● Development Reports ●

FOMA 901i Series

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*All models of the FOMA 901i series, released in December 2004, provide 3D sound melodies and 3D graphics functions to be used in i-appli in order to achieve versatile expression. Moreover, the Flash®*1 player were enhanced in order to expand the animation functions in the i-mode browser.*

1. Introduction

The Freedom Of Mobile multimedia Access (FOMA) service was launched in 2001, and since then has achieved considerable success in penetrating the market as mobile terminals that can be accepted by wide generations due to the 900i series, which was released in the spring of 2004 and helped FOMA renew its conventional image of being a mobile terminal for the innovative elite. As of February, 2005, the number of FOMA subscribers exceeds 10 million people.

The 901i series (SH901iC, F901iC, N901iC, P901i and D901i) is a series of terminals developed for users who seek for high-functionality, high-performance mobile terminals with enriched basic functions and advanced capabilities to provide highly sophisticated mobile multimedia services. All models of the 901i series are equipped with twin stereo speakers as standard equipment, enabling them to play 3D sound melodies. By combining 3D sound and 3D graphics in i-appli, it becomes possible to achieve a unique, lifelike sound that varies with, for example, the movement of a flying golf ball, which makes it possible to create attractive contents providing more realistic experiences than ever before.

In addition, SH901iC, F901iC and N901iC are equipped with the FeliCa*2 functions, including FeliCa's remote lock function, adopted for the purposes of preventing illegal operations by third parties and providing safer FeliCa services.

This article outlines the main points in the development of each 901i FOMA series terminal and explains some of the func-

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*1 Macromedia and Flash are trademarks or registered trademarks of Macromedia, Inc. in the USA and other countries.

*2 FeliCa, which goes under the nickname "mobile wallet," is a technology that allows shopping and member authentication with a mobile terminal by mounting a non-contact IC card called the FeliCa chip in the terminal.

tions incorporated in all models as standard, in particular the "3D graphics function," which provides improved drawing capabilities for i-appli, the "3D sound function," which allows playing melodies in a highly realistic manner, and the "Flash® player," which has been developed specifically to increase the expressive power of i-mode sites.

2. Characteristics of the 901i Series

Photo 1 shows the appearance of the models of the 901i series and **Table 1** lists the basic specifications.

This chapter outlines development points for each model that deserve special note.

2.1 SH901iC

SH901iC is the only one 901i model that adopts a rotary 2-axis structure. Taking advantage of the rotary 2-axis type mechanism, this FOMA terminal has an unconventional style. The Liquid Crystal Display (LCD) screen is based on the "mobile Advanced Super View (ASV) LCD" technology, which is an adaptation for mobile applications of the ASV method used in the "AQUOS" brand of LCD TVs developed by Sharp Corporation. The ASV method achieves a wide-angle field of view where the image do not become reversed even when looking at the screen from an oblique angle. Moreover, the terminal is equipped with a "TV recording function," which takes advantage of the rotary 2-axis structure and mobile ASV LCD technology. This model supports the National Television Standards Committee (NTSC)[*3] video standard; it is possible to record TV programs and similar by connecting an AV device to the FOMA terminal via an AV input/output cable. Furthermore, the basic operations can be performed by the four command keys placed underneath the LCD screen set in the operation area, for the sake of operability when the terminal is closed with the LCD screen on top.

Photo 1 FOMA 901i series

2.2 F901iC

In F901iC, the functions related to security, including finger print authentication, are strengthened. The range of privacy modes normally found in conventional mobile terminals has been expanded, allowing the user to set individual modes for the

*3 A standard for terrestrial analog color TV broadcast system defined by the American standardization committee. The standard is adopted in Japan.

