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Personal Video Recorder Function Based on Android Platform Set-top Box

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Abstract

In order to satisfy the constantly increasing appetite of consumers for content in today's world, Personal Video Recorder (PVR) function is implemented in digital TV set-top box (STB) based on Android platform. An algorithm that adjusts video Presentation Time Stamp (PTS) based on audio PTS is presented, which aims at the problem that audio is not synchronized with video existing during playback. And a method of generating index file based on the information of I-picture is presented, which aims at the implementation of trick modes. Namely, the location of I-picture which is used to generate index is recorded while audio and video data are being sent to storage medium in Packetized Elementary Streams (PES) format. The test results show that the TV STB designed can implement synchronization of audio and video accurately and reliably and the recorded programs can be played on the STB at different speeds.

Keywords: Personal Video Recorder, set-top box, Presentation Time Stamp, trick play

1. Introduction

Digital TV set-top box (STB) is a TV network terminal device which converts digital signal to analog signal [1]. Nowadays, most digital TV STBs are based on Linux platform. The quantity of existing applications on this kind of platform is limited, so more money will be spent if we want to develop new applications on the same platform. In addition, due to the portability between two existing platforms is not easy enough, more resources will be wasted if providers want to develop the same application on different platforms. Android system has many advantages over traditional platforms. For example, it is open source, cross-platform and easy to be developed [2, 3]. Therefore, digital TV STB based on Android platform is used to implement Personal Video Recorder (PVR) function in this paper.

PVR is defined as using a local hard disk or other storage medium to record and play back broadcast programs [4]. There are huge amount of programs being established in the storage medium [5]. The digital TV STB with PVR function can revolutionize the way consumers watch television. Consumers can not only view scheduled live television broadcasting in accordance with their needs, but also play back TV programs associated special trick modes, such as pausing, rewinding, jumping forwards or backwards, and playing at different speeds, etc.

2. Design of PVR System

The design of PVR system mainly consists of hardware architecture and software architecture. In terms of hardware architecture design, the receive buffer and playback buffer are added to the traditional digital TV STB so as to reduce times of reading and writing storage medium. In order to obtain the PES stream of audio, video and program information smoothly during playback, the software demultiplexing module is also added to the traditional digital TV STB. In terms of software architecture design, we mainly design some functions, such as PVR_MAIN, PVR_REC, PVR_PLAY and PVR_SATA, so as to reduce the code redundancy and make each function have a clear division of responsibilities.

2.1. Hardware Architecture

The researched digital TV STB is equipped with the source decoder chip Hi3716C which is particularly powerful. The digital TV STB is mainly composed of tuner, demodulator, demultiplexing, decoder, the system control section, the expansion interface and power. The internal architecture of digital TV STB is shown in Figure 1.
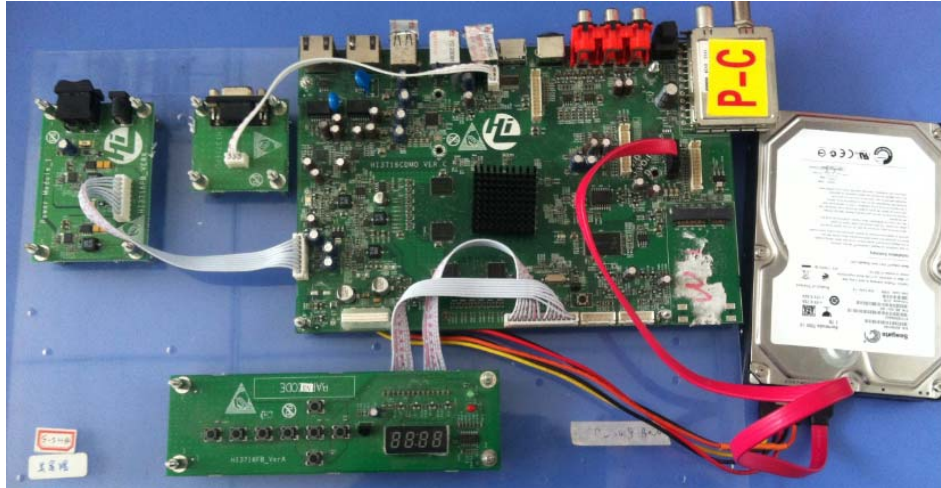

