TELEVISION ANIMATION STORE:
Control system operation and implementation

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Summary

This Report describes the computer control system of the electronic rostrum camera animation system developed to enable picture sequences to be generated directly as television signals, instead of using cine film.

The ergonomics of the control system are described, together with some of the more demanding aspects of its implementation, which allow complex animated sequences to be generated and replayed in real time.
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1. INTRODUCTION

Film animation techniques have been widely used in the production of television programmes for many years. Almost every programme produced uses some work which has been created in this way. Traditionally film rostrum cameras have been used to carry out this work and the techniques involved, developed in parallel with those in the film industry, have become increasingly sophisticated over the years.

In a television environment there are difficulties in using film for animation work. Where a programme is live or recorded on video tape there is a noticeable change in picture quality where film inserts are used. In addition, both film and telecine facilities are required for the compilation of the programme. It is also difficult to use electronic effects generators as part of the animation without additional transfers between film and video tape with an inherent loss of picture quality. A fundamental difficulty with film is the inability to see the results as filming is in progress. Errors may not be noticed when they occur and as a result several days' work may be ruined.

These difficulties led to the BBC's Studio Capital Projects Department being asked to develop a video rostrum camera facility capable of performing all the effects currently achieved with film animation. Furthermore, the system would need to handle work which, in a film environment, would be carried out separately by optical printing processes.

A video animation facility has two separate parts, a video rostrum camera and a picture storage and processing system. The rostrum camera or animation stand is essentially the same as that in a conventional film facility but with the film camera replaced by a television camera. The rostrum camera which is in use with the Television Animation Store is shown in Fig. 1. It consists of a television camera mounted on a vertical column over a horizontal table on which artwork can be placed. The camera and lens are counterbalanced and are free to travel up and down the column; the table can be moved horizontally in north-south, east-west directions and rotated about a vertical axis. In addition, set into the table top are four sliding tracks (called 'panning bars') designed to locate accurately and individually move separate pieces of artwork.

The positions of the camera and table are controlled by a computer system using servomotors and this enables a high degree of table accuracy and very smooth movement to be achieved. The computer is also able to control zoom, focus, iris and black level on the lens and camera.

The operator controls the position of the camera and table by using eight of the large knobs shown to the lower left in Fig. 1. After adjustment, the positional information is stored by the control system and the operator is free to move the camera and table to the next position and repeat the procedure. A continuous move may be defined by

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**Fig. 1**
The Video Rostrum Camera used in conjunction with the Television Animation Store.

The controls associated with the rostrum camera are towards the lower left of the picture.

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storing several points along its route and this will be traversed automatically, linking the points together either by a straight or curved path.

The control system for the camera is able to send and receive triggering signals which allow its operation to be synchronised to the picture storage and external video and sound recorders.

The second part of the video animation facility, the picture storage system, is used to record the output from the camera. Where animation is being performed, the artwork under the camera may need to be changed on every frame. In this case, the storage system must have the capability of recording and replaying both single frames and continuous picture sequences at the normal television rate of 25 pictures per second.

In the Television Animation Store a modified computer disc drive is used as the recording system and this has the capacity to store up to 815 different pictures. Facilities are also provided to allow pictures to be combined by mixing and chroma-key before or after recording, so that complex animated effects can be built up in stages. The animation can be checked at any time and modifications made as necessary.

Manual control of a video system of this complexity would be a slow and difficult process. A computer control system has therefore been incorporated within the equipment to perform the control functions as necessary during the operation of the store. With this arrangement the operator need not be aware of the internal architecture of the system and only simple control information is required to define the record and replay operations.

This Report, one of a series which describe the Television Animation Store, concentrates on both the facilities provided by the store and its comprehensive control system developed to assist in its operation. Other BBC Reports describe the general design of the system, the digital chroma-key unit, the design of the disc recording and replay system and the digital PAL decoder unit.

2. THE BASIC REQUIREMENTS OF A VIDEO ANIMATION SYSTEM

To gain acceptance, a video animation system must be able to perform at least the basic operations available with a film rostrum camera. This means that the video system must be able to record both single frames and continuous sequences and replay them as one continuous sequence. Furthermore, it must be able to perform the mixing and matting of pictures to give dissolves and superimposition effects. In television terms this implies that, in addition to a recording device, the system must also contain a video mixer with chroma-key facilities.

The increasing availability of video effects equipment within studios means that many complex effects can now be generated more rapidly than with film techniques. In order to benefit from this the video animation system must be able to accept pictures from any source, e.g. video tape or electronic drawing systems, and combine them with pictures from the rostrum camera. This considerably increases both the range of effects that are possible and the speed with which they can be produced.

Once these basic facilities have been provided, many enhancements can be included without additional video hardware. Additional features, which were considered essential on the system and hence formed the starting point for its specification, provide the following capabilities:

- to view a picture prior to recording and mix it, if necessary, with a stored reference picture to allow checking of alignment.
- to view pictures individually after recording, allowing errors to be isolated.
- to re-record single frames as necessary to correct any errors.
- to modify aspects of the animation, e.g. the order in which pictures are replayed, without re-recording.
- to mix and key together any number of recorded pictures to form each output frame.
- to operate on separate component (YUV) video signals thus avoiding luminance/chrominance cross-effects but also to be able to accept composite (PAL) signals, maintaining the highest possible quality in the decoding process.