Table 1 Basic specifications of the FOMA 901i series

Model		SH901iC	F901iC	N901iC	P901i	D901i
Continuous call time	Voice	App. 130 min.	App. 160 min.	App. 140 min.	App. 140 min.	App. 150 min.
	Video phone	App. 80 min.	App. 80 min.	App. 90 min.	App. 80 min.	App. 100 min.
Continuous standby time	Stationary	App. 370 hrs.	App. 570 hrs.	App. 435 hrs.	App. 500 hrs.	App. 300 hrs.
	In transit	App. 320 hrs.	App. 410 hrs.	App. 350 hrs.	App. 350 hrs.	App. 300 hrs.
Dimensions (height × width × thickness)		109 × 49 × 25 mm	105 × 51 × 28 mm	102 × 48 × 26 mm	102 × 49 × 22 mm	106 × 50 × 25 mm
Weight		148 g	129 g	119 g	104 g	136 g
Main display		App. 2.2 inches (240 × 320 dots)	App. 2.4 inches (240 × 320 dots)	App. 2.3 inches (240 × 345 dots)	App. 2.2 inches (240 × 320 dots)	App. 2.4 inches (240 × 320 dots)
		Mobile ASV LCD, 260,000 colors	TFT LCD, 260,000 colors	TFT LCD, 65,000 colors	TFT LCD, 65,000 colors	TFT LCD, 260,000 colors
Sub-display		—	App. 1.0 inches (96 × 96 dots)	App. 0.96 inches (30 × 120 dots)	App. 1.0 inches (96 × 64 dots)	—
		—	Color organic EL, 65,000 colors	STN LCD, 4,096 colors	STN LCD, 4,096 colors	—
Outer camera (effective number of pixels)		2.02 Mpixels	2.04 Mpixels	1 Mpixels	2.02 Mpixels	2 Mpixels
Inner camera (effective number of pixels)		110,000 pixels	320,000 pixels	110,000 pixels	100,000 pixels	320,000 pixels
FeliCa support		Supported	Supported	Supported	—	—

EL: Electro-Luminescence STN: Super Twisted Nematic liquid crystal TFT: Thin Film Transistor liquid crystal telephone book, incoming call records and schedule functions. The target range of data saved in the miniSD[*4] was also expanded, such that video, still images and melodies can be imported and exported. In addition, it is equipped with anti-aliased fonts like the ones generally adopted in PCs etc., which makes it possible to display very smooth characters.

2.3 N901iC

In N901iC, the video phone function was strengthened based on the concept of "Heartful Communication," considering the mobile terminal as a tool that conveys feelings fluently. It is equipped with the petite message function that allows sending characters while conducting a video call via the Short Message Service (SMS). The mobile terminal receiving the call automatically displays the message on the video phone screen. In addition, it is equipped with a decoration video phone function that makes use of face tracking technology, which automatically keeps track of a person's face. This function can recognize the position of the eyes and nose of the person at other end to display a decorative stamp image of, for example, a beard.

2.4 P901i

P901i is the smallest and lightest FOMA terminal among the 901i series, though it does not support FeliCa (Table 1). It inherits the custom jacket of P900i, and a rich selection of design variations is available. It is equipped with various functions, including the "moving character stamp" creation function that allows to post any character stamps for decoration mail, which contributes to further promotion of the usage of decoration mail.

2.5 D901i

D901i is the first FOMA terminal to adopt a sliding body (Photo 1). It has a spring-loaded sliding structure that can be opened or closed simply by sliding the body to a certain position. In addition, if there is an incoming call when the slide is closed, it automatically receives the call when the slide is opened; various other functions are also activated when the slide opens and closes.

3. 3D Graphics Function

The term 3D graphics refers to drawing three-dimensional images on a flat surface. In the world of TV games, an increasing number of games are adopting 3D graphics functions to render realistic-looking video images. The 901i series is equipped with the 3D graphics function as standard, so that such contents can be enjoyed on the FOMA terminals as well. The drawing engine adopted is Mascot Capsule Engine Micro3D Ver.4[*5] (hereinafter referred to as Micro3D V4), made by HI Corporation. By using this engine with i-appli to display 3D graphics, these terminals can provide richer graphical contents than any conventional mobile terminal. **Figure 1** shows an example of 3D graphic contents.

