A Hard-Disk based Portable Entertainment Device for Managing Contents on the Go

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Abstract: - This paper presents a design and implementation of a hard-disk based portable entertainment device based on an ARM-based system for managing thousands of personal photo/music/video collections anywhere you go. This device is designed as a music-centric entertainment player, slideshow player, digital photo storage and video player with built-in metadata database to sync and manage the contents. There are many obstacles during the design of such devices e.g. managing large content, intuitive user interface design and power consumption on hard-disk access. To overcome these design issues, a prototype system has been presented in this paper with a player called photo jukebox (PJ) at client side and a digital media manager system on the host computer. Hardware and software architectures of PJ are presented. Also, an iterative process of user-centered design is applied on this device. Therefore, the ease of use of its user interface was investigated using the human computer interaction (HCI) methods of heuristic evaluation and usability testing. At last, the dynamic power management is explored by different user profiles to enhance the battery life on such devices.

Key-Words: - Human computer interaction, Graphical user interfaces, Metadata, Content management, Photography, Hard-disk, Power management

1 Introduction
With the wide acceptance of digital cameras/camcorders as the tools for a consumer image capture, personal digital photos, video clips are becoming a common valued form of personal content. Photo applications or services are replacing film paper with digital files and album books with digital file folders. In addition, digital music e.g. MPEG-1/2 Audio Layer 3 (MP3) [1] /Advanced Audio Coding (AAC) [2] /Windows Media Audio (WMA) [3] has booming via the transmission from the Internet, followed by storage on home computers. Digital music and pictures are the most popular personal computer digital media activities for entertainment contents currently.

Furthermore, the new demanding for extending the personal computer media experience to portable devices is booming. Take digital music as an example, it is replayed through portable device analogous to the "walkman". Hence, users are looking for these new devices to make them take hours of digital audio with them, too, keeping their favorite music with them at all times. And, they can bring pictures of the family or their favorite vacation spot while on the road. Those make it easy for consumers to enjoy all their digital content on the go.

Those applications above are requiring devices with the ability to store gigabytes of data. Hence, the growth in demand for such portable consumer electronics is driving the need for high-capacity storage. Furthermore, the use of hard-disk drives (HDD) in consumer devices is growing due largely to the low cost/gigabyte they offer compared with solid-state memory such as flash [4]. A HDD player stores data in much the same way as a desktop or laptop computer. A physical disk inside the player spins and stores information. However, the power consumption of the HDD becomes an issue since it demands too much current while the disk drive is spinning up and accessing the data.

Another issue is how to create a portable entertainment device to satisfy the above requirement and apply for an intuitive interface design to seamlessly find, synchronize, manage, store, play, and project thousands of personal digital music, photo collections and video clips from the personal computer (PC) to these portable devices.
Existing devices e.g. PDA (Personal digital assistant) or cell phones do not naturally support the above user requirement. Current form factors and user interfaces present barriers to thousands of digital contents.

To overcome these limitations, a prototype system has been presented in this paper with a player called photo jukebox (PJ) at client side and a digital media manager system on the host computer. This PJ is equipped with a HDD that can sync the digital music and photo contents through PC via high speed universal serial bus (USB) [5]. With the dynamic buffering power management for HDD, the power consumption can be reduced dramatically. Furthermore, by applying for the process of the user centered design, PJ presents an intuitive interface that requires no training to select and display a sequence of media contents stored from host computer, digital cameras and Secure Digital (SD) card. PJ also can display photos on television or print it via photo print.

The rest of the paper is organized as follows. Section 2 presents the proposed design including both hardware and software architectures on this HDD portable entertainment device. The digital media manager application on host computer is also presented. Section 3 describes the process of user-centred design applied for such device. Its user interface was investigated using the human computer interaction (HCI) methods of heuristic evaluation and usability testing. Section 4, the dynamic power management scheme is explored by different user profiles to enhance the battery life. Section 5 provides final conclusions on the work.