Bearing in mind the complexities of the hardware, simplicity of operation was an important goal in the design of its control system. It was felt that facilities should be available using only simple keystrokes and that the animation details to be entered by the user should be in a clear and concise form. The subsequent modification of these details should be straightforward with as many 'side-effects' as possible being handled automatically by the system.

In practice, the control system which has been implemented goes far beyond these requirements. It offers the operator considerable flexibility in manipu-
lating single pictures and picture sequences and combining them to form complex animated sequences.

3. THE ERGONOMICS OF THE TELEVISION ANIMATION STORE

With the complexity of the various hardware elements of this system, its manual control would soon become overwhelming for anything but the simplest of animation. In order to overcome this problem, a computer system is used to coordinate the operation of the equipment and hence the controls presented to the operator can be greatly simplified. As a consequence, the operator must give details describing the required animation so that the control system can process the pictures and produce the required animated result. Inevitably, there can be a large amount of information in a description of an animated sequence and so a convenient method of entering and displaying this control information is required.

A visual display unit (VDU) is used to present information to the operator and ten different display ‘pages’ are available to show various aspects of the system operation. Instead of the alphanumeric keyboard of the VDU, dedicated control panels are provided to allow the operator to enter data and control the operation of the system using single keystrokes. The VDU and control panels are housed in a control desk, shown in Fig. 2, together with other panels which control additional equipment within the area.

The panels controlling the Television Animation Store contain illuminated pushbuttons, alphanumeric displays, rotary controls, linear fader controls and a ‘trackerball’ control. The rotary controls and the linear faders allow manual adjustment of the chroma-key and video mixer circuits. Similarly, the trackerball allows control of the picture movement and chroma-key ‘garbage matte’ facilities. The control panels are described in more detail in Section 4.2.2.

A portable control panel is also provided which allows a limited number of operations, mainly the control of picture recording, to be carried out remotely from the control desk. Primarily this is intended for use close to the camera when artwork changes are required after each picture is recorded.

The operations which the user must perform to produce a sequence of animation using the Television Animation Store can be divided into five distinct stages, carried out in the following order:

1. Data entry. During this stage the user enters details describing the required animation in terms of picture order, durations, mixes between pictures and chroma-key etc.

2. Allocation of disc space for the animation. This is an automatic phase carried out by the system after all data entry has been completed. It ensures that sufficient space is available on the disc for the sequence being produced.

3. Loading of pictures. This is the recording process where pictures are input from the selected source and transferred to the disc for later replay.

4. Assembly of the animation. This is an internal processing phase which produces the multi-picture effects which cannot be generated from the original pictures during real-time replay. This limitation is imposed by the disc drive which, having only one video channel, cannot replay more than one picture at a time.

5. Sequence replay. At this stage the complete, assembled animation can be viewed and if necessary recorded on video tape.

After the fifth stage has been completed, changes can be made to the animation by modifying the information entered at stage one. When the

![Fig. 2](image)

*The control panels for the Television Animation Store and the associated Video Rostrum Camera.*

The right-hand third of the panels are used to control the movement of the rostrum table, the operation of the camera and the lighting. The centre third of the panels (in front of the operator) control the Television Animation Store and the left-hand third control the other facilities in the area such as video routing and mixing, audio monitoring and a video tape recorder.
subsequent automatic allocation and assembly operations have finished, the modified sequence is available for immediate viewing.

Steps 2 and 4, the allocation and assembly operations, are required because there are a number of constraints to the way in which the disc drive can be used. However, once invoked, these operations are carried out automatically by the control system.

The allocation process calculates the amount of disc space required to produce the animated sequence and then allocates a contiguous area of disc space to the sequence. This contiguous area on disc is required so that real time replay can be achieved, since, under these circumstances, only adjacent pictures can be accessed from the disc. During the allocation process, optimisation is carried out so that the space required on the disc is minimised. Furthermore, this process allows a previous piece of animation to be modified and the corresponding allocation of disc space will be changed, as necessary, to produce the new animation.

The assembly process is required for sequences in which individual output pictures are obtained by combining two or more recorded pictures. These effects are prepared automatically before the sequence is viewed and the resultant pictures are stored on disc for subsequent replay. During this operation the user can have the option of manually adjusting parameters, e.g. mixer levels, chroma-key settings etc., whilst viewing the result, to achieve a desired effect.

If, on viewing, any part of the animation is found to be unsatisfactory, then the corresponding frames can be isolated by pausing the replay and viewing in a frame-by-frame mode. Modifications can then be made to the data describing the animation to reflect any changes needed and these will be incorporated during the next assembly operation. In this way the animation can be changed repeatedly without the necessity of re-recording any of the original pictures.

A single, complete sequence of animation (referred to as a 'Run') can be used as a picture source within another Run. This allows complex animated effects, which use several pictures, mixing and keying operations, to be built up in layers from simpler sequences. This cascading of Runs can be continued up to seven levels allowing, in theory, over 2000 pictures to contribute to a single frame of animation. Each of these layers can use the entire facilities of the Television Animation Store, they can be individually previewed, corrected and then combined to form the final animation. Subsequent changes which may be required can be made to any of the component layers and the resultant effect can be viewed immediately.

This cascading of facilities considerably enhances the capabilities of the system and has proved to be a very powerful feature of the equipment.

Facilities are also provided to allow a section of the animation to be repeated by the repeated replay of one sequence of pictures. This repetition can be continued for as many frames as required.