3.1 Elemental Technologies Supporting 3D Graphics

1) Z-buffering

Z-buffering refers to one of the methods for comparing differences in depths and automatically draws only the parts of the image that are in the front view when drawing a 3D image. In conventional mobile terminals, a heavy burden was placed on contents creators because they were required to take the depth into consideration when creating 3D contents.

2) Fog Effects

Fog effects refer to fog-like hazy blurring effects applied to an image. The thickness and colors of the effect can be specified freely and used to draw scenes containing fog and similar phenomena. **Figure 2** (a) shows an example of fog effects.

3) Texture Distortion Correction

Textures are images mapped onto the surface of an data in order to increase the material impression and provide a realistic feel to the data. Previously, it was necessary to divide a texture into small segments in the software and then map these small segments onto the object in order to eliminate distortion of the image generated when applying the texture. The 901i series is equipped with a function that automatically shrinks distortion

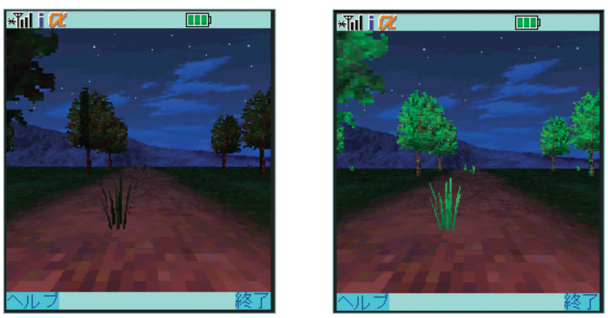
*4 miniSD is a registered trademark of SD Association.

*5 Mascot Capsule Engine Micro3D Ver.4 is a 3D middleware engine developed by HI Corporation and a registered trademark.

Figure 1 Image showing 3D graphics contents

Without fog With fog

(a) Fog effect



1 light source 5 light sources

(b) Effect of multiple light sources

Figure 2 Examples of graphics rendered by the new micro3D V4 function

generated at mapping, thereby eliminating distortion.

4) Wide Array of Drawings Using Multiple Light Sources

Now, it is possible to set multiple light sources simultaneously in 3D space. This makes it easy to draw scenes where a given object is spotlighted from multiple directions. Fig. 2 (b) shows the difference between two scenes, where the number of light sources is 1 and 5, respectively. With only 1 light source, the expression is limited to moonlight or similar when expressing a night scene. If the number of light sources is increased to 5, on the other hand, it becomes possible to express scenes where the moonlight is combined with other light sources such as a flash light.

5) Realistic Drawing Using Alpha Blending

Alpha blending refers to semi-transparent processing of objects in an image. In conventional mobile terminals, processing of 50% semi-transparency was the limit. From the 901i series, semi-transparency values can be set in the full range from 0 to 100%. This allows drawing scenes seen through window glass in a more realistic fashion.

3.2 Use of Micro3D V4 from i-appli

Micro3D V4 provides the basic functions for 3D graphics discussed in Section 3.1. In order to use these functions from i-appli, we developed an i-appli Application Program Interface (API) and implemented it in the 901i series. This API allows implementing the following functionality.

- It is possible to create matrix transformations and three-dimensional vector objects that are common to 3D graphics and 3D sound. This allows linking 3D graphics objects and 3D sound objects together in i-appli contents, thereby achieving combined 3D graphics and sound.
- The concept of scene graphs (scenes containing geometry objects, light sources, camera, etc.) was adopted to achieve grouping of 3D objects. For example, when composing one object from multiple objects (e.g., a human model consisting of head, torso, arms and legs), these objects can be processed at the same time when performing rotation and viewpoint transformation.
- Since the 3D graphics function rotates and moves objects using matrix operations including trigonometric functions, floating point calculations[*6] are required. However, floating point calculations require large amounts of processing. This means that sufficient throughput performance cannot be obtained in case of mobile terminals, where it is necessary to take battery consumption and operation complexity caused by the accompanying increase of the amount of processing into careful consideration when deciding upon a Central Processing Unit (CPU) to install. In order to solve this problem, we developed and implemented a library that converts floating point calculations to fixed point calculations[*7] within the 3D engine to be able to perform high-speed operations.