2 Proposed Design

To fulfill the features of end users to capture, store, play and display their entire music, album art, and photo collections on a single device that fits in their pockets, the proposed design and features of a HDD portable PJ are described as below:

2.1 Features of the Proposed Portable Photo Jukebox

The work concentrates on photos and music management at portable device with large capacity. The proposed concept is using metadata database management. The information of media content is extracted from the tags of media content such as ID3 [8] for MP3, EXIF [9] for JPEG. Table I lists the functions and its major operations defined in this paper for music and photos. This system design allows for a user to easily manage a personal collection of photos and music as well as the slideshow that are distributed between host computer and PJ. A slideshow is organized into a number of photos, music and tags. And, a slideshow playlist is defined as XML (eXtended Markup Language) [11] format that can easily manage the operations such as delete, insertion and merge functions. The following describe the XML tags and their meanings. <BACKGROUND> is defined to be independent list of media. <FOREGROUND> is defined to be the dependent list of media. The list in <FOREGROUND> determine the duration of the presentation. The background will repeat until the presentation time of <FOREGROUND> has completed. Additionally, some associated media tags are defined. For examples, <AUDIO> is defined as any audio asset and <PHOTO> is defined as an image asset. The properties of <PHOTO> are <TRANSITIONEFFECT> and <DURATION>. <TRANSITIONEFFECT> describes the transition effect to be used when switching to this asset e.g. "HorizontalWipe", "VerticalWipe" and "AlphaBlend". <DURATION> defines the duration for which the photo shall be presented in milliseconds (ms). A hierarchical XML format shows an example of the slideshow (Fig. 1). The slideshow can embedded a music file as the background and a list of photos with the setting of transition effect and duration. A slideshow defined as XML format that can have child slideshows; thus a hierarchical organization is possible.

<? xml version="1.0" encoding="UTF-8"?>
<SLIDESHOW>
  <BACKGROUND>
    <AUDIO>MUSIC\Sample.mp3</AUDIO>
  </BACKGROUND>
  <FOREGROUND>
    <PHOTO>
      Photo\P1.jpg
      <TRANSITIONEFFECT>HorizontalWipe</TRANSITIONEFFECT>
      <DURATION>3</DURATION>
    </PHOTO>
    <PHOTO>
      Photo\P2.jpg
      <TRANSITIONEFFECT>HorizontalWipe</TRANSITIONEFFECT>
      <DURATION>3</DURATION>
    </PHOTO>
  </FOREGROUND>
</SLIDESHOW>

Fig. 1. An example of Slideshow format based on XML.
TABLE I
THE FUNCTIONS FOR PROPOSED HDD PORTABLE PHOTO JUKEBOX

<table>
<thead>
<tr>
<th>Functions</th>
<th>Operation description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Music Management</td>
<td>1. Artist, Album and Genre (Metadata in e.g. ID3 of MP3, WMA)</td>
</tr>
<tr>
<td></td>
<td>2. Playlist</td>
</tr>
<tr>
<td></td>
<td>3. Digital rights management[10] for subscription-based and downloadable services</td>
</tr>
<tr>
<td>Photo Management</td>
<td>1. Extract thumbnail from EXIF</td>
</tr>
<tr>
<td></td>
<td>2. Add/remove thumbnail and related metadata of photos into database</td>
</tr>
<tr>
<td></td>
<td>3. Add/remove photos into folders</td>
</tr>
<tr>
<td>Photo Operation</td>
<td>1. Copy, Rename</td>
</tr>
<tr>
<td></td>
<td>2. Rotation, Zooming/Panning</td>
</tr>
<tr>
<td></td>
<td>3. EXIF metadata presentation</td>
</tr>
<tr>
<td>Slideshow Management/O</td>
<td>1. Select photos</td>
</tr>
<tr>
<td>peration</td>
<td>2. Set overall time interval and transition style</td>
</tr>
<tr>
<td></td>
<td>3. Change order</td>
</tr>
<tr>
<td></td>
<td>4. Set time interval and transition style in individual</td>
</tr>
<tr>
<td></td>
<td>5. Select background music (multiple songs selection)</td>
</tr>
</tbody>
</table>

2.2 Designing Hardware Platform for the Portable Photo Jukebox

Fig. 2 (a) depicts the proposed hardware block diagram of this HDD PJ and Fig. 2(b) is the appearance of this PJ.

The key components are described as follows.

- **Embedded media player system on chip (SOC):** This SOC is an ARM-based CPU [12] optimized for low-power multimedia processing including audio codec, image processing etc. as well as integrated required peripherals to support hard-disk storage and fast data transfer from USB.

- **System memory:** In addition to store the running program and data, the memory is also used to buffering the contents from hard-disk to reduce the duty cycle of the data access of hard-disk and the probability of the hard-disk drop at operation mode.

- **Boot ROM (Read Only Memory):** Its stores the boot-loader and the parameters used for operation systems. Hence, those parameters can be kept even the hard-disk is replaced with a new one. The boot-loader also keeps the device-specific secure key to insure the integrity of the operating system.