Figure 1. Physical map of STB internal architecture

The ARM's advanced Cortex A9 architecture processor is adopted on Hi3716C chip. For the excellent characteristic of Hi3716C chip that 3-way TS inputs can be supported on it, two tuners are used in the hardware architecture design of this system. There is only one tuner in traditional TV STB, so it is only possible to record one program and watch another which is in the same TS stream. While on the Hi3716C platform, it is possible for consumers to record one program and watch another which is in any TS stream. The hardware architecture of STB with PVR function is shown in Figure 2.
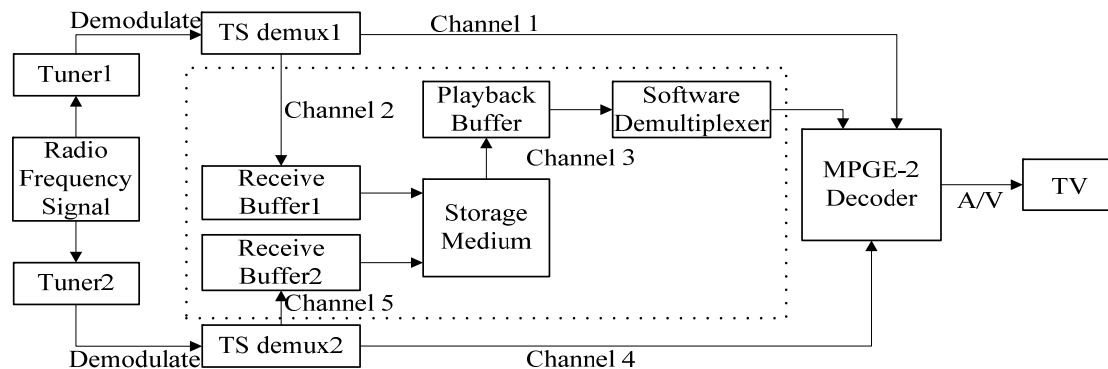

Figure 2. Hardware architecture of PVR system

As shown in the dashed box in Figure 2, the receive buffer is added to the traditional hardware architecture, so as the playback buffer and the software demultiplexing module to implement PVR function. In Figure 2, channel 1 and channel 4 are used to play programs in real time, channel 2 and channel 5 are used to record programs, and channel 3 is used to play back programs.

2.2. Software Architecture

In order to implement the PVR function, there are four functions designed in the application layer.

(1) PVR_MAIN

This is the main function. There is a corresponding sequence which is called "PVRMsgQueue" specified in this function. Request is sent to PVRMsgQueue through remote-controller. After the message which is received form PVRMsgQueue being parsed in PVR_MAIN function, PVR_REC function or PVR_PLAY function will be informed to perform PVR functions which include recording, playing back, pausing and so on in accordance with consumer's operation.

(2) PVR_REC

This function is responsible for recording programs. It is in a waiting state until recording request is being sent from PVR_MAIN function to this function. Then the data stored on the SDRAM-A buffer will be sent to storage medium.

(3) PVR_PLAY

This function is responsible for playing back recorded programs. Firstly, the data stored on the storage medium are sent to SDRAB-B buffer. Secondly, the data will be sent to the buffer of audio and video decoder [6] in the A/V DMA mode when the SDRAB-B buffer is full. Besides writing data, trick play module and time shifting module are managed in this function, which is different from PVR_REC function.

(4) PVR_SATA

This function is responsible for controlling operations to storage medium. There is also a corresponding sequence which is called "HDMsgQueue" specified in this function. When the receive buffer is full or the playback buffer is empty, the message which is received form HDMsgQueue will be parsed and relevant drivers will be called to write or read files.

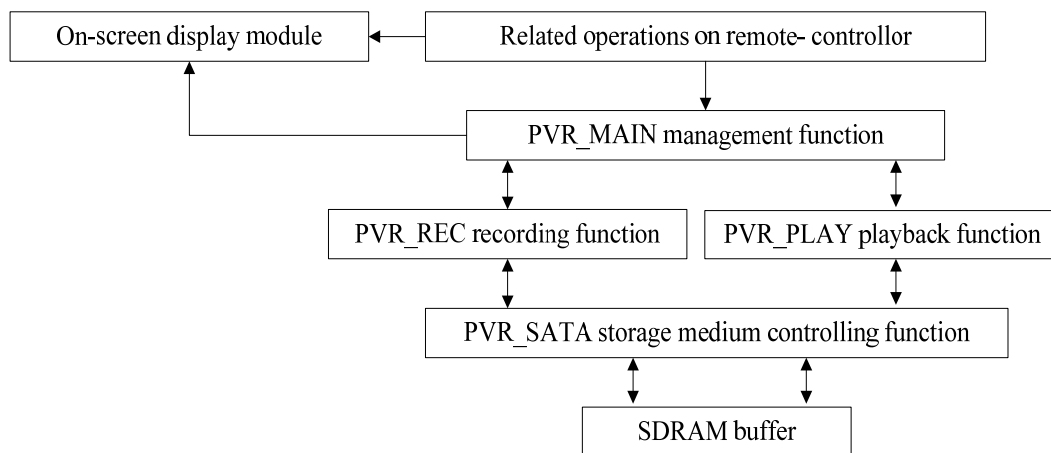The relationship among these four functions is shown in Figure 3.

