ters, proved to be easier to implement, numerically more robust, much faster in design delivery and (in most cases) produced better complex filter results than Hankel-norm optimal approximation. All these considerations make BMT preferable to HOA for most filter design situations.

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# Robust differential chain coding scheme

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*Indexing terms: Computer graphics, Image processing, Codes, Error correction*

In differential chain coding (DCC), the bandwidth efficient relative vector is sensitive to channel errors, resulting in error propagation and corruption of the decoding process. A robust differential chain coding scheme is presented for stopping error propagation in the relative vector without increasing its bandwidth or using an additional forward error correction code. In this scheme, the relative vector is combined with the previous absolute vector to form a new error-resistant channel codeword. Experiments showed that, compared to DCC, the new scheme notably improves subjective quality when subject to transmission errors.

*Introduction:* Differential chain coding (DCC) is an efficient scheme for coding line graphics by exploiting the differential information between successive vectors. DCC encodes the three most probable vector differences into 2 bit relative vectors (RVs) and all other vectors into absolute vectors (AVs) using $2 + I\,[\log_2 8n]$ bits for a coding ring with $M = 8n$ nodes where $n = 1, 2, 3, \ldots$. However, as with any differential source coding scheme, DCC is sensitive to channel errors [1, 2]. Two error-sensitivity problems in DCC are error propagation in RVs and corruption of the decoding process due to either errors in the 2 bit AV prefix or errors in RVs which cause them to become the pattern of the AV prefix [2]. A 1 bit error in an RV will cause erroneous decoding of all the following RVs until an AV arrives. In general, AVs are more error-resistant than RVs and therefore error propagation from an erroneously decoded vector link can be partially stopped by a subsequent AV. However, long strings of RVs are very vulnerable to transmission errors. For smooth handwriting and line drawings, small vector differences are more probable and therefore long strings of consecutive RVs are very common in the encoded vector chains.

Several techniques have been proposed [1] for reducing the error propagation effect such as splitting up traces into subtraces with shorter lengths, or replacing RVs by AVs periodically. However, none of them is aimed at improving the error performance of RVs. We propose a new approach for incorporating error correction and error detection into RVs. The new coding scheme efficiently stops error propagation effects in long strings of RVs. It also enables error detection when an RV is decoded into an invalid pattern, which prevents errors in RVs from corrupting the decoding process. The proposed scheme combines the bit rate efficiency of RVs and the fast error recovery of AVs.

The hybrid D-PCM system described in [3] shows much better error performance than a conventional differential pulse code modulation (DPCM) system. It reduces the error sensitivity of the DPCM codewords by incorporating the pulse code modulation (PCM) information in the conventional DPCM codewords without increasing the bit rate. This hybrid D-PCM system achieved rapid error correction in videophone pictures. As we have discovered, there is great similarity between picture coding and chain coding for dynamographical signals. The AV is similar to the PCM codeword such that they are both error-resistant except for one difference. Since raster scanning is used in video coding, the two-dimensional position information is implied and hence decoding of a PCM codeword has no dependence on previous PCM codewords. However, chain coding encodes two-dimensional dynamographical information into one-dimensional vector nodes, and therefore decoding of an AV is independent from the previous vectors in direction but is dependent in position. However, the occurrence of an AV still has the effect of partially stopping the error propagation because the decoded trace may still be recognisable [2]. However, RV is very similar to DPCM codewords such that they are both bandwidth efficient and sensitive to channel errors.