- **USB OTG (On the go) [5] interface:** It supports both USB host and client functions. With the USB host function, the device can support connecting to e.g. cameras or card readers. By using the USB client, the device can transfer data from host PC to the hard-disk.

- **Audio codec interface:** This is essential for music playback device. It supports high quality codec with headphone out and microphone interface.

- **Battery interface:** The device applies for dumb battery and simply detects the voltage by using 8 bits ADC (analog-to-digital converter) interface. The battery voltage algorithm is profiled in advance by discharge curves under various scenarios (e.g., temperatures and battery charge cycles).

- **IDE interface:** This hard-disk interface can apply for small form-factor from 1-inch (1.5GB to 10GB) to 1.8-inch (20GB to 80GB) hard-disk. For the content of the hard disk, in addition to those digital contents, it stores those certificates used for the DRM (digital rights management).

- **RTC (real time clock):** RTC mainly is used for subscription-based service such as a monthly fee, unlimited music downloads and transfers. The service utilizes RTC to support the functions of expiration and metering for leased content.

- **VFIR (Very Fast Infrared) [13]:** This component connects the processor via SPI (Serial Peripheral Interface) with maximum data transfer rate up to 16 Mbits/sec. This
interface provides high speed peer to peer content sharing.

- Dock interface: This dock interface includes USB host interface, display signal interface and I2C (Inter-Integrated Circuit) interface to support future extension for accessories. I2C interface is used as control interface between the device and the dock. A command set can be defined to support the communication protocols between the device and the remote controller for example.

2.3 Designing a Software Architecture on the Portable Photo Jukebox

The users expect to do more with their portable devices to manage content quickly and easily, change content automatically or manually as well as put files of all kinds on the PJ, including arbitrary data and purchase content online and use it on this device. Also, the PC has a vital role in managing these devices, providing intuitive and flexible user interface to handle large storage and connectivity via high-speed data transfer between PC and the portable device.

To achieve these goals as above, the proposed embedded media software architectures from presentation user interface, middleware (software manager layer and libraries) to device specific drivers are listed as in Fig. 3. The operating system (OS) kernel is based on ThreadX [22] with characteristics of priority inheritance, preemption-threshold, efficient timer management, picokernel design, event-chaining, fast software timers, and compact footprint. The dedicated drivers connect the OS to the specific hardware blocks such as display controller, USB, power mangement, VFIR, disk/memory devices, etc. The middleware layer combines both manager and libraries framework needed for PJ. The manager layer focuses on functions needed to implement the graphical user interface along with media and device handling primitives. This block is also enhanced by digital rights management functions. Furthermore, the libraries layer needed to handle the media related functions are implemented e.g. metadata parsing, media buffering, encoding, decoding and rendering functions for audio and still images.

The media manager software on host PC is utilized for synchronizing the contents to the devices, managing the device (e.g. firmware update) and complying with those content service providers (Fig. 4). The driver layer related to PJ is implemented as the USB driver with the support of mass storage class (MSC) and media transfer protocol (MTP) [23]. The MTP provides the command and control primitives for synchronizing and managing the contents between portable device and the host computer. The middleware layer (libraries and manager) is implemented to support the device handling functions and content management. This layer also provides the plug-in interface for content service providers to integrate their service with media manager.

With the hardware and software architectures proposed for the PJ, PJ has the basic framework for designing portable entertainment devices based on various user scenarios and specific profiles. In the later sections, the user centered design process is employed to design the detailed user flow. And, several examples are proposed after usability test.

![Fig. 3 Proposed software architecture of the photo jukebox](image)

![Fig. 4 Proposed host PC software of the photo jukebox](image)
3 Process for User Centered Design
In this section, the generic user centered design process [6][7] is applied for this portable device from user research, user/task analysis, user scenario, use model, conceptual model and prototyping to usability testing. As Fig. 5, this iterative process is applied from earlier user research stage to final implementation stage. The goal is to find out the major features and enhance the user interface on this device.

For example, there is a user research results for knowing how people manage their digital music and digital photos. 120 people (80 male and 40 female) with college degree or above have been interviewed. And, the target users are set all age to 54 years old. During the interview, all participants have been asked on a questionnaire including the use experiences of personal digital assistant (PDA), MP3 player and digital camera. One quick summary is as below:

(a) **Music issues:**
- Most people get their MP3 music from Internet (101 of 120). The second resource is ripping audio CD (51 of 120), and the third one is from friends (32 of 120).
- Most people have more than 500 MB MP3 music files in their computer (102 of 120).
- All people organize their MP3 file by artists and album (120 of 120). Some of them will add more rules to organize their music such as language, the gender of an artist, or published date.

