Dynamic Digital Depth (DDD) and Real-time 2D to 3D conversion on the ARM processor

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Abstract

The use of mobile devices for entertainment consumption is a rapidly growing, global industry. Over 600 million mobile phones are sold each year and many of them are highly capable media devices. The combination of graphics, ringtones, and games for mobile devices accounted for over US$8bn in revenues per annum in 2004. It is against this backdrop that DDD offers a radical new type of visual entertainment: stereo 3D without glasses (autostereo) for a wide range of ARM powered devices in all global mobile markets. *DDD offers 2D3™, our core software/hardware process for converting 2D information into 3D and efficiently rendering it on the widest variety of standard 2D displays and a new wave of 3D displays.*

The Business Problem: Expanding entertainment options (and revenue) for mobile devices

Mobile Entertainment

The mobile handset is considered an entertainment platform. The under-30 demographic is typically the biggest consumer segment and they spend money to use their handsets for entertainment. In 2004, it was reported that worldwide global revenues for entertainment data (ringtones, graphics, SMS) totaled over US$8B. Of particular interest to the mobile industry is the adoption rate of video consumption on mobile devices. Many devices and many carriers offer the service, but in most jurisdictions the services are still being used only by a small early-adopter consumer. The following data provided by the Points North Group and Horowitz associates attempts to capture the current interest and potential uptake of video on computers as well as mobile devices:

U.S. Consumer Internet Video Interest	
Activity	**Percentage of Users**
Watch regular television shows on a PC or laptop	28
Download, store and play video content from the Internet directly to your TV	22
Watch real-time live newscasts on your cell phone or portable device	19
Watch entire TV shows on cell phone or other portable device	17
Watch entire movies you downloaded from the Internet on your cell phone or other portable device	16
Being able to click on an advertisement and get more detailed information about a product on your TV	16
View entire live sporting events through your cell phone or other portable device	12
Notes: 1. n=1,098 2. Percentage based upon respondent rankings of 4-5 on a scale of 1-5 for each activity.	
Source: Points North Group and Horowitz Associates, Inc., 2005	

Mobile carrier networks are experiencing very low growth rates for telephone service and so all are seeking to boost revenues and profits by providing advanced data services such as those mentioned in the data above. Some services are business oriented, but the main effort is to entice consumers to use more data for downloads and streaming of audio/visual content. The mobile device generally can be viewed as an alternative medium for experiencing content that can be found elsewhere: TV or internet. 3D video and graphics are unusual in that such content may be *only* available on mobile devices for months or years.

DDD's Mission

DDD's mission is to partner with display manufacturers, device manufacturers, and software companies to enable glasses-free 3D viewing of video, photos, games, and CG content for consumer mass markets on a variety of platforms. Additionally, we offer solutions for selected professional markets such as molecular modeling, computer animation, and computer aided design. Our products are marketed under the DDD Mobile™ or TriDef® Brands. DDD offers technology, licensing partnerships, and products for each of the "3 screens" in consumers' lives: television, PC, and handheld. Our core technology is our ability to convert the world of 2D video content into 3D, either in real-time or in an off-line, artist-directed process. A strong, global Intellectual Property library supports DDD's software and content capabilities for the creation, conversion, transmission and delivery of 2D-compatible-3D™.