4. 3D Sound Function

3D sound is a technology for expressing three-dimensional sound images and gives a realistic feel of acoustic space, such as a sense of direction (up/down, left/right) and depth of the sound images by controlling the way sound is transmitted from the two speakers to both ears. In general, the 3D sound function is obtained by folding a Head Related Transfer Function (HRTF) onto a waveform of a sound source and changing the phase and amplitude of the waveform of the sound source that is

*6 A method used to express a numerical value using a “mantissa,” a row of bits representing the value of each digit of the number, and an “exponent” indicating the position of the decimal point. Although it allows expressing a wide range of values, the calculation speed is low.

*7 A method used to express a numerical value where the decimal point is fixed to a specific position. Although the range of values that can be expressed is narrower than floating point, the calculation speed is high.

transmitted from the two speakers in the front to the left and right ears (**Figure 3**).

4.1 3D Sound Function of the 901i Series

All the models of the 901i series are equipped with stereo twin speakers and a 3D sound engine that performs the aforementioned HRTF folding operation processing as standard. Sound source waveforms generated from a Musical Instrument Data Interface (MIDI) engine, a standard for electric instruments, are processed in the 3D engine, converted from digital to analog signals by a Digital Analog Converter (DAC) and then played from the twin stereo speakers (**Figure 4**).

By using this function for playing melodies using a ringtone melody player and i-appli, the power of expression of the music evolves from conventional improvement of the sound quality to actually achieving a spatial expression of the sound, and a world where the user is immersed in the sound can be created. The 3D sound function in ringtone melodies and i-appli is explained below.

1) Ringtone Melodies

The conventional melody format specification supporting i-mode (Melody Format for i-mode (MFi)) has been expanded so that 3D location information can be stored in a melody file, enabling the terminal to play the ringtone using 3D sound. In this way, when a FOMA terminal is playing, it can provide three-dimensional acoustic effects as the 3D sound engine controls the sound source waveforms in the melody file based on the 3D location information.

The main information elements added to the MFi specification include “3D location information” and “3D location function usage information.”

3D sound adopts the concept of virtual sound sources, in the sense that a virtual sound source corresponding to an actual sound sources such as speakers exist in 3D space, in order to express the effect that sound is heard from a certain single point in space. By operating on the location and movement of such virtual sound sources, the creation of a three-dimensional sound image becomes possible. In the MFi specification, the location and movement of a virtual sound source relative to the listener are specified by 3D location information. The 3D location information contains virtual sound source ID, distance, azimuth, elevation angle and moving time as parameters. In other words, any movement of a virtual sound source can be controlled freely by continuously updating the 3D location information in the melody file.

The 3D location function usage information associates the virtual sound sources above with channels. In the MFi specification, there can be multiple logical channels within one melody file. For example, when it is desired to play a piano melody and percussion sound at the same time, the piano and percussion can use separate channels. By setting the 3D location function usage information for each channel, different virtual sound sources are assigned to the piano and percussion, and the sound image movements of the piano and percussion can be expressed independently.

2) i-appli

We defined a new 3D sound API for the DoCoMo Java (DoJa) i-appli implementation. This new API allows a contents programmer to specify the positions of virtual sound sources

