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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A new code search technique for high-rate convolutional code is developed using the pruned-trellis algorithm. The search time and memory size is significantly reduced from standard techniques. Some new high-rate systematic and nonsystematic optimum convolutional codes have been found by this new search technique.

The real advantage of the pruned error-trellis, syndrome decoding technique is the reduction of the memory size required with little performance loss. An LSI chip is developed to realize this new algorithm.

Furthermore a new decoding procedure and its VLSI architecture is developed for the decoder of (23,12) and (24,12) Golay codes.

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The Algebraic Structure of Convolutional Codes

FINAL TECHNICAL REPORT

AFOSR - 87 - 0358

Irving S. Reed

September 1, 1987 - August 31, 1988

Final Technical Report

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3. Period Covered: September 1, 1987 - August 31, 1988

4. Report Prepared By: Prof. Irving S. Reed, Principal investigator

5. Date Prepared: Oct. 31, 1988

6. A One Year Technical Research Summary:

-"Searching High-Rate Optimum Distance Convolutional Codes."

A new pruned-trellis search algorithm for high-rate convolutional code is developed. The search time and memory size is significantly reduced by this new search technique.

Some high-rate systematic optimum convolutional codes are being searched with rate up to 7/8 and of constraint length up to 15. These codes can be efficiently decoded using pruned error-trellis syndrome decoding.

The search technique are also being applied to the search for nonsystematic convolutional codes. The distance properties of nonsystematic convolutional codes are being studied.

-"Pruned Error-Trellis Syndrome Decoding for Convolutional Codes."

A new pruned error-trellis syndrome decoding scheme for CCs is developed. It is demonstrated that the real advantage of the pruned error-trellis decoding over both Viterbi and sequential decoding of CCs is the reduction of the number of states and transitions between any two frames.

-"A Simplified Procedure for Decoding the (23,12) and (24,12) Golay Codes"

A new decoding procedure and its VLSI architecture is developed for the decoder of (23,12) Golay code. A computer simulation shows that this algorithm is modular, regular and naturally suitable for both VLSI and software implementation. An extension of this new decoding procedure is used also to decode the 1/2-rate (24,12) Golay code.

7. Abstracts for Published Papers and Dissertations:

7.1. Published Papers

-J. Sun , I. S. Reed, H. E. Huey and T. K. Truong, "A Pruned-trellis Search for High Rate Convolutional codes " will be published on IEE Proceedings, Computer and Digital Techniques. January 1989.

Abstract- by means of a pruned trellis. This makes possible a reduced search procedure which cannot be done by standard methods. This new search procedure makes use of the expanded column distance sequence profile and a maximization of d_{free}, a number of efficient systematic convolutional codes of rated 3/5, 3/4, 4/5, 5/6 and 6/7 are found and listed in this paper.

-I. S. Reed and T. K. Truong, "Sequential Syndrome Decoding Techniques for Convolutional Codes," submitted to IEE Proceedings, pt.E.

Abstract- structure of convolutional codes and extends those studies to apply to sequential syndrome decoding. These concepts are then used to realize by example actual sequential decoding, using the stack algorithm.

-J. F. Wang, I. S. Reed, T. K. Truong and J. Sun, "Algebraic Syndrome Decoding of Dual-K Convolutional Codes," to be submitted for publication soon.

Abstract- extend the early syndrome decoders of high rate convolutional codes such as the Wyner-Ash code. In this paper, syndrome

decoders are designed to decode the rate 1/n dual-K nonsystematic convolutional codes. The advantage of the algebraic syndrome decoders over error-trellis decoding of dual-K convolutional codes is that the message sequence can be corrected without the necessity of storing a large number of states or path in a constraint length of the error trellis diagrams.

-I. S. Hsu, T. K. Truong, I. S. Reed and J. Sun, "A New VLSI Architecture for the Viterbi Decoder of Large Constraint Length Convolutional Codes," IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, Victoria, B.C., Canada, June 4-5, 1987.

Abstract- the Viterbi decoder of a convolutional code. This new architecture uses a single sequential processor to compute the path metrics in the trellis diagram. Also the systolic array method is used to store the path information as well as to perform the decoding process. It is expected with current VLSI technology that with this new architecture, a Viterbi decoder for a moderate constraint length can be implemented on a single chip. Furthermore, with this new algorithm and architecture, if the constraint length of the convolutional code is too large to put the Viterbi decoder on a single chip. It is shown that the decoder can be partitioned naturally with relative ease into several separate chips with new architecture.