DDD Technology Overview: Bringing 3D to Mainstream

DDD's 2D-to-3D conversion and Intellectual Property

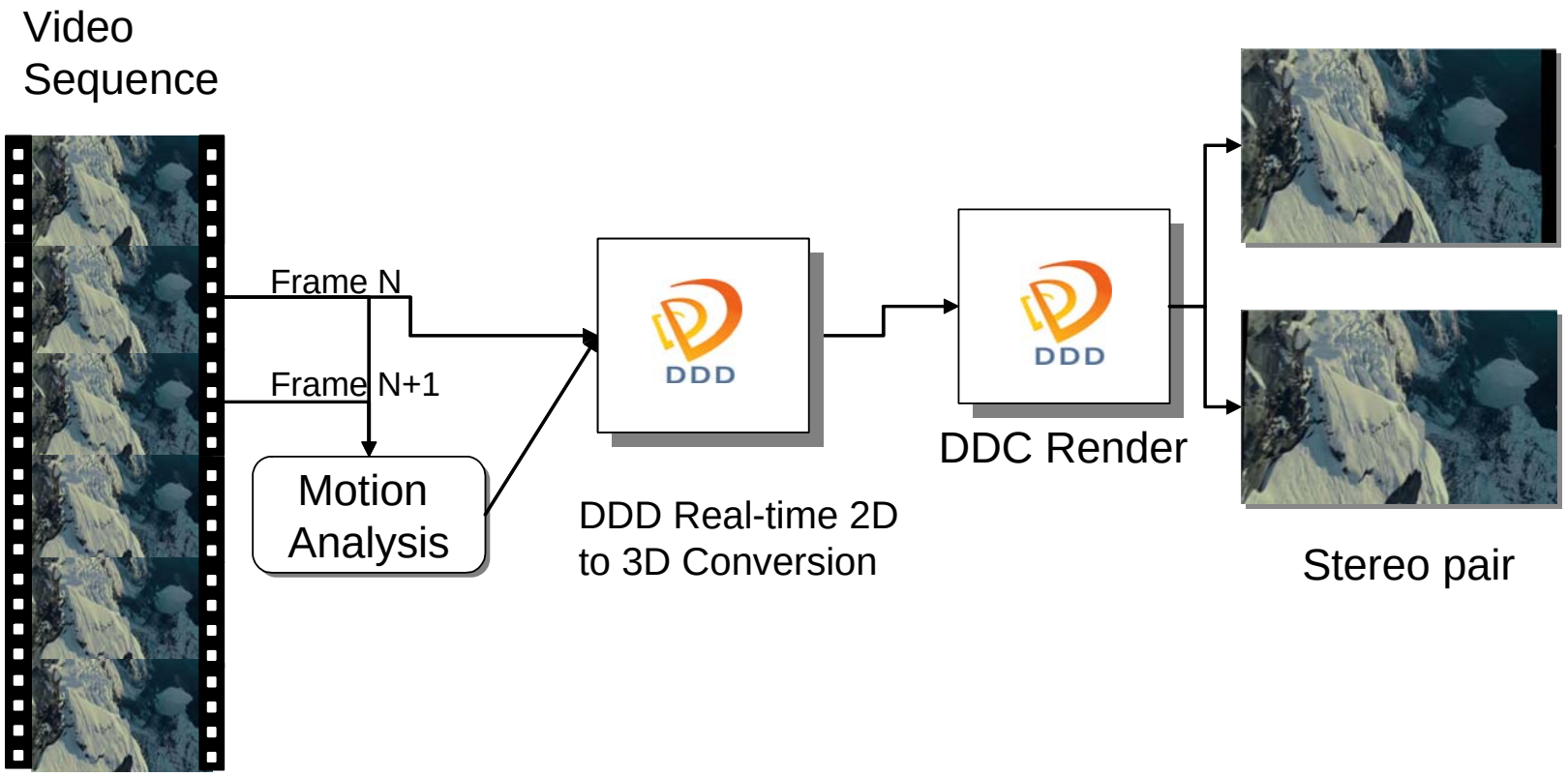
Real-time 2D to 3D conversion has been a long sought after goal in the 3D entertainment industry. The costs involved in offline 2D to 3D content conversion severely restrict the supply of 3D content. The lack of available 3D content is widely recognised as one of the major impediments to the mainstream adoption of stereoscopic 3D display technologies.

Since the late 1980s there have been numerous attempts to develop real-time conversion technologies in both hardware and software. These systems have been restricted to prototypes, primarily due to the low quality of the conversion.

More recently, the evolution of high speed computing on consumer devices has opened up new possibilities for real-time 2D to 3D conversion. DDD used its extensive experience in offline conversion to develop an advanced image analysis system for real-time conversion. The quality of DDD's real-time conversion technologies has been well received in the industry. In March 2005, DDD entered into an agreement with Sharp Corporation to license the conversion technology for Sharp's innovative range of 3D laptops. This event marked the first commercial deployment of real-time 2D to 3D conversion.

DDD holds important patents in the field of stereo 3D. DDD's "DDC/1" patent addresses the process of efficiently rendering an image into 3D by compressing and expanding different areas of the 2D image based on a depth map. This patent has priority in all jurisdictions and is a very important gatekeeper for DDD. This technique of rendering 3D is very powerful and in our opinion has already been used improperly by other groups. The following graphic shows the basic functionality of 2D3™, DDD's patented real-time conversion process:

DDD's 2D3™ Process



DDD Mobile™

DDD has developed software solutions over years on standard desktop computing platforms. The recent increased focus on mobile devices as media devices (more powerful, more media choices) has been embraced by DDD. We have ported our core technologies, some in a slightly abbreviated form, to the mobile platform. This suite of technologies is collectively known as DDD Mobile™. The core piece of technology, the ability to convert 2D video to 3D (add depth) in real time, is known as DDD's 2D3™ Process.

