattern (5, 9) may be summed and produce the syndrome word "000011". However, this syndrome word now indicates the error pattern (0, 1), and the error pattern (4, 5, 8, 9) is not considered. The same syndrome word "000011" is also found by bit-wise modulo-2 addition of the syndrome words "111111" (63) and "111100" (60), and also by addition of the syndrome words "111101" (61) and "111110" (62). The table states all twelve error words which contain only one incorrect code bit, and also all $66=\frac{1}{2}\times12\times11$ incorrect words which contain two incorrect code bits. It appears that the following errors can be corrected:

a) a single incorrect code bit in a code word is always corrected because a unique syndrome word is associated therewith,

b) two incorrect code bits in a code word are also always corrected if they do not both belong to the even code bits of the code word or both to the odd code bits of the code word,

c) when two code bits of the code word are incorrect, both bits having an even or an odd order number, the two most significant data bits are correct or will be properly corrected. In the case of eight different results for the syndrome word (sixteen feasible error patterns in the code word), one data bit must be guessed. In the case of six other different results for the syndrome word (fourteen feasible error patterns in a code word), two data bits must be guessed. In the case of one different result for the syndrome word (several feasible error patterns), the entire data word must be guessed because in that case at least three code bits are incorrect.

Description of the decoder.

Figure 11 shows a block diagram of a decoder for use with the described code. The correct or incorrect twelve-bit code words $\hat{C}$ arrive on input 76. Element 78 is the syndrome generator which generates a six-bit syndrome word on output 80 by means of the parity check matrix [H], and which conducts the six most significant code bits on output 82. Element 84 is a read-only memory which is addressed by the six syndrome bits; a synchronizing clock system has been omitted for the sake of simplicity. The read-only memory 84 outputs nine error indication bits: six on output 86 and three further error indication bits on output 88. The first six error indication bits $e_0 \ldots e_5$ indicate the errors detected in the six most significant code bits; for (64–8–6–1)=49 different syndrome words this is the only correction required. In the multiple EXCLUSIVE-OR element 87 these error indication bits are modulo-2 added to the associated, more significant code bits $\hat{C}_0 \ldots \hat{C}_5$. In element 90, the six-bit data word m′ is reconstructed from the six repaired code bits received. The described circuit elements, exclud-

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