Once an animated sequence has been reviewed and is satisfactory it can be recorded onto video tape for subsequent editing into a programme. During this process a 'slate' picture can be added prior to the sequence to identify it for later tape editing.

Preview facilities are also provided to allow single pictures to be viewed in isolation or mixed and keyed with other pictures to test an effect before use. In a similar way, frames from a completed sequence can be previewed by entering the appropriate frame number and stepping forwards or backwards about that point in the sequence. This gives a quick and easy way of isolating faults in the animation without the necessity of running through the sequence from the beginning.

4. THE HARDWARE OF THE TELEVISION ANIMATION STORE

4.1 Video processing and storage hardware

The main picture storage device in the Television Animation Store is a modified magnetic disc drive which is capable of storing up to 815 television pictures in digital component form. A digital video mixer and chroma-key unit is also included to allow pictures to be mixed and keyed together. Temporary storage of pictures during internal processing operations is provided by three frame stores.

The disc drive, frame stores and mixer form the central part of the Animation Store. However, additional units are included to perform input and output functions, including PAL decoding and encoding, and odd/even field interpolation for 'field grabbing' of images from a sequence containing movement. All of these units are interconnected using a video routing system which is capable of re-routing signals to different destinations under computer control.

Fig. 3 shows a schematic diagram of all the video hardware and the arrangements for their interconnection using the multiway video routing system. The disc drive together with the two equipment bays which house the remainder of the hardware are shown in Fig. 4. The individual hardware units are described in the following sub-sections.
4.1.1 Disc drive

The disc drive is a modified Ampex DM331 drive which uses a removable disc pack containing eleven discs and has a capacity of 815 television pictures (1630 fields). Although picture transfer to and from the disc is at full video rate, pictures which are to be replayed as a continuous sequence must occupy adjacent spaces on the disc. This restriction is imposed by the 1.5 ms track-to-track seek time which allows only a single track seek within the television field blanking interval. A detailed description of the record and replay electronics for the disc drive is given in a separate Report\textsuperscript{4}.

4.1.2 Video mixer and chroma-key unit

The digital video mixer has two video channels with a third channel for keying signals. The chroma-key unit, closely interconnected with the mixer, allows high quality keying, including shadow and transparency effects, to be produced. A keying signal can be derived from a picture applied to the mixer or a third, unrelated picture. Chroma-key operation is possible from any ‘key’ colour and luminance (black/white) keying is also available.

A ‘garbage matte’ is also provided which allows a rectangular keying shape to be electronically generated and used in addition to the normal key signal. This allows, for example, the edges of a picture to be keyed correctly when uneven illumination or unwanted objects cause unsatisfactory chroma-key operation. The size and position of this rectangular garbage matte can be changed by the control system.

The detailed operation of the chroma-key equipment is described in a separate Report\textsuperscript{4}.

4.1.3 Frame stores

The three frame stores, each capable of holding a single picture, permit the re-timing of a complete picture whilst it is being input or output. Up to plus or minus four television lines of timing variation can be accommodated in this way. This provides a means of correcting the timing of video signals, by advancing or delaying either the read or write timing, as pictures pass through one of the frame stores. This feature is primarily used to compensate for the delays introduced as the video signals are fed internally from one unit to another.

The frame stores are also capable of moving a picture horizontally or vertically relative to line and field blanking, allowing re-positioning or simple animation effects to be produced. When a picture is displaced in this way the blank area of the screen which is revealed can be filled with any desired colour.

4.1.4 Video input unit

The equipment will accept either analogue RGB colour components or PAL encoded signals. The video input unit converts these signals to digital $YUV$
Fig. 4 - The disc-drive and equipment bays.
component form for distribution to the rest of the equipment. In the case of PAL encoded signals, further decoding is carried out on the YUV components, as discussed below, before the picture is used.

4.1.5 PAL decoder

The PAL decoder operates in conjunction with one of the frame stores and provides high quality decoding of PAL signals. Two modes of operation are available; the first is for general use and particularly where the pictures being decoded depict movement from field to field. The second is for 'stationary' pictures, i.e. scenes with no movement between fields, where very high quality decoding can be carried out. Details of the decoder are given in another Report.

4.1.6 Vertical interpolator

This unit interpolates between the lines on one field of a picture to produce suitable vertical detail for the lines of the interlaced field. This process gives improved picture quality in operations such as slow and reverse motion of a stored sequence and when a 'frozen' picture is grabbed from a moving input sequence.

4.1.7 PAL encoder

The PAL encoders provide the two encoded outputs from the system. The YUV signals within the equipment are first converted into digital PAL and then into an analogue signal prior to output.

4.1.8 Video routing system

The video routing system, shown schematically in Fig. 3, provides a means of interconnecting the video units within the equipment. It is capable of simultaneously routing several digital video signals, in parallel form, and this routing can be changed under computer control.

The routing system consists of six routing boards each with two inputs and two outputs and these boards are interconnected by six parallel video busses. This arrangement allows up to six signals to be routed between boards and hence to any one or more of the output ports. Where source and destination ports are on the same board, internal routing can be performed leaving the main interconnection busses free for inter-board signals.

If necessary, the routing can be changed on each field to allow dynamic re-configuration of the system as an operation is in progress.

4.2 Control system hardware

4.2.1 Main control system

Control of all operations within the Animation Store is carried out by a DEC* LSI 11/23 microcomputer with 196 Kbytes of memory. Tape cartridge drives are provided for the storage of the user's data entered on VDU displays and a printer can be used when a listed output is required.

