Personal Jukebox (PJB)

Systems Research Center and PAAD

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What Is This?

♣ Cool consumer device, exploring convergence of:
  – cheap, low power, fast, imbedded computers
  – powerful, common, home PC’s with Internet access

♣ Portable audio system: 100 CD’s in your pocket
  – Take all your music everywhere

♣ Research project that became a product
The Technology

- CD-quality audio compression: 11-to-1 (1 MB/min)
- 2.5” disk is 6.5 GBytes, 4 ounces, 3/8” thick
  - 110 hours of CD-quality music (340 hrs on 20 GB)
- Lithium-Ion cell: 5 Watt-hour, 2 ounces
  - We achieve 11-hour playing time between charges
- PC for acquisition, management, content labeling
Using the PJB

 Everywhere:
  – On that 11-hour flight
  – In your car
  – In your office
  – At home

 Choose your music after you leave home
PJB Workflow

Online Music Resellers

CDDB

CD-ROM drive

Jukebox Manager on Home PC

MP3 on PC

Audio CD

Internet

PJB

MP3 on PC

PJB Workflow
Hardware Overview

- **USB (12 Mb/s)**
- **Flash ROM (1 MB)**
- **DRAM (12 MB)**
- **2.5” disk (many GB)**

**DSP (Motorola 56309-80)**
Running at 35 MHz; about 72 KB on-chip RAM

- **Memory bus**
- **Serial**
- **GPIO**
- **Serial**

**LCD (128x64x1)**

**Buttons & Power Mgmt**

**DAC (44.1x2x16)**

**Amp**

Audio output
Hardware Reality
Hardware Close-up (Prototype)
Hardware Anatomy (Prototype)
Physical Robustness

- Disk withstands 150G for 2ms while operating
  - roughly a drop from a desk onto carpet

- Reality: some temporary non-recoverable errors
  - (while running)

- Firmware can continue with small audio loss

- LCD is most liable to permanent damage
Player Unit UI Overview

- Human-sensible names (from CDDB initially)
- 3-level hierarchy: “set”, “disk” (playlists), “track”
  - multiple copies of a track or disk are (almost) free
- 6 buttons: start/stop, up/down, left/right (+volume)
- Bitmapped display allows redesigns (& games!)
UI Physical layout (prototype)
User Interface Details

Current Set, Disk, Track

- This Track
- This Disk
- This Set

Sequential
Shuffle
Repeat

Normal,
Extra Bass,
Super Bass

Track, Track Left
Disc, Disc Left

Volume Level
Ethernet/USB
Link Status

Time Indicator

Set: rock
Disk: The Beatles/Revolver
Track: Eleanor Rigby
Play: This Set
Order: Sequential
One: Extra Bass
Time: Track
00:00:00
Firmware Overview

- No operating system! (manual event loop)
- Compression format neutral (select per-track)
  - MP3, AAC, MSAudio, SDMI, ...
- About 40,000 lines of C (“char” is 24-bits!)
  - but … assembler is factor of 10 faster
- Decoder, CRC, and disk read loop in assembler
Firmware - main loop

- Poll the devices
  - simpler than interrupts

- Main loop calls each component in turn to give it processor time.

- Need to call player process frequently enough!
Firmware - logical flow

- Buttons
- LCD
- User Interface
- RPC
- Ethernet or USB driver
- File System
- IDE Driver
- Decoder
- DAC
- Player Process
- 10MB Buffer
- Disk Drive
- amp
File System Overview

- Single meta-data object “Table of Contents” (TOC)
- Managed by PC software
- Single stream of plain text:
  - Identifies PJB, set, disk, track (each by text name)
  - “track” has location (first allocation block number)
  - Includes map of blocks-in-use
  - Includes CDDB keys
File System On-disk Structure

TOC (static 4 MB area)

Music (128 KB blocks)
Content blocks in detail

- Doubly linked lists (w/ redundant forward links)
- Header identifies content and origin (for scavenging)
- Supports continuously encoded music (extents)
Disk Error Handling

- Bad TOC - use replica
- Bad TOC replica - use old version
- Bad forward pointer in block - use replica
- Bad replica forward pointer - abandon track
- Bad payload in block - skip and resync music
File System Maintenance

- No fragmentation worries
  - worst case is seek every 128KB (8 seconds)

- No fsck or scandisk (no inconsistent states)

- Relies on:
  - large files
  - no file modification
  - single writer
Power Management

- 2.5” disk in sleep mode consumes about 100 mW
- Disk spin-up takes 5W-secs (2x AA’s don’t work)
- Power-up disk, read 10 MB into DRAM, power off
- Use on-chip memory for inner loop, not DRAM
- Total average PJB power consumption 450 mW
Market Area

♣ PJB was the first product in its category
  – Less than $10/hour of music (Rio is $200/hour)
  – Only prerequisite is owning a PC

♣ Lots of other possibilities in this area, e.g.:
  – Internet music purchase: store in PJB, cache on PC
  – Caching CD player in your car
  – Home network with custom audio in each room
Status

- Research project ended up with 100 prototypes
- Licensed to third party (HanGo)
- Now shipping (http://www.pjbox.com)
- Project details:
  - http://research.compaq.com/SRC/pjb/