

**Fig. 2. Interface developed for control of MPEG enhancement parameters and matrix coefficients with key sections enlarged. Default settings are shown. (a) Full interface – inter and intra matrix are editable. (b) Enlargement of one of 64 matrix element controls. (c) Setting of constants (essential for implementation of previous algorithm). Includes option to use constant as a scalar on manually set values. (d) Controls to leave portion of output unenhanced. (e) Shifting controls for moving a defined set of coefficients ('filter') around the 8x8 matrix. (f) Other global controls.**

The second objective, dependent on the first, was to use this new real-time capability as a tool to investigate the effects of variations of the algorithms and parameters [5, 6, 10].

We present this successful implementation and show that the method is valid for *any* MPEG-2 source. We also illustrate how this new application is enabling further research into compressed-domain contrast enhancement techniques.

## 2. Implementation

### 2.1 Platform choices

We investigated a number of potential platforms on which to implement the system.

Modifying an MPEG-2 decoding circuit inside an existing DVD player or TV set-top box would have been a solution. However, this would have not readily transferred to other decoding systems.

Video decoding on a Digital Signal Processor (DSP) is an expanding field of technology. Using a DSP combines the ease of development given by a fully programmable environment with the power of specialized, dedicated hardware. We investigated this possibility, but were unable to find a partner willing to allow us (a small third party) examine or modify their decoder implementations on these devices.

We chose to modify "open-source" [2] software that is freely available to decode MPEG-2 streams on standard PC platforms. The software library, libmpeg2 [4] is written in the C programming language.

### 2.2 Software modifications and control

We modified the MPEG decoding library code such that it would perform a pointwise multiplication of the quantization matrix (Fig. 1b) whilst decoding luminance blocks. Values are read from memory, set by a user interface. We also made modifications so that this multiplication would be performed only on a portion of the picture specified using the interface. Matrices and parameter values are read at regular intervals, allowing real time adjustment of the output at will.

### 2.3 Functionality and motivation

The matrix multipliers and other parameters are written to memory by a separate user interface computer program. This developed over time to meet the two objectives outlined above.

The user is presented with an array of 64 identical controls, representing the 8x8 point-wise multipliers of the quantization matrix (Fig. 2a). A single element is shown in Fig. 2b. For each coefficient, the user can choose to leave the coefficient unmodified ('1'), multiplied by a constant  $\lambda$  ('L') or multiplied by a constant  $\lambda.\alpha$  ('LA'). There is also a manual setting where the value can be set to any numeric value, including 0. Below these elemental controls are a number of global controls (Fig. 2f). These allow the values of constants  $\lambda$  and  $\alpha$  to be set, provide matrix shift control, scale the manually set values, reset the matrices to all '1's or the set of default values, load/save the matrices/parameters and allow specification of what area of the picture should not be enhanced.