* DEC is a registered trade mark of the Digital Equipment Corporation.

![Diagram of control interconnections](image)

Fig. 5 - A schematic of the control interconnections.

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Fig. 5 shows a schematic of the control interconnections within the equipment. Within the computer rack there is an interface board for each item of video hardware which partially decodes the control signals before sending them to their individual hardware unit. This strategy, rather than distributing the parallel computer bus to all units, helps to minimise the number of signals which must be handled externally to the computer system. A reduction in the overall amount of control circuitry can, therefore, be achieved.

All the video hardware is designed so that control is field synchronous, i.e. changes sent from the control computer are not implemented until the start of the next television field. This allows the computer to preload control data into the hardware during the previous field, hence giving it more time to service all the units during real-time operation.

The computer is capable of both generating and receiving triggering signals so that the operation of associated equipment can be synchronised to start on a selected frame. This is particularly important for the recording and replay of sequences where video tape is involved and also for the recording of moving sequences obtained from the rostrum camera.

4.2.2 Control panels

The control panels, shown in Fig. 6, contain a variety of illuminated pushbuttons and controls arranged in separate groups according to their function. The area to the right of centre is used to call up the various display pages (described later in Section 5) and to program the operation of the system. The trackerball, towards the bottom right of this area, gives two-dimensional control by turning the captive ball in the appropriate direction. This is used for the horizontal and vertical movement of pictures and adjustments to the shape, size and position of the garbage matte in the chroma-key unit.

The section of the panel to the left of centre which includes both the two faders and the cluster of numeric keys, is used for previewing operations. This facility permits pictures or frames to be referenced by number and simple mixing to be performed. This area of the panel also contains five alphanumeric displays which show the reference numbers of the pictures or frames being previewed.

The narrow panel farther to the left provides facilities for the long term storage of both the pictures from the disc and the user’s data. A further key on this panel allows a printout to be produced, giving a permanent record of the user’s data. The section of the control panel on the left containing both buttons and knobs is for the adjustment of the keying and colour separation overlay functions. This facility is described in detail in another Report.

The control panels are linked to the main control computer by a serial line running at 9600 bits per second. A microprocessor within the panels monitors all the controls and when any change is detected the new setting, or a code representing the key pressed, is transmitted back to the system computer. Commands can be sent back to the panels to illuminate selected push-buttons, update the alphanumeric displays or sound a warning tone.

Fig. 6 - The control panels for the Animation Store.
5. OPERATIONAL PROCEDURES

5.1 General Description

The operations which the user must perform to produce a sequence of animation using the Television Animation Store have already been described in Section 3. This section describes in more detail how those main steps are carried out and the various VDU displays which are used.

5.2 Data entry and disc allocation

The first operation required to produce a sequence, listed in Section 3, is the entry of the user's data to describe the animation. This information is entered into the 'Run' display which is called up by pressing the 'Run' button on the 'programming' section of the control panel (see Section 4.2.2).

The Run display, shown in Fig. 7, allows the operator to build up a description of an animated sequence ('Run') using picture reference numbers, (known as 'still' numbers), durations and mixing information. Using this display a sequence is specified in terms of pictures being applied to the two video inputs (A and B) of the internal mixer together with the required fader levels. This allows simple mixing operations between pictures or sequences of pictures to be carried out and this alone can account for a large proportion of animation work.

The data shown in Fig. 7 is typical of a simple piece of animation using two picture sequences. Since the system can simultaneously store several Runs each is identified by a unique 'Run number' in the range 1 to 999, shown on the top line of the display. The 'Last frame' column of the display indicates the point during replay at which each operation is to take place. It is important here to distinguish between frame numbers and picture numbers. Frame numbers refer to the individual frames of the output sequence in a similar way to timecode. Picture numbers refer uniquely to individual recorded pictures, many of which may contribute to an output frame. Thus, the first line indicates that picture number 1 is to be replayed for a duration of 25 frames. The mixer information, towards the end of the line, shows that during that time the A channel of the mixer is faded up from zero to full level (F). The second line shows a replay of the pictures numbered 1 to 50 as a real-time sequence starting at frame number 25. In the subsequent lines, this is followed by a cross-fade to another sequence and eventually a fade down at the end of the Run.

Further facilities can be accessed by calling up the 'Run level 2' page, shown in Fig. 8. This display is used to give more information for each line of the previous Run display. The facilities accessed using this page are chroma-key, garbage matte and picture movement for the video and keying sources, and the cyclic repetition of a section of animation.

For mixer, chroma-key, picture and garbage matte parameters, it may be difficult, at this stage, to enter appropriate values. In many cases their adjustment may be critical and can only be carried out whilst viewing the resultant effect. To overcome this problem, the system will accept the manual adjustment character 'm' rather than a numeric value during data entry. This defers the entry of these values until the assembly phase, described in Section 5.4, when the appropriate pictures can be viewed and adjustments made.

After these details have been entered, disc space can be allocated to the Run by pressing the 'Allocate' button on the control panel. During this operation the user's data is checked for errors and, if all are correct, disc space is allocated to the Run. If errors are encountered, these are reported to the operator and the line in error is flagged on the display.

This completes the first two steps in producing the animation and the operator can proceed with the loading of pictures onto the disc.
5.3 Loading pictures

The Load display, shown in Fig. 9, is primarily used to control the recording of pictures and is called up by pressing the 'Load' button on the control panel.