In Q2 of 2005, DDD entered into an exclusive contract with a top five global handset manufacturer to provide stereo 3D software and content for embedding and after-market purchase. This handset is designed with a switchable 2D/3D QVGA LCD display employing a lenticular lens to create separate right and left eye views. DDD's clear leadership in technology and content distribution contacts was decisive in being selected to exclusively provide software applications for 3D viewing. DDD has now effectively deployed DDD Mobile™ on a high-end handset using an ARM9 core, ready for release in 2005.

The Solution: DDD Mobile™ For ARM9

Project Overview

DDD was approached by the handset manufacturer to provide software for a new cutting-edge handset that features a 3D display. A little history: in 2003 a 3D handset was released in Japan, sold 3 million units and was discontinued. It is believed that the almost complete lack of 3D content was a main reason. One important goal for the new handset was to correct this problem. When DDD was contacted, the manufacturer had not decided on which of 3 competing displays to use or which graphic processor would be best. DDD gained the upper hand for the work because of the flexibility of the conversion process and our ability to work with virtually any display. In the early stages there were only two requirements for DDD's conversion software:

- Maintain 15 frames per second for video conversion
- Utilise 30% or less of the CPU's processing time

The Hardware

The communications and computing platform on which the new handset is based is:

- Qualcomm MSM6550 Chipset Solution
  - **ARM926EJ-S microprocessor core**
- 3rd Party Graphics Processor with Memory Control Unit

DDD focused primarily on the interaction between the ARM core and the 3rd Party GPU. The MSM6550 solution contains a 2D/3D graphics core supporting OpenGL ES graphics, but the additional 3rd Party GPU was chosen by the handset manufacturer

because of a combination of memory access limitations and pure processing power required for stereo 3D video conversion. The polygon transform rate and 2D fill rates of the GPU are far in excess of those for the built-in graphics core on the MSM6550.

The Software Development Process

DDD's intellectual property is encapsulated in library code that exposes a simple interface, which can be easily integrated into a wide variety of applications.

The library code is written in C++, and can be compiled using almost any modern C++ compiler, including Arm ADS1.2, Arm RVCT2.1, MSVC 7 (for x86) and Visual Studio 2005 (for x86 and ARM9 instructions). The main porting difficulties came from a lack of C++ namespaces (eg, ADS1.2) or a lack of the standard template library.

The portability of this code has allowed for a very efficient development process. Almost all the development, debugging and unit testing was done using the Windows development platform, using the x86 version of the library. The faster debug cycles, greater flexibility gained by using such tools as scripting and a variety of images sources all contributed to the robustness of the final solution. Almost all of the classes used in the library are also used in the production of DDD's retail PC products, ensuring that the latest technology is available across the board.