Figure 3. Software architecture of PVR system

3. Key Technologies on PVR Function

After implementing recording and playing back function, this section discusses how to solve the problem that audio is not synchronized with video existing during playback and how to implement trick modes.

3.1. Audio and Video Synchronization Issues

By researching MPEG-2 synchronization theory of audio and video [7], an algorithm of adjusting video PTS based on audio PTS is presented to solve the synchronization problem in PVR system.

3.1.1. Synchronization Algorithm

It is in PES format that audio and video data are stored to the storage medium to implement PVR function. Due to the Program Clock Reference (PCR) is located in the TS packet header, the method of setting clock recover unit by PCR which is similar to broadcasting stream cannot be used in PVR system to achieve synchronization of audio and video.

An improved algorithm that the audio rate is kept constant and the video rate is changed based on PTS in the same time point is presented. The first reason to present this algorithm is that audio and video PTS are located in the PES packet header and accurate relative time between audio and video can be transmitted by them. The second reason is that consumers are more sensitive to changes in audio than in video for audio is continuous while video is intermittent.

The concrete steps of the presented method are as follows:

Step1. Generate audio PTS table in accordance with the flow chat shown in Figure 4. The PES packet header is parsed while audio PES data are being sent to audio channel buffer in the A/V DMA mode.
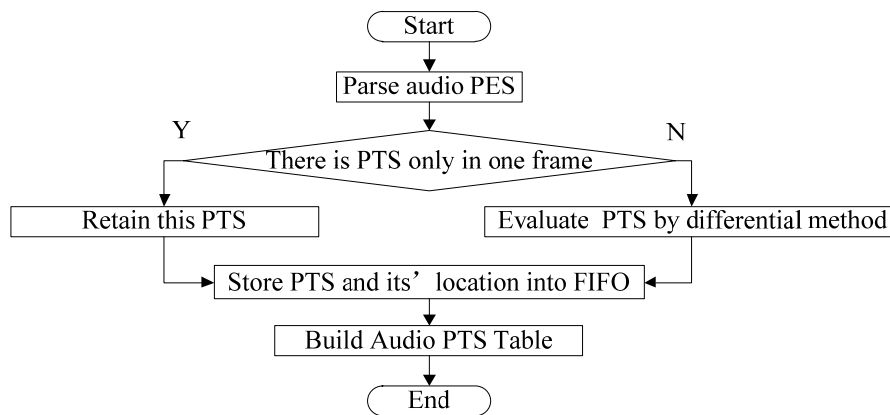

Figure 4. Construction Method of Audio PTS Table

Step2. As for video data, generate video PTS table using the method reference to Step1. The data structure of PTS table is described as follows:

```
typedef struct _T_AVPTS
{
        UINT32 *pWrite; //write pointer
        UINT32 *pRead; //read pointer
        UINT32 TimeStamp; //time stamp
        UINT32 PacketAddress; //the location of time stamp
} T_AVPTS;
```

Step3. Begin to decode. The decoder is always in a waiting state until the first audio PES package is detected on the Hi3716C platform. Firstly, audio is interrupted and the audio PTS is generated. Secondly, the value in the System Clock Reference (SCR) counter is changed based on audio PTS. At last the value in SCR counter is compared with video PTS gotten when video is interrupted. If the speed of decoding is too fast, I-pictures and P-pictures can be displayed repeatedly so as to save the actual storage space in the decoder. On the contrary, B-pictures can be dropped cleanly before being sent to the decoder considering that B-picture is shorter than others.

3.1.2. Confirm Audio PTS

The concrete implementation of using differential method to confirm audio PTS in Figure 4 of subsection 3.1.1 is introduced in this subsection. The PTS of each frame is determined by sampling rate and sampling number per frame. The PTS is one in 300 of a 27MHz system clock [8], and it can be described in Eq. (1):

$$PTS(k) = (27MHz \times tp_n(k))/300 \tag{1}$$

Here, $tp_n(k)$ is play time of play unit $p_n(k)$, and $PTS(k)$ is PTS value of $p_n(k)$.