The top section of this display page allows the source of the input pictures to be selected, typically either the external analogue RGB or PAL encoded input. Copying and deletion of pictures is also supported together with the deallocation of areas of the disc previously reserved during an allocation phase.

Having selected the picture source, a single picture can be recorded by entering its reference number as the first still number and pressing the 'go' button. A sequence of pictures can be recorded by entering the reference numbers for the first and last pictures of the sequence and then selecting the appropriate record mode. This mode can be either 'continuous' or 'single still' depending on whether the entire sequence is to be recorded in real-time or as a series of individual pictures. Pressing the 'go' button will then carry out the recording.

![LOAD OPERATION](image)

**Fig. 9 - The Load display.**

The Load display also permits the recording of input pictures superimposed or keyed over a previously recorded background picture. However, mixing and keying operations performed at this stage have the disadvantage that they cannot be changed after the recording has been made. Nevertheless, this has the advantage of minimising the amount of disc space required to create an effect since the original, unprocessed pictures are not retained. Furthermore, the chroma-key signal is derived from wide bandwidth, 12 MHz sampled, U and V signals rather than the narrower bandwidth, 4 MHz sampled U and V signals used for stored pictures.

5.4 Sequence assembly, viewing and editing

After the pictures which make up the sequence have been recorded, the Run can be assembled by re-entering the Run display and then pressing the 'Assemble Run' button. The system will then make the multi-picture effects required in the Run.

It is during this phase that manual adjustments can be made to those entries on the Run or Run level 2 displays which have been marked for adjustment. This marking is done by entering the character 'm', rather than a numeric value, at the earlier data entry phase. In this case, the assembly operation pauses after loading the appropriate pictures and enables the controls on the panel, allowing adjustments to be made whilst viewing the resultant effect. In this way, the mix levels, chroma-key settings, picture and garbage matte movement can be adjusted whilst viewing the result rather than relying on numerical values entered directly onto the Run display.

In the case of cross-fades, picture or garbage matte movement, an end value or position may also be given. During the replay of the sequence, a linear change between start and end values will take place. Where this facility is used and manual adjustments are being made, the operator can change between adjusting the start and end values until both are satisfactory. When adjusting the end positions, the corresponding pictures are loaded, so that adjustments are made in the correct context. This is particularly important where movement is being matched along a sequence. Under these circumstances it is vital that the first pictures of the sequence are displayed as the start positions are adjusted and then the last pictures as the end positions are adjusted.

When all manual adjustments have been made and the assembly phase has been completed the animation can be viewed by pressing the 'go' button. As the sequence is replayed the 'pause' and 'single forwards' buttons can be used to pause the replay and step through the sequence one frame at a time.

Should the sequence be unsatisfactory at this stage, the details on the Run display can be changed and the sequence assembled again. The control system, detecting that the details have been changed, will perform a re-allocation operation automatically prior to assembly. The modified sequence is then available for viewing.

5.5 Previewing pictures

A previewing facility is provided which allows recorded pictures or frames from a Run to be viewed individually. This facility is invoked by entering the reference number for the still or frame using the numeric keypad to the left of the two linear faders in Fig. 6. The picture will then be shown on the main output monitor. Mixing and keying of single pictures
is also provided. This is invoked by directing the selected pictures to the A, B or C channels of the mixer, as appropriate, and previewing the output of the mixer. The mixer and keying controls are automatically enabled, allowing the user to make adjustments as required.

As well as browsing through recorded pictures, this facility allows errors to be isolated and new effects to be tried before being incorporated into a sequence.

5.6 Status information

To keep track of the usage of the still reference numbers, which identify pictures in the system, there are two status display pages. The displays, one of which is shown in Fig. 10, provide a convenient means of monitoring which reference numbers are in use and whether those pictures have been recorded. An indication of the amount of disc space remaining is also provided on the bottom line of this display.

5.7 Storage of user data

A tape cartridge is available for the storage of data which has been entered on the Run display by the user. Each cartridge can store up to ten independent jobs, each of which can use any number of Runs, limited only by the amount of memory available in the control system computer. Two display pages are used to control the storage and retrieval of the user’s animation details using the two data cartridge drives.

5.8 Long term picture storage

The Long term picture storage facility allows pictures from a disc pack to be archived onto video tape either for use later or to free a disc for current work.

This process is not the same as the normal recording of a user’s animated sequence since each picture from the entire disc pack is recorded onto tape for eight successive television fields. By recording the pictures in this way, they can be subsequently recovered, without noticeable degradation, by using the PAL decoder in its stationary mode. This relies on the fact that after four fields the phase of the chrominance signal is exactly inverted and hence can be eliminated from the luminance by summation across a four-field delay. Similarly, the luminance can be eliminated from the demodulated chrominance signals by subtraction across the same delay. Thus all chrominance/luminance cross-effects can be removed.

The two ‘Long Term Storage’ display pages, which are used to control this archiving and reloading, are called up from the Long Term Storage section of the control panel. Prior to the recording operation, the user has the option of adding a ten-second slate sequence to identify the recording later.

The reloading of pictures from the videotape must be synchronised exactly so that the correct eight fields are decoded for each picture. For this reason the

Fig. 10 - The first of the two status displays.
reloading operation is always started using a triggering signal derived from the time-code recorded on the videotape.