(b) **Photo issues:**
- People usually use "delete" (120 of 120) command when using digital camera. Some people uses "rotate" (54 of 120)
- After people transfer their photos from digital camera to computer, they usually use "rotate" (111 of 120), "resize" (92 of 120).
- Most people have more than 750 MB digital photos on computer and photo CD (80 of 120).
- Most people rely on the date to organize their photos (110 of 120). Meanwhile, they may add more rules to organize photos, such as location, or event.

Additionally, the usability guidelines for such entertainment devices were derived as below: (1) Good graphic user interface design (layout and style) for small display; (2) Simple user interaction with well organized menu architecture; (3) Limited steps to reach designated content from thousands of data and perform content editing e.g. slideshow; (4) Provide thumbnails for pictures browsing; (5) Intuitional photo and music management for people with minimal computer and Internet knowledge. And, usability goals for testing PJ and host application are: (1) High user satisfaction; (2) 100% task completion rate; (3) Low assist rate; (4) Low error rate.

Think aloud protocol [21] is performed when the participants conducted the interaction tasks. What the participant said was recorded and further analyzed. And, their interaction processes were observed. This protocol is suitable for observing a user working with an interface. By focusing on how effectively a user performs the required tasks, verbalizations are useful in understanding mistakes that are made and getting ideas for what the causes might be and how the interface could be improved to avoid those problems while interacting with the system.

There have been some research results [14-17] based on this prototype. [14] and [15] are to design the display layout and style based on mental models of the users. [16] presents the example of icons design on such small display devices. Furthermore, small screen interface icons [17] present the research on the mapping between graphical and solid user interfaces based on the operations of the
users on the buttons.

Fig. 6 presents an example of the physical controls for the user to operate the complete user flow. This design uses hierarchy controls to let user complete all the operations with limited keys. By using the left and right keys of the navigation keys, the user can switch between different layers. Right key can also be overloaded to execute the selected item for those items at the last level. And, the up and down keys are used for item selections. The option key can provide all advanced options as we use the right click of the mouse at windows system.

Fig. 7 (a) and (b) show an example of display layout for such device. Display layout and physical control determine the basic elements of usability.

Then, Fig. 8 depicts the examples of the functions and the operation flow for music.

With the examples for the design of the user flow, there is another key factor for designing such portable entertainment device which is the battery life. Hence, in the next section, the design of HDD-based dynamic power management is explored on the portable photo jukebox. This platform can also be the test-bed for dynamic power management on such portable entertainment devices.

**Fig. 6 An example of physical controls for the portable photo juke box**

**Fig. 7 (a) and (b) show an example of display layout for such device.**

**Fig. 8 Music functions and its related operations defined in the photo jukebox**

### 4 Proposed System Power Management

This section provides an overview of the proposed power management states, and how they relate to applications running on proposed PJ. There have been several researches on dynamic power management [18-20]. Those techniques can apply to design such devices by taking the activity of HDD into considerations. Firstly, the power states and transition diagram need to be defined. Besides the system enters the OFF mode, the system should be capable of defining more power states to adjust dynamically. Thus, we define more states according to the requirement as in Fig. 9.
The power management states come with five state levels: On, Idle, HDD spin-down, Suspend and Power off. These states that map into the PJ required modes of operation, and the condition change to another state are described as below.

**On Mode:** In the On mode, the CPU and peripherals are executing program logic which depends on the different user scenarios.

**Idle Mode:** In the Idle mode, the kernel thread scheduler only runs the media application after inactivity for some specified seconds. Under this mode, the CPU only runs the audio decoding application, the panel backlight is off, and other peripheral devices unused are off.

**HDD spin-down Mode:** In this mode, cache media into system memory, spin up the hard drive, fill the memory buffer then spin down the hard drive. This will achieve low HDD duty cycle and help to reduce shock effects.

**Suspend Mode:** In the Suspend mode, the kernel thread scheduler has no threads to run, applications are in the sleep or wait state, the screen is off, and the CPU is put into sleep mode, but the power key interface is waiting for the signal to wake up the system.

**OFF Mode:** In the OFF mode, all devices are off except the RTC. It is used for keeping the count of time for subscription-based music service.