If $p_n(k)$ represents audio frame, $tp_n(k)$ can be calculated directly as follows:

$$tp_n(k) = (PTS(k) \times 300)/27MHz \tag{2}$$

If there is no PTS in the following audio frame, differential method is used to calculate $tp_n(j)$, see Eq. (3).

$$tp_n(j) = tp_n(k) + (j-k) \times N_f / f_s \tag{3}$$

Here, N_f is sampling number included in an audio frame and f_s is sampling rate of audio signal.

3.2. Trick Play Issues

During playing back a recorded program, trick play technology [9] is presented so as to make consumers watch TV in a human friendly manner. Trick play is defined as a various play modes, such as pausing, rewinding, jumping forwards or backwards, and playing at different speeds, etc.

Moving pictures in digital video are composed of pictures frame by frame. The implementation of trick modes relies on operations to frames. Group of Picture (GOP) is defined so as to make random-access easier [10]. There are three different picture types in GOP: I-picture, P-picture and B-picture, which have a relationship of prediction and generation. The first picture in decoding order of GOP must be an I-picture [11].

More details on each of the picture types are listed in Table 1.

Table 1. Picture Types in GOP

Picture type	Encoding Style	Reference Frame	Binary Code
I-picture	Intraframe Coding	Null	001
P-picture	Predictive Coding	Encoded I-picture, P-picture	010
B-picture	Bidirectional Predictive Coding	The before and after two pictures: I-picture, P-picture or P-picture, P-picture	011

Record the location of I-picture and then generate index file when audio and video data are being sent to storage medium in PES format. The extraction process of I-picture is shown in Figure 5. Figure 5 shows that the extraction process of I-picture is as follows:

Step 1. Analyze each TS package of playback program stored on the storage medium, then save the video PID in accordance with the message in the TS packet header.

Step 2. Ensure if there are valid data in TS package in accordance with the value of "adjustmentbytes".

Step 3. If the current PID is video PID, then ensure coding style of this video in accordance with the valid data.

Step 4. If the current frame is I-picture, save data in index file.

Step 5. If it is not the end of I-picture, repeat step3 to step4 until finishing analyzing and extracting current I-picture.

Step 6. For the next TS package, handle data in TS package in accordance with Step 1 to Step 5 until all the video data of playback program are analyzed.
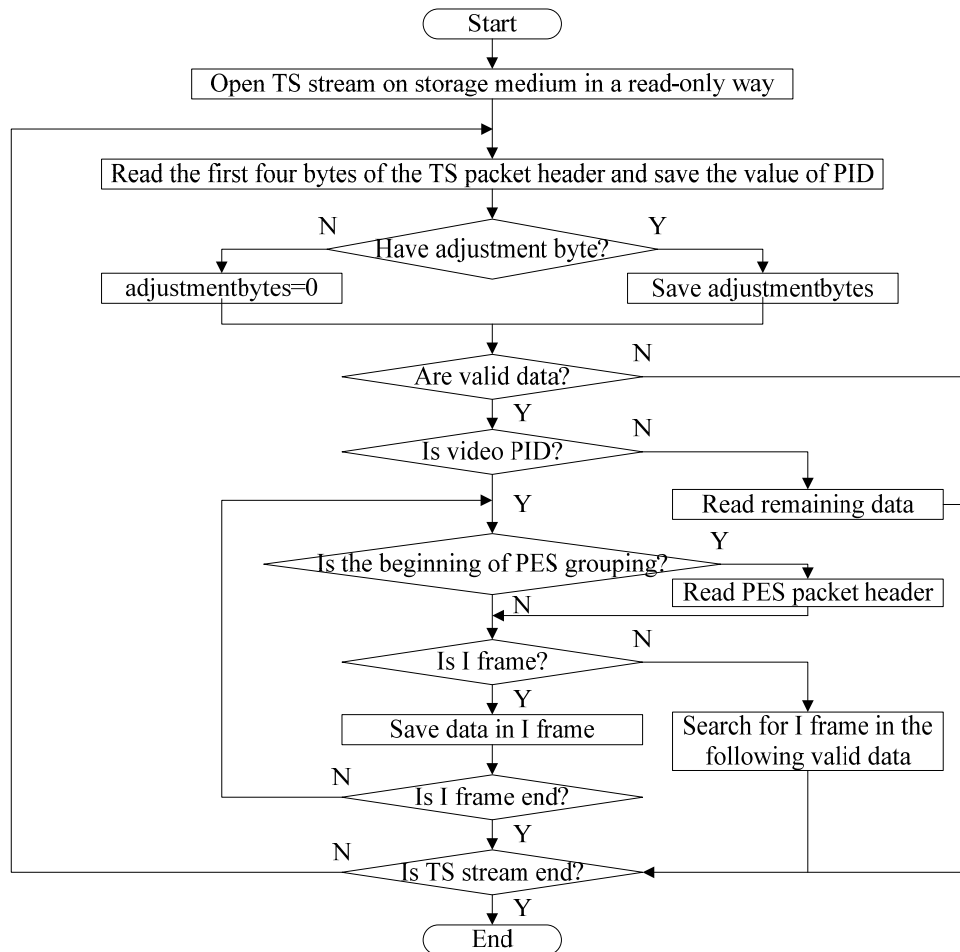
Figure 5. Extraction process of I-picture flow chart