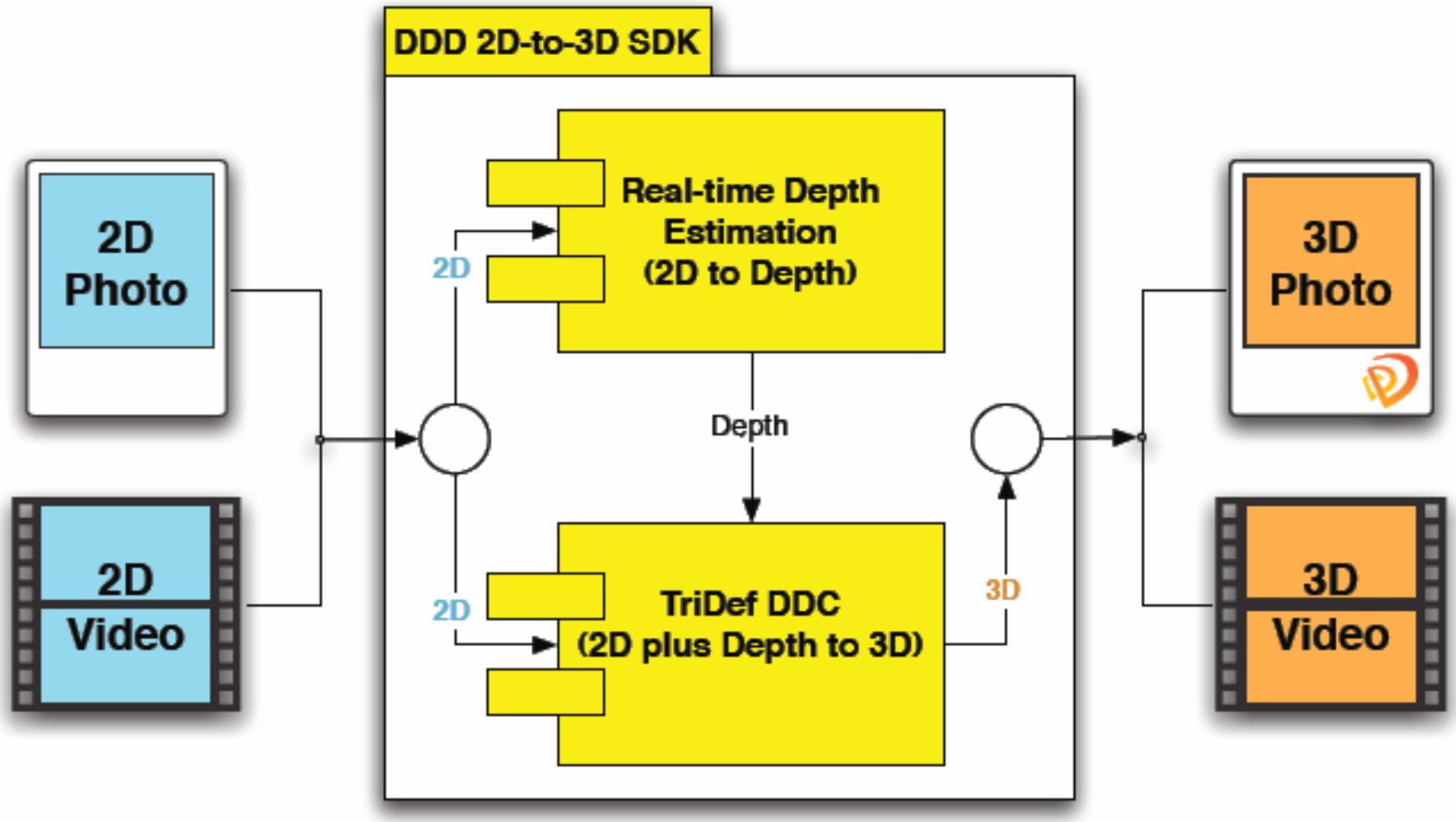
A variety of pixel formats are supported by the library, both in terms of the input (RGB, RGB565, rotated/not rotated) and output(RGB/RGB565, anaglyph (red/blue stereo), pixel interleaved stereo, interlaced stereo). DDD can easily produce a special version of the library that includes only a subset of these features as required by customers by some simple command line switches.

Especially on mobile devices, performance is critical. In order to achieve the great advantages of portability, while also maintaining optimal performance, C++ templating was used. The template patterns allowed for a single, easy to maintain version of the code that can be customised at *compile time*, making the compiler do all the work of code duplication and customisation. This compile time optimisation gives both flexibility and speed.

Since every compute cycle on a mobile device is precious, an iterative procedure was used to optimise the inner loop of the code. By altering the C++ code, and checking the resulting assembly code generated by the compiler, the instruction count was reduced to match the instructions in “hand optimised" assembly code. Some changes included changing the order in which instructions were executed and use of the keyword "register” where appropriate. It was also interesting to note that when the inner loop was relatively simple, the Thumb instruction set performed almost as well as the ARM9 instructions, however, when a little bit more complexity was introduced, the Thumb instructions suffered from a lack of fully-usable registers. The ARM C++ compiler did not seem to assign variables optimally between the lower, more usable registers, and the higher registers, and hence some hand optimisation may be appropriate if forced to use the Thumb instruction set.

Initially, DDD did not have access to the target hardware, and ultimately did not have debugging facilities or complete source code for the target. To test and benchmark the library on something closely resembling the target hardware, an ARM926EJ-S development board was used. Connections were made using the serial interface to display benchmarks and the VGA output, set in QVGA mode with a RGB565pixel format, to mimic the mobile device's display characteristics. A USB cable was used for debugging/downloading.

This turned out to be an excellent development setup, since the performance measured on the development board translated accurately to the target hardware, and exactly the same library file could be linked into both the target hardware and the development harness, increasing robustness of the delivered solution. See the block diagram of the SDK and process on the following page.


DDD 2D-to-3D SDK
2D Photo
2D Video
Real-time Depth Estimation (2D to Depth)
2D
Depth
2D
TriDef DDC (2D plus Depth to 3D)
3D
3D Photo
3D Video

Conclusion

DDD Mobile

DDD is the only company to have successfully deployed robust 2D to 3D video conversion on a mobile platform. This technology is a necessary prerequisite for ubiquitous 3D graphics and video because so little content has been recorded in or converted to stereo 3D. DDD's 2D3™ process enables true 3D viewing of all programming if the viewer chooses. This technology provides major benefits to 3D display manufacturers, media companies, and consumers of all types of video entertainment.

Contacting DDD

DDD is interested in partnerships with embedded technology providers as well as visual entertainment companies of all kinds. Please contact us.

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