6. CONTROL SYSTEM SOFTWARE

6.1 General

The structure of the control system software broadly follows the operation of the equipment with independent software modules handling the different operating modes, their displays and subordinate commands. Fig. 11 shows the structure of the first few levels of the software.

The upper level is the command recognition phase which activates one of the main control modules e.g. Run, Load, etc., in response to the display selection made by the operator. There are four commands that can be sent to these modules from the command recognition level, as follows:

INITIALISE:
initialise all variables with default values, ready for use later.

START:
start execution of the module, i.e. generate displays, reconfigure the hardware etc. as required for the module.

CONTINUE:
re-enter module after a temporary absence, e.g. after dealing with unrecognised characters.

ABORT:
end execution of module.

On exit the module returns one of the two following result codes to indicate its outcome:

SUCCESS:
indicating that the module has terminated correctly, or

BADCHARACTER:
indicating that a command character not recognised by the current display mode has been received from the control panel and re-inserted into the input buffer for subsequent analysis. This code would normally be expected on a change of mode invoked by the user.

When a new operating mode is selected with a START command, it will start by rewriting the VDU display with its particular screen format; examples of these are shown in Figs. 7, 8, 9 and 10. Further commands received from the control desk will then be treated as sub-commands within this mode until an unrecognised command is received. In this latter case, the module will return the BADCHARACTER code and the rejected character is analysed at the command recognition level to determine if a new display mode has been requested. If a change of display mode is required, then the execution of the previously selected mode is first ended by sending it an ABORT command. The new mode is then invoked with a START command and the operation continues as before. If a change of mode is not required then the

COMMAND RECOGNITION

Fig. 11 - The structure of the top levels of the control software.
character is ignored and the previous mode is resumed by sending it a CONTINUE command.

The operations under the 'Run' module divide into four independent areas, namely, data entry and internal storage, disc space allocation, sequence assembly and real-time sequence replay. These are described in more detail in later sections.

The 'Load' module handles all picture recording operations invoked by the user. This entails the selection of the incoming video source, the searching of the disc allocation list for the correct storage location for a picture, and the control of the recording process.

The remaining control modules in the upper level fulfill subsidiary roles in the normal operation of the system. At any time, the 'Preview' mode can be invoked by the operator to browse through pictures on the disc or frames from a Run. The operation of this module is transparent to the others in that it can be entered at any time and causes the previous module to be suspended. On completion of the preview operation, the previous module is resumed from the point where it was earlier suspended. As a result, the Preview facility does not disrupt the operator's course of action and can, therefore, be used to confirm picture reference numbers, etc., during other operations.

These modules operate in isolation without any direct exchange of data between them. This results in smaller software modules which in turn leads to easier development and maintenance of the system.

The following sections describe, in more detail, the software implementation of some of the main system operations.

6.2 Main system operations

6.2.1 Data entry and its internal storage

Almost all of the operating modes expect data entry from the control desk and a common data entry and editing function has, therefore, been implemented. This generates a formatted screen on the VDU display and permits data entry by the user at preset positions across the screen. Each operating mode has an internal table which describes the format of the screen display; it includes the coordinates of each data entry position and which buttons on the control desk can be used at each point.

The Run mode display, shown in Fig. 7, is generated using this function. The isolated line at the bottom of the display, called the 'edit line', is used to enter and edit lines of data prior to their insertion in the main display area. There are 14 predefined positions, one in each column except the last, which are defined in the display table for this mode. The user can enter data at any of these positions, using cursor movement buttons to skip over previous or unused entries. When data entry is complete, the line is transferred automatically to the main display area and the edit line is cleared ready to accept the next line of data.

The data entered into the Run display by the user is stored in a linked list structure, shown in Fig. 12. Each element in the list holds the data for one line of the Run display and a pointer indicating where the next line is stored in the computer's memory. Since the system can hold several Runs simultaneously, a two dimensional list has been used, with links between the first element of each Run and links between each line within a Run. This data structure will increase and decrease in size as Runs and lines within them are added and deleted. It is, therefore, stored in an area of free memory, referred to as a 'heap', from which free space can be allocated and returned during editing. A further set of routines perform the management of this heap space, attempting to minimise the fragmentation of the free memory as elements are requested and subsequently returned after use.

6.2.2 Allocation of disc space

After the data entry has been completed it is necessary to allocate a contiguous area of disc space to the Run and correctly order the pictures within it for real time replay. This may also be necessary where a Run has been modified after a previous allocation of disc space has been made. Under these circumstances, a re-arrangement of the pictures recorded in the previously allocated area may be required so that their order matches the new allocation.

In order to conserve disc space, the allocation algorithm applies three rules which help to minimise the space required for a Run. These rules are:

1. If a single picture is replayed for more than one frame then store only one copy and replay it for the specified number of frames.

2. If a sequence of pictures is to be replayed several times in succession then store only one copy of the sequence and replay it for the specified number of cycles (see Section 6.2.5).

3. When two or more pictures are combined, off-line mixing and recording of the combined picture sequence is carried out. In this case, the length of the resultant sequence can be reduced by the highest common factor of the hold times of the component sequences. This
economy can only be made providing no other changes, e.g. fading of the mixer, are taking place.