The data structure of I-picture is described below:
typedef struct I_Frame_Info
{
        Void * I_Frame_ptr; // the location of I-picture on storage medium
        UINT32 I_Frame_Index; //the index number of I-picture
} I_Frame_Info;
Some frames can be skipped in the decoder to create the visual effect of fast-forward or fast-back. As shown in Table 1, when trick modes are implemented through the way of skipping frames, it is better to skip B-pictures so that there is less impact on other pictures. The skipping number of each GOP is decided by play speed. The more frames skipped, the quicker the speed is. During playback, the I-pictures required are read through index and then sent to decoder. After decoding, the effect of fast-forward and fast-back can be implemented.

Splendid senses can be played slowly by replay technique, the theory of which is that the playback speed will be slowed down to N times if each frame is replayed N times in the decoder.

4. Test Methods and Results
Firstly, software implemented PVR function is burnt to the digital TV STB based on Android platform. Secondly, the test environment is built as shown in Figure 6.
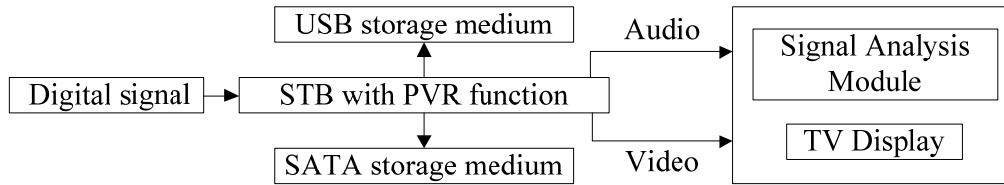
Figure 6. Test Environment of PVR Function

Test the performance and the function of PVR system with two devices which are Signal Analysis Module (SAM) and TV display respectively. The test methods and results are shown in Table 2.

Table 2. Test Methods and Results

Test Method	Test Result
Test interchange effect among normal play, quick play and slow play by TV display	All play states can switch smoothly
Test continuity of audio signals by TV display	No interruption happens
Test times crash happens by TV display	Zero
Test the speed of fast-forward by SAM	Can play fast-forward 2,4,8,16 times
Test the speed of fast-back by SAM	Can play fast-back 2,4,8,16 times
Test the speed of slow-forward by SAM	Can play slow-forward 1/2,1/4,1/8,1/16 times
Test interchange time between two play states by SAM	Average interchange time is 55ms
Play recoded programs on computer	Can play smoothly

Table 2 shows that the digital TV STB based on Android platform designed can record and play back programs, and the recorded programs stored on storage medium can also be played on computer smoothly. What's more, the audio and video are in a good synchronization without interruption and that trick modes can be implemented at different speeds during playback.

What is more, two programs in different TS streams can be recorded at the same time for two turners are adopted in the STB designed in this paper. The design method is better than that in reference [12], for there is only one tuner adopted. And the algorithm presented in this paper that adjusts video PTS based on audio PTS to solve the problem that audio is not synchronized with video existing during playback is better than the method presented in reference [13], for consumers are more sensitive to changes in audio than in video for audio is continuous while video is intermittent.

5. Conclusion

The implementation of PVR function in digital TV STB based on Android platform is presented in this paper. The test results show that the algorithm of adjusting video PTS based on audio PTS can solve the problem that audio is not synchronized with video accurately and reliably and the method of generating index file based on the information of I-picture can implement trick modes easily and effectively. PVR function is changing the way consumers treat broadcast media sources. For the PVR system has very important technical significance and practical value, there will be a broader development prospect.

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