-I. S. Reed, T. K. Truong and Xiaowei Yin, "A Simplified Procedure for

Decoding the (23,12) and (24,12) Golay Codes" Submitted to IEE Proceedings, pt.E. Computers and Digital Techniques.

Abstract- Golay codeword. A computer simulation shows that this algorithm is modular, regular and naturally suitable for both VLSI and software implementation. An extension of this new decoding procedure is used also to decode the 1/2-rate (24,12) Golay code, thereby correcting 3 and detecting 4 errors.

7.2. Dissertations

-H. E. Huey, "Convolutional codes Generated by Primitive Polynomials," Ph.D. dissertation, University of Southern California, August, 1987.

Abstract- codes that have structural constraints placed on the subgenerators. It is shown that many families of these structure constrained codes have properties which are not conducive to generating a family of codes with good properties. A family of convolutional codes using primitive polynomials is studied which have both large free distance and minimum average weight per branch. A method is given that provides a selection of the subgenerators of a 1/2 rate non-systematic code.

An analysis is presented about the weaknesses of the various structure-constrained codes such as convolutional codes generated by cyclic codes and convolutional codes which have constraints placed on their subgenerator polynomials. The analysis is minimum average weight per branch, the generator weight distributions, and catastrophic code generation.

A weight distributions and catastrophic code generation. A list of properties that tend to lead to the creation of bad families of codes is developed from the study of structure- constrained codes.

Theoretical results are presented that show a relation exist between the two distance measure, free distance and minimum average weight per branch. This relationship is due to the fact that upper bounds can be established for both distance measures which show a dependence on the weight distribution of the subgenerators. The established upper bounds and an analysis of the best free distance codes show that good codes should have a total generator weight near the Heller upper bound and that the subgenerators should have balance weight

An algorithm is presented that shows how to determine candidate 1/2 rate convolutional codes that should have good distance properties using primitive polynomials as subgenerators. Primitive convolutional codes generated by this algorithm are listed. It is shown that these codes are capable of a better free distance and minimum average weight per branch than the beat previously defined structure-constrained codes, the complementary codes.

-J. Sun, "Pruned Trellis for Convolutional Codes," Ph.D. dissertation, University of Southern California, October 1987.

Abstract- decoding of high rate convolutional codes. By the use of a pruned coding trellis, an "expanded" column distance function (expanded CDF) is obtained from the search algorithm. This expanded CDF approaches the

desired CDF of the code as the pruning weights in a pruned trellis become large. New optimal non-systematic convolutional codes, of rate k/n, are found by this new search algorithm.

If a pruned error-trellis is used to decode a convolutional code, a substantial number of state transitions of the error-trellis can be eliminated. Simulations show that for high-rate non-systematic convolutional codes, this reduction is significant, and that the error probability performance suffers only a small degradation, about 0.2 dB below that of a convolutional Viterbi decoding algorithm.

8. List of professional Personnel Associated with Research Effort:

- Irving S. Reed received the B.S. and Ph.D. degree in mathematics from the California Institute of Technology, Pasadena, In 1944 and 19491, respectively.

- T. K. Truong received the B. S. degree in electrical engineering from the National Cheng Kung University, Taiwan, in 1967, the M. S. Degree in electrical engineering from Washington University, St. Louis, MO, in 1971, and the Ph. D. degree from the University of Southern California, Los Angeles, in 1976.

- In-Shek Hsu received the B. S. and M. S. degree in electrical engineering from National Taiwan University, Taipei, Taiwan in 1978 and 1980, and the Ph. D. degree in electrical engineering from the University Southern California, Los Angeles, in 1984.

- H. E. Huey received the B. S. degree in electrical engineering from polytechnique Institute of Brooklyn in 1976, the M. S. degree from the University of California, Los Angeles, in 1981, and the Ph. D. degree from the University of Southern California, Los Angeles, in 1987.

- Ju Sun received the M. S. and Ph. D. degree in electrical engineering from the University of Southern California, Los Angeles, in 1983 and 1987, respectively.