Table II shows one example of the instantaneous power consumptions for different power states. From this comparison table, backlight and hard-disk are the two most power-consumed components for such devices. Thus, to optimize the power consumption, the device needs to change the power states dynamically based on different usage models. Below are the examples to illustrate the power consumption for different usage models, three possible scenarios are defined as follows:

**Scenario 1:** Playing music with 50% volume; screen backlight off; no equalizer; hard disk at 2% duty cycle.

**Scenario 2:** Running Baseline JPEG photo slideshow at 5 seconds per frame; backlight at 50% brightness, hard disk at 1/5 duty cycle.

**Scenario 3:** Running Baseline JPEG photo slideshow at 3 seconds per frame with background music.

Based on those scenarios, power consumptions by hardware and software co-design can be optimized. Furthermore, some measurements are explored for the impact of battery life with different memory buffers. Fig. 10 shows a snapshot captured by an oscilloscope for the power consumption during HDD (Hard-drive disk) access for media buffering. This measurement is based on buffering 8MB data from HDD to system memory for 192kbps WMA (windows media audio) files. The snapshot shows that HDD takes about every 10 seconds (secs) to spin up the power, seek the disk, access the data, idle for timeout then spin down. The impact of the battery life with different memory sizes has been experimented (Table III). With the increase of the memory buffer size, the battery life will increase because of the reduction of duty cycle. By trading-off the battery life and the cost of memory, the adequate selection of the size of memory buffer is 15 MB in this case.
design is applied. Therefore, the ease of use of its user interface was investigated using the human computer interaction (HCI) methods of heuristic evaluation and usability testing. The user interface was subsequently modified, and a follow-up usability test confirmed improvements in ease of use. These findings demonstrate that HCI (Human Computer Interaction) methods can be used to enhance the usability of handheld-based entertainment device. Also, system power management techniques are explored on such portable HDD-based entertainment device. The proposed methodology has been implemented on the real platform and evaluated on different power states, usage models and sizes of memory buffer.

References:
[19] Luca Benini, Alessandro Bogliolo, Giovanni De Micheli, "A survey of design techniques for


TABLE II
THE COMPARISON TABLE OF EACH SYSTEM POWER STATE

<table>
<thead>
<tr>
<th>POWER STATES</th>
<th>Voltage V (Volts)</th>
<th>Current A (Amps)</th>
<th>Power (W)=V × A</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON mode (Playing music with 50% volume; screen backlight on; hard disk accesses)</td>
<td>4.112 V</td>
<td>466 mA</td>
<td>1916.192 mW</td>
</tr>
<tr>
<td>ON mode with HDD spin-down (Playing music with 50% volume; backlight on; hard disk at 2% duty cycle)</td>
<td>4.134 V</td>
<td>215 mA</td>
<td>888.81 mW</td>
</tr>
<tr>
<td>Idle mode with HDD spin-down (as ON mode except backlight off)</td>
<td>4.154 V</td>
<td>109 mA</td>
<td>452.78 mW</td>
</tr>
<tr>
<td>Suspend mode</td>
<td>4.197 V</td>
<td>5.5 mA</td>
<td>23.0835 mW</td>
</tr>
<tr>
<td>OFF mode</td>
<td>4.198 V</td>
<td>2.39 uA</td>
<td>10.0332 uW</td>
</tr>
</tbody>
</table>

TABLE III
DUTY CYCLE V.S. MEMORY BUFFER SIZES

<table>
<thead>
<tr>
<th>Memory buffer</th>
<th>Test conditions</th>
<th>Measured average current when HDD access</th>
<th>Measure average current when memory buffering only (HDD spin-down)</th>
<th>Total power/Estimated Battery life with 1000mAh</th>
<th>Battery life (Real case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8MB</td>
<td>Repeat 20 songs of WMA with 192kbps (about 5MB per songs) and Backlight off</td>
<td>340mA (~4% duty cycle - 10 secs * 15 times/hour)</td>
<td>92mA (96% duty cycle)</td>
<td>101.92 mA/9.81 hr</td>
<td>9.4 hr</td>
</tr>
<tr>
<td>15MB</td>
<td></td>
<td>360mA (~2% duty cycle - 10secs *8 times/hour)</td>
<td>92mA (98% duty cycle)</td>
<td>97.36 mA/10.27 hr</td>
<td>9.9 hr</td>
</tr>
<tr>
<td>30MB</td>
<td></td>
<td>373mA (~1.7% duty cycle - 10secs *4 times/hour)</td>
<td>92mA (98.3% duty cycle)</td>
<td>96.77 mA/10.33 hr</td>
<td>10.03 hr</td>
</tr>
</tbody>
</table>