As a simple example of this final condition, suppose that two short sequences are being mixed at constant level. The first sequence is five pictures, each shown for 12 frames and the second is four pictures each shown for 15 frames. This gives the resultant sequence of 60 frames duration which is illustrated in Fig. 13. The algorithm detects that changes only take place in the resultant sequence at multiples of three frames, the highest common factor of the two hold times, 12 and 15 frames. Disc space is therefore allocated for 20 images, each of which will be shown for three frames when the completed sequence is replayed. Further economy of disc space could be achieved by recording only the pictures where a change takes place. However, this could lead to a different hold time for each image of the resultant sequence and a corresponding complication of the software which controls the real-time replay.

The allocation process starts by determining the number of disc spaces already allocated to the Run or, for a new Run with no previous allocation, by setting this value to zero. The details of the Run are then scanned to produce an ordered list which shows the arrangement of pictures required and the number of contiguous disc spaces required to hold them. A search is now made for a contiguous block of space on the disc to accommodate the Run, producing one of the following five results:

1. The previous space allocated to this Run is large enough for the new allocation.

2. The previous space is not large enough but vacant disc space is available on either side for expansion.

3. The previous space is not large enough and cannot be expanded but sufficient space is available elsewhere on the disc for the entire Run.

4. The previous space is not large enough, cannot be expanded and no other single block is
available although there is sufficient space fragmented across the disc for the Run.

5. There is insufficient free space on the disc for the Run.

Providing sufficient free space can be found, the system will automatically rearrange the pictures on the part of the disc involved to match the sequence required for the Run. When the disc space becomes fragmented, as in case 4, repacking of the disc will take place to coalesce the free space into one area where it can be more efficiently used.

6.2.3 Assembly

The assembly operation consists of two phases. The first phase automatically produces the multipicture mixes which, because the disc drive has only a single video channel, cannot be produced 'live' as the sequence is replayed. It is during this phase that manual adjustments can be made to those entries on the Run or Run level 2 displays which have been marked for adjustment (see Section 5.4). To carry out this mixing operation the system first loads the frame stores with the source pictures which make up the mix. The mixer levels, keying parameters and any movement offsets that have been selected are then set and the resultant picture from the output of the mixer is recorded. This recording takes place at the disc location allocated for the mixed picture during the earlier allocation phase. The whole operation is then repeated for each frame of each mix in the Run. Where multiple Runs are being used, i.e. Runs are used as sources for another Run, the assembly software recursively calls itself to assemble single frames of the component Runs prior to final mixing. These intermediate results, produced as the 'subordinate' Runs are made, are stored temporarily on the disc and are discarded after the final mix is completed. If the 'manual' adjustment phase is required, the appropriate controls will be enabled after the first pictures have been loaded, allowing adjustments to be made, as described in Section 5.4, while viewing the result. If manual adjustments are not required, then this process will continue without intervention until all frames have been assembled.

The second phase of the assembly process scans the Run data entered by the user and generates a list of internal commands which will be used during real time replay. The operation of this list is described in more detail in the next section.

6.2.4 Control of real time replay

During real time replay of a sequence, field-by-field control of the hardware is performed by using the list of internal commands previously generated during the assembly operation. This list has at least one entry for each line of the Run details and contains the low-level commands and the field numbers at which those commands are to be executed. The organisation of this list is illustrated in Fig. 14. During sequence replay the command list, shown to the left of the figure, is scanned and on the appropriate field the corresponding command is submitted to low-level control routines to be performed. There are about 30 different low-level commands and typical commands include fade mixer, sequence disc drive, re-time frame stores and change video routing. Each command has access to the original line of user data, using the pointers across to the right of Fig. 14. This allows further data to be extracted as the command is executed. As an example, a mix command will use this mechanism to extract the start and end mixer levels directly from the user's data.

Once a command has been issued to a low-level control routine, the entire command will be executed for the required number of fields without further intervention. For example, fade commands for the mixer are issued once at the start of their fade interval. After receiving the command, the low-level mixer control routine will automatically update the mixer levels on each successive field of the fade until it is completed.

6.2.5 Implementation of sequence repetition

A frequently used technique in animation work is the repetition of a section of animation, particularly for background scenes. This can considerably reduce the number of images that are required for a given duration of sequence. The repetition may not be for a complete number of cycles; for example, a 10-frame sequence may be repeated for 25 frames, resulting in the final cycle being terminated after 5 frames.
START OF REAL-TIME REPLAY

from last Run in list

Run number
linking pointer

Data line pointer

to next Run in list

First line of user data
Pointer to next line

Second line of user data
Pointer to next line

Third line of user data
NULL pointer

Commands and their appropriate field numbers for first line

Pointer to data line
Field number
Command
Field number
Command
NULL

Commands for second line

Pointer to data line
Field number
Command
Field number
Command
Field number
Command
NULL

Commands for third line

Pointer to data line
Field number
Command
NULL

Internal control data to operate system during real time replay.

User data stored internally (as shown in Fig. 12) and accessed by commands during replay. This data is presented to the user on the Run and Run level 2 display pages.

Fig. 14 - Structure of command table for real time replay.