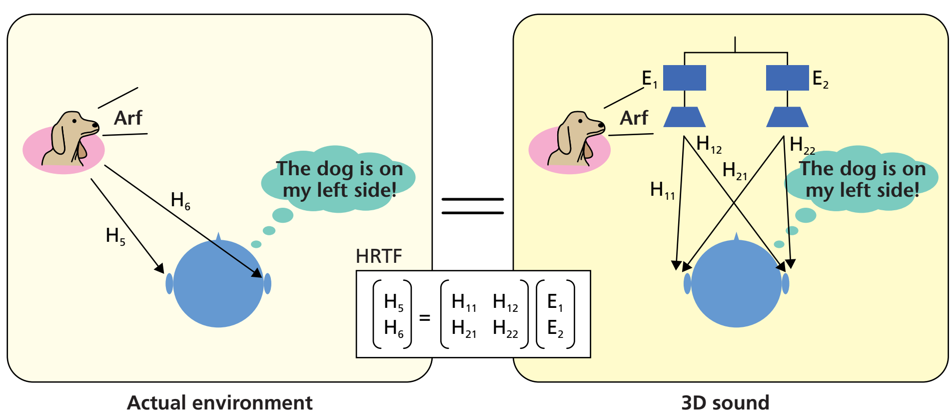
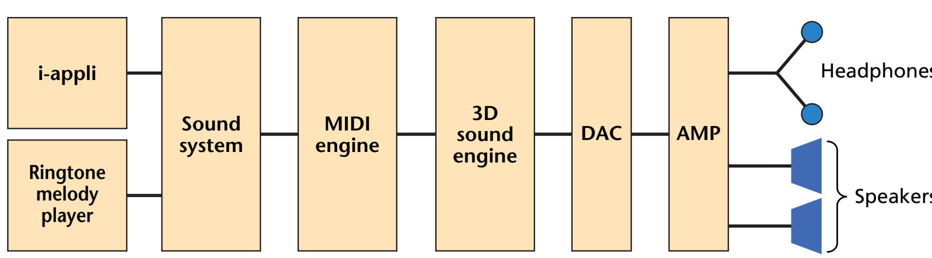


Figure 3 3D sound function



AMP: AMPlifier (transmission power amplifier part)

Figure 4 Block diagram of the 3D sound function

freely when creating i-appli.

When controlling sound with i-appli, the relationship between a virtual sound source and a listener who listens to the sound within 3D space is specified as 3D location in a polar or Cartesian coordinate system (**Figure 5**). The origin of the polar coordinate system is always fixed at the listener and the position of the virtual sound source seen from the listener is specified using three coordinates: γ: distance, θ: azimuth and ϕ: elevation angle. This allows specifying the location in the local coordinate system centered at the listener. In the Cartesian coordinate system, the positions of the virtual sound source and listener are specified using x, y and z-coordinates, respectively. This allows specifying the locations based on the objective positions of the virtual sound source and listener. If the virtual sound source remains still relative to the listener, the 3D location can be specified using either the polar or the Cartesian coordinate system. If the virtual sound source is moving relative to the listener, the 3D location can be specified using either the polar or the Cartesian coordinate system, with the spatial relationship between the listener and virtual sound source as well as time information that expresses the new locations of the sound source and listener and the time at which they move.

i-appli for the 901i series can play up to four melodies at the same time. By specifying 3D location for each melody, it is possible to express the movements of multiple sound images independently and in parallel.

In the future we intend to add acoustic effects experienced in the real world, such as Doppler effect, as well, aiming to improve the power of expression further.

5. Enhancement of the Flash® Player

The Flash® player equipped in mobile terminals of the mova 505i series and FOMA 900i series and later allowed contents that use Flash® files in i-mode services. In the early phase of the development, we adopted only the minimum functions in order to prioritize implementation in early stages. In the 901i series released this time, we upgraded the player and enhanced the functions. Accordingly, Macromedia's Flash Lite™ 1.1[*8] was adopted instead of Flash Lite™ 1.0.

The main enhanced functions of Flash Lite 1.1 are explained below.

5.1 Updating Difference Files

We incorporated functions that update only parts of Flash® files to be displayed as Web contents. They are "loadMovie," which updates image data, and "loadVariables," which updates text data. They allow, for example, updating only changed parts of articles displayed in a news site, in actual services (**Figure 6**).

If data is updated infinitely, however, the Flash® player will eventually run out of memory resources and become unable to function. We took a countermeasure against such abnormal contents and secured stable operation by placing an upper limit on data acquisition.

5.2 Acquisition of FOMA Terminal Information

We included a function that acquires FOMA terminal information using the Flash® player. The information that can be acquired include time, radio wave status (maximum value and current value), power source/battery status (maximum value and current value), volume status (maximum specification value and current value), information of language used and type/model of FOMA terminal. By reflecting the acquired information in the Flash® files, contents can be displayed according to the situation.