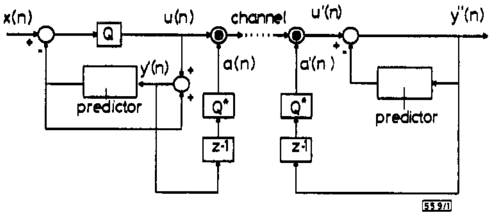

**Fig. 1** *Block diagram for generating robust channel codeword*

*Robust differential chain coding scheme:* The proposed scheme first encodes a line graphic by exploiting the dependence of a vector link $v_i$ on its predecessor $v_{i-1}$. Let $d$ be the difference between the two adjacent vector links $v_i$ and $v_{i-1}$. If $d = 0$, $+1$ or $-1$, $v_i$ is relatively encoded into a 2 bit relative vector 00, 01 or 10. Otherwise, $v_i$ is encoded by memoryless standard chain coding (SCC) into an absolute vector using $b + I\,[\log_2 8n]$ bits where the extra $b$ bits are used as the prefix. The 2 bit RV is then combined with the previous AV to form a new error-resistant channel codeword for robust transmission over a noisy channel. The block diagram for generating the robust channel codeword is shown in Fig. 1. The locally reconstructed AV $y'(n)$ is more error-resistant than an RV but requires more bandwidth. To maintain the same bit rate efficiency as an RV, an AV component is added to the RV as follows: The two most significant bits $a(n)$ given by a quantiser $Q^*$ from the previously reconstructed AV are added to the 2 bit RV $u(n)$ by modulo-2 addition. Therefore, the error-resistant channel codeword $u(n) \oplus a(n)$ still has a 2 bit bandwidth. At the decoder, the received channel codeword is again added to the previously reconstructed 2 bit AV component $a'(n)$ by modulo-2 addition, to recover the RV, based on the fact that the only information available at the differential chain decoder is the previous AVs and present received codeword. For error-free transmission, $a'(n) = a(n)$ and $u'(n) = u(n)$. Hence the transmitted 2 bit RV can be recovered perfectly and the new scheme has no effect on the received RVs. However, in the case of transmission errors, the erroneous RV becomes $u''(n) = u'(n) + c(n)$, where $c(n)$ is the transmission error. This would imply an error propagation into the subsequent decoded trace segments at sample times $n + 1$, $n + 2$, .... In such a case, the new scheme provides forward error correction and error detection. An error $c(n) = u''(n) - u'(n)$ at time $n$ will lead to a difference term $a''(n + 1) - a'(n + 1)$ at time $n + 1$, which serves as a reasonable estimate of the error $c(n)$. Therefore, the effect of $c(n)$ can be gradually cancelled out at times $n + 1$, $n + 2$, ..., and hence the error propagation can be stopped.

Since the new 2 bit channel codeword takes all the four binary combinations, 11 is now a valid channel codeword and it cannot be used as the prefix of the AV. Therefore, the prefix of the AV requires a longer length to distinguish it from the channel codeword. However, this also means that the new scheme has the advantage of no corruption of the decoding process due to errors in RVs. Furthermore, DCC is considered generally less efficient but more robust than chain difference coding [2]. Owing to the statistical properties of smooth handwriting and line drawings, the probability of large variations between adjacent vectors is small and, consequently, most of the encoded vectors are RVs. Table 1 shows the percentage of AVs in a total number of AVs and RVs for four different handwriting and line drawings. Table 1 shows that the percentage of AVs is very small compared to that of RVs. Therefore, the new scheme is considered very efficient.

**Table 1:** Percentage of AVs for different line graphics

| Line graphics | English | Chinese | Map | Drawing |
|---|---|---|---|---|
| Percentage of AVs | 3.18 | 7.73 | 7.92 | 4.60 |

**Table 2:** Errors introduced for two schemes

| | Robust scheme | DCC scheme |
|---|---|---|
| 2nd trace | 11 → 01 | 10 → 00 |
| 3rd trace | 00 → 10 | 00 → 10 |
| 4th trace | 10 → 11 | 01 → 00 |
| 5th trace | 01 → 11 | 10 → 00 |
| 6th trace | 00 → 01 | 00 → 01 |