Disc drive

First frame store

Second frame store

Output

Fig. 15 - The configuration of the hardware for sequence repetition.
With the limited picture capacity of the disc, a method of repeated replaying of the same block of stored pictures is required; simple duplication of the sequence would soon entirely fill the disc. This repetition is complicated by the fact that the disc drive can only move between adjacent cylinders in a field blanking interval. Interruptions in the sequence are therefore introduced as the drive skips back to the first picture and at the end of the sequence. These are avoided by employing two frame stores in conjunction with the disc drive, as illustrated in Fig. 15. During the first cycle of the sequence, the first picture is simultaneously output and stored in a frame store for future use. Similarly, as the picture which will be the final frame of the repeated sequence is replayed for the first time it is simultaneously stored in the second frame store. After the initial pass through the sequence has been completed, the video routing is changed to replay the output of the first frame store instead of the disc drive. This will show the first picture of the repeated section for a second time. The disc drive now moves back to the second picture of the sequence in preparation for the subsequent replay of the remainder of the sequence. This operation continues for each complete cycle through the repeated section of animation until the final loop is reached. For the final repetition, replay up to the end point is carried out as before but with the final picture replayed from the second frame store instead of the disc drive. This allows time for the disc drive to skip to the first picture beyond the repeated section of animation ready for normal replay of the remainder of the animation.

6.3 Software development

The software was developed on a separate DEC PDP 11/34 computer and was downloaded into the LSI 11/23 within the equipment via a serial data line. Since the equipment is installed in an area of the BBC remote from the development computer, software maintenance work is carried out using high speed modems linked over private audio circuits.

The most significant problem arising through this choice of computer hardware and support has been the limited address space of the LSI 11/23 minicomputer. This has required the software to be split into several overlays and, even with memory management hardware, has resulted in complications during software development which could otherwise have been avoided. In hindsight, it would also have been better to install an operating system with software development tools on the LSI 11/23. This would have avoided the problems associated with its interconnection to a remote computer for software development and maintenance.

The majority of the 20,000 lines of software for the control system is written in the programming language 'C'. Assembly language was used only for those routines where speed of operation was critical.

The main software modules were designed to operate in isolation without any direct exchange of data between them. Common data storage is provided by two globally accessible data structures which store control information describing the current allocation of disc space and the user's animation data. The software was segmented in this way to minimise, where possible, the subsequent effects of software maintenance and to enable a number of engineers to develop modules independently. Both these objectives were successfully achieved and, since entering service, several minor improvements suggested by Graphic Design staff have been implemented.

7. OPERATIONAL EXPERIENCE

The Television Animation Store was first used to produce animated sequences in September 1982. At that stage, the software offered many of the basic facilities required and allowed them to be evaluated by operational staff. In October 1983 the equipment was installed at the BBC's Television Centre. After the training of staff and testing of more sophisticated software, the facility became fully operational in April 1984. It has become very popular with Graphic Design staff, particularly because animation can be checked as it is produced and changes, if required, can be made immediately. Virtually all the facilities of the equipment are used regularly and none appears to be unnecessary. The ability to build up complex animation, using Runs as picture sources within other Runs, has significantly increased the potential of the system, allowing extremely complicated animation to be produced with relative ease.

Fig. 16 shows examples of programme output that have been produced with the equipment.

8. CONCLUSIONS

The Television Animation Store described in this Report has been successful in overcoming many of the problems of producing animation for television. The digital picture storage system, with its random access capabilities, has allowed enhanced facilities to be developed and an extensive computer control system allows these to be exploited without difficulty.

Many of the effects produced could not be created using video tape unless extensive tape editing were carried out; subsequent modification of individual frames of the animation would then be a laborious task to perform.
Fig. 16 - Some frames of animation illustrating the type of work carried out using the Animation Store.

**TOP LEFT:** This photograph illustrates the superimposition facility, used here to create 'streaks'. The effect is produced during the Load operation by accumulating pictures in a picture store whilst the source is moving. The resulting sequence has then been keyed into a still picture containing the caption. *(From the programme "Saturday Review").*

**TOP RIGHT:** In this animation the pages of the book are being turned continuously illustrating the ability of the system to repeat a cycle of a previously recorded sequence without re-recording. *(From the programme "Saturday Review").*

**CENTRE LEFT:** This photograph shows the repetitive use of keying and mixing effects. The figures are rising separately over the caption, apparently on soap bubbles, whilst a mass of smaller bubbles move within the black rectangle of the caption. *(From the programme "Saturday Review").*

**CENTRE RIGHT:** This shows a frame of animation combining a 'live action' sequence (the ripples on the water), a moving computer generated pattern and a static pattern. The picture within the triangle moves with the pattern and subsequently dissolves into another image. *(From the title sequence of "The Life and Loves of a She Devil").

**BOTTOM LEFT:** This more ambitious animation shows a compact disc spinning downwards toward a Wurlitzer juke box. As it does so, figures are animated on the surface of the disc, matching its movement. The background shows a swirling cloud effect behind a dot pattern. The sequence continues with further animation as the disc comes to rest within the juke box. *(From the title sequence of "The Video Juke Box").*
The ability to add animated effects into recorded video sequences allows effects to be achieved without the use of an intermediate film process. Furthermore, movement within a 'live action' sequence can be followed accurately without the difficulties introduced by the frame-to-frame 'weave' frequently associated with film. In addition, complex animation can be produced immediately which, if carried out using film, would require extensive matteing and optical processing operations.

The advantage of having a simple control system, which allows very complex operations to be carried out easily by non-technical staff, has proved to be a particular strength of this equipment. Together with the ability to modify individual parts of a complex piece of animation with relative ease, this has resulted in a system which has considerable benefits over other approaches to animation.

This work has shown that a video animation system can be capable of performing all of the work currently undertaken with film. In addition, such a system offers instantly available results and allows highly developed television studio techniques to be applied to this form of television.

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10. REFERENCES


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