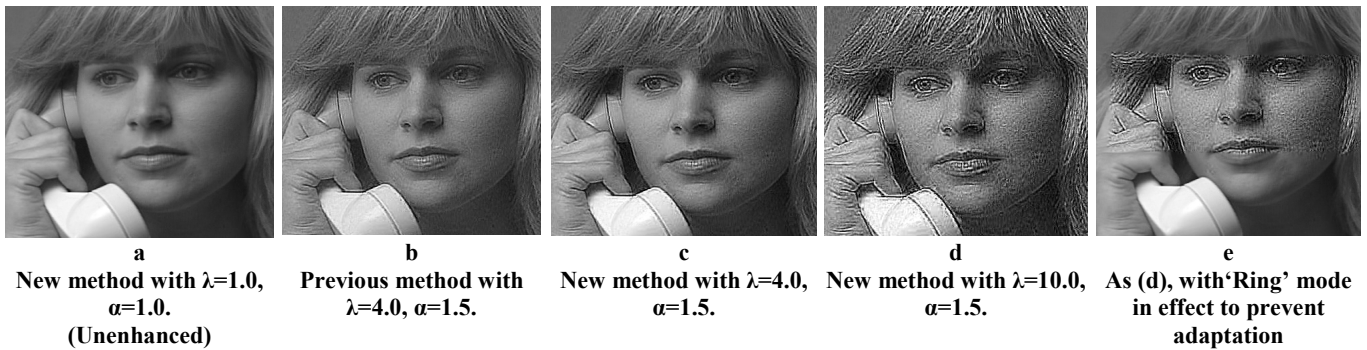


Fig. 3. Illustration of MPEG based enhancement using new (libmpeg2) and previous (Restream™) methods.

The previous study's algorithm [5, 6] can be demonstrated by setting constants in the bottom left-hand corner of the interface (Fig. 2c) and ensuring the "Change Both" option is checked (Fig. 2f). The interface starts with the set of "default" constants given in Fig. 1b.

Within an MPEG stream, there is usually one intra dequantization matrix, and this is applied by the decoder to both chrominance and luminance blocks. The previous method could only change this single matrix within the input stream, so both luminance and chrominance were enhanced. As our modified library performs the modification within the decoder, we have the

ability to enhance only luminance blocks. This is the default behavior; chrominance enhancement can be enabled by checking the box shown in Fig. 2f.

Previously [6] it was noted that artifacts appeared during motion in the MPEG sequence. These artifacts were associated with the weighting of inter matrices by the same amount as intra matrices. It was hypothesized that modifying the inter matrix less than the intra matrix might address this issue, and this is why independent control of the two matrices was important. We now believe that these motion artifacts arose from viewing of interlaced source material on a progressive monitor, as discussed in Section 2.5.

As part of our ongoing research into finding the most effective set of coefficients for subject viewing, we required the ability to move the entire set of coefficients along the upper-left to lower-right diagonal axis of increasing spatial frequency. This permits viewing the effects of coefficient sets over a range of spatial frequencies. The interface can move (Fig. 2e) an 8x8 'filter' without losing the original contents of that filter. If a new preferred position is found, the button "Redefine" may be clicked to use that 8x8 set as that which is retained during further shifts. The results of shifting operations are demonstrated in Fig. 4.

It is possible that a smoother, less uniform distribution of coefficient multipliers will provide more effective enhancement. To investigate this, a facility to multiply all manually set values has been provided. (Fig 2b, c). Coefficients can be set to values between 0 and 1 such that a gradual scaling of a 'smoothed' set of coefficients will be accomplished by adjusting the  $\lambda$  value.

A phenomenon of *adaptation* was recently reported, whereby the viewer's vision becomes adapted to an enhancement and perceives it as the normal level [11]. To attempt to prevent this, the interface can set parameters (Fig. 2d) such that a corner or 'ring' (Fig. 3e) will not be enhanced by the decoder. The effect of the enhancement is now always apparent to the viewer.