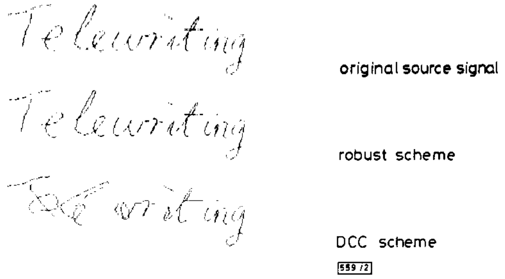

**Fig. 2** *Responses of robust scheme and DCC scheme*

*Experimental results and discussion:* Errors were introduced in the bit stream to evaluate the performance of the proposed robust scheme. This scheme is compared to that of DCC. The responses of the two schemes illustrated by the decoded dynamographical images for a handwriting source signal are shown in Fig. 2, and the introduced errors are summarised in Table 2. In the handwriting, some corrupted traces are smooth and the vector chains consist of only RVs while others have a mixture of RVs and AVs . The channel errors introduced include errors in the higher order bit and lower order bit, respectively. It can be seen that the error effects in DCC propagated extensively, and the remaining traces are severely distorted, which makes the decoded image very difficult to recognise and comprehend. Except for the robust scheme, the error propagation stopped quickly and the image has a very good subjective quality. For some errors in the robust scheme, the RV was decoded as 11, which led to error detection because 11 is not a valid pattern for RVs. Therefore, retransmission might be invoked. Except for DCC, if an RV is corrupted into 11, the decoder will take it as the prefix of an upcoming AV and the following $l[\log_2 8n]$ bits will be erroneously decoded as the AV, which will corrupt the decoding process.

*Conclusions:* A robust differential chain coding scheme has been introduced. By incorporating the most significant two bits of the absolute vector with the relative vector, the proposed scheme stops error propagation in relative vectors and provides error detection when a relative vector is decoded into an invalid pattern. Compared to DCC, the new scheme has a much improved error performance.

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# 10 bit 200 MSPS GaAs BIFET sample and hold circuit

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*Indexing terms: Sample and hold circuits, Field effect transistors*

A GaAs BiFET sample and hold circuit has been implemented and evaluated. SINAD (signal to noise and distortion) was measured to be ~60 dB, but was limited by the test setup. The device accepts a differential input and produces a differential output. The S/H is clocked differentially at rates of up to 200 MHz. 12 bit performance was expected from SPICE simulations. Despite our test setup limitations, 10 bit performance was observed at 200 MSPS with an input signal frequency of 198 MHz.

*Introduction:* A high performance S/H was fabricated with Rockwell's BiFET process [1] which monolithically integrates GaAlAs/GaAs heterojunction bipolar transistors (HBTs), metal-semiconductor field effect transistors (MESFETs), and GaAs Schottky diodes. Excellent BiFET devices have been produced by this technology. The BiFET-HBTs have good current gain ($\beta > 50$ at $2.5 \times 10^4$ A/cm$^2$) and excellent RF properties ($f_t$ and $f_{max}$ >50 GHz). With a 1 μm gate, the Schottky diode achieved an $f_t$ of 500 GHz. The $f_t$ and $f_{max}$ of the BiFET FETs were measured to be 17 and 19 GHz, respectively; the $g_m$ of the FETs ranged from 250 to 350 mS/mm. The S/H takes full advantage of the HBT's high switching speed, high drive capability, excellent threshold voltage matching, and low $1/f$ noise; the MESFET's high input impedance, high density, low power dissipation and low noise, as well as the Schottky diode's high speeds in implementing the various S/H components all on a single chip.

*Circuit design:* A typical S/H consists of five basic components: an input preamplifier, a sampling switch, a hold capacitor, a clock buffer, and an output amplifier. (See schematic diagram in Fig. 1). The core of the S/H is a Schottky diode bridge used to implement the sampling switch. Implemented with GaAs Schottky diodes, the bridge provides a good drive and a low input impedance for charging the hold capacitor. Furthermore, it switches very quickly between conducting and non-conducting states. Colleran provides an excellent analysis of diode bridges and their function in sample and hold circuits [2].

The diode bridge is driven by an HBT emitter follower preamplifier on its input. The current through the emitter follower