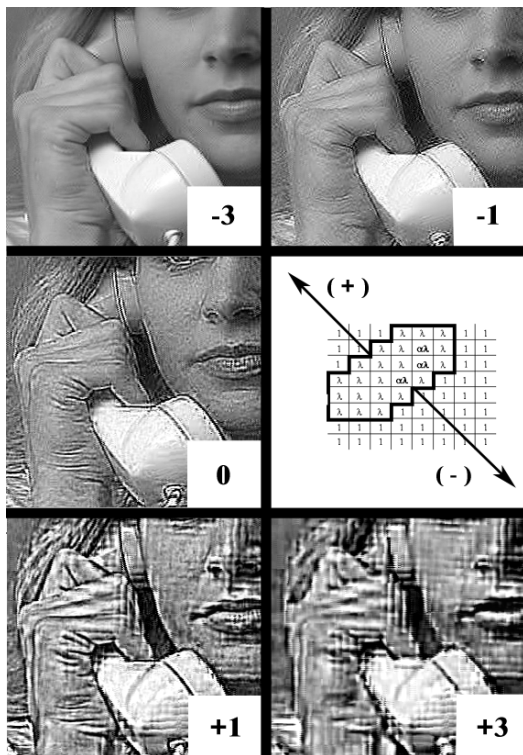


Fig. 4. Section of video output whilst moving the set of coefficients ( $\lambda=10.0, \alpha=1.5$ ) along the block diagonal axis as shown. Positive values indicate shifting the matrix into areas of lower spatial frequency. Negative values indicate shifting the matrix into areas of higher spatial frequency. Note the very small visible effect once the filter is not modifying any information within the top 6 bands (-3).

## 2.4 Software utilization

A major advantage of our approach was the existing integration of the software library into more complete software "media players", an example being VLC [1].

Most development work was completed using short MPEG-2 sequences stored in computer files as MPEG Elementary streams (ES). Streams are rarely presented in this simple format however, and are usually contained inside Program Streams (PS). Program streams are designed to include a 'program' of information including audio and other additional data. They are used for DVD video. Such program streams may in turn be contained within Transport Streams (TS); these are designed to be resilient to



**Fig. 5. Enhancement and reduction of interlacing artifacts. Shown are three segments of frames from a motion event. Areas where the effect is particularly prominent have been circled for emphasis and comparison.**  
**(a) Interlacing artifacts caused by the combination of two fields from two different instants in time.**  
**(b) Enhancement ( $\lambda=4.0$ ,  $\alpha=1.5$ ) without deinterlacing accentuates these artifacts.**  
**(c) Using VLC 'linear' deinterlacing filter reduces these interlacing or "motion" artifacts.**

transmission errors encountered in broadcast over a distance using cable, satellite and terrestrial distribution.

By recompiling VLC with our modified library, raw MPEG-2 ES data extracted from higher level streams can be passed to the library for decoding. Uncompressed video data is returned from the library back to the player for output. This has made it possible to apply the enhancement to any MPEG-2 source readable by the player. We have successfully enhanced material direct from DVD using this approach.

## 2.5 Viewing procedures

Most subjective viewing and demonstrations were initially made using progressive computer monitors. We later switched to viewing on an NTSC 27" CRT television, at distances similar to those used in the homes of TV viewers. This change was helped by the addition of a remote control to vary the enhancement level. It also provided a natural way to reduce interlacing artifacts exhibited on progressive computer monitors. Without viewing on an interlaced display (or without the use of a suitable deinterlacing filter on a progressive display), enhancement along each video line will not align vertically with the subsequent line. This effect is always present when viewing interlaced material on a progressive monitor, but enhancement exacerbates the problem. We believe this may have been largely to blame for the 'motion artifacts' noted in the previous study. An example of this phenomenon and its resolution is shown in Fig. 5.

## 3. Discussion and future plans

We have successfully implemented the algorithm from the previous study [5, 6]. A demonstration of the video output of the method is shown in Fig. 3; a comparison with the previous method is included.

The software implementation ran in real time, showing that the technique was computationally inexpensive as was previously argued [5, 6].

We addressed two problems with the previous method, namely motion artifacts (Section 2.5) and an inability to only enhance luminance components (Section 2.3).

The implementation has facilitated research into the most suitable arrangement and values of the filter matrices. We intend to begin a new study examining benefits of such enhancement. We are currently finalizing the filter matrix for this study, and developing an experimental protocol.

We are planning to make the future study both stimulating and interesting for subjects by using segments from films that they might see in everyday life. At least one key variable will be assigned to vary the degree of enhancement and subjects will be able to control this by means of the infrared remote control unit.

## 4 Licensing and patent issues

We have used a licensed encoder to generate test MPEG-2 streams, and are in the process of licensing our decoder with the MPEG licensing authority (MPEG-LA).

## 5. Acknowledgements

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