For example, contents that change images to be displayed in

*8 Macromedia and Flash Lite are trademarks or registered trademarks of Macromedia, Inc. in the USA and other countries.

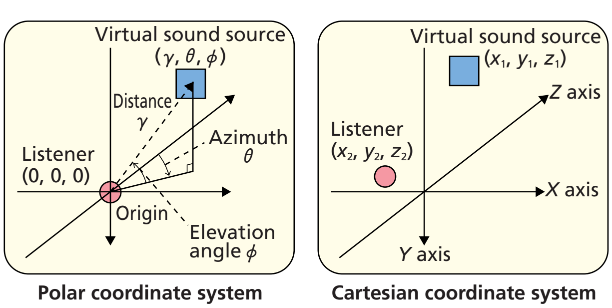


Figure 5 3D sound coordinate systems

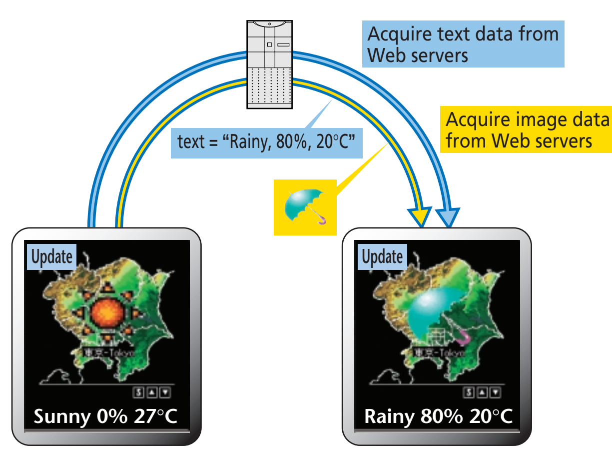


Figure 6 Examples of loadMovie and loadVariables

the standby screen according to the time can use the terminal time data to do so (**Figure 7**).

It is noted that FOMA terminal information is personal information; it is necessary to obtain the user's permission before transmitting the terminal information from the FOMA terminal. In order to guarantee this, we implemented an additional function that limits to aquire FOMA terminal information for browsers and screen memos that have communication function.

5.3 Other Functions

We added several important functions for enriching the contents provided in order to catch up with Flash® contents on the Internet.

First, we added functions that allow the user to input text messages and send them to a server. This allows making use of user information for contents such as fortune-telling services.

Secondly, we removed the limitation that requires a user to confirm that sound is allowed to be played and added a sound play function synchronized to playing of animation. This made it possible to play music as background of an i-mode site.

Thirdly, we expanded the applications that can play Flash® files. It is now possible to play Flash® files on the screens that notify about incoming and outgoing calls on FOMA terminals and the screens that notify about transmission and reception of mails.

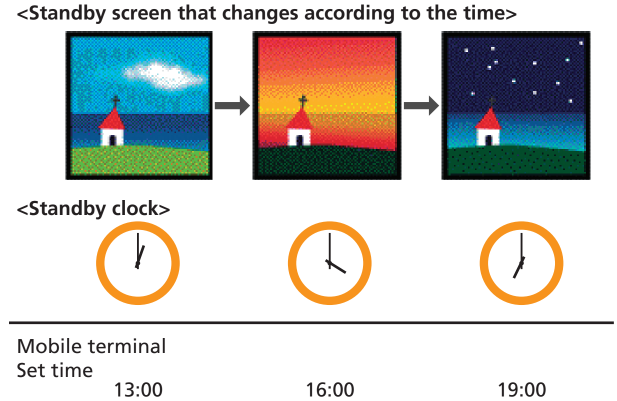


Figure 7 Example of FOMA terminal data usage

6. Conclusion

This article described the implementation of support for 3D sound, i-appli 3D graphics functions and our enhancements of the existing Flash® player functions, which are main functions incorporated in the FOMA 901i series as standard. By adopting these functions, versatile expressions have been made possible, which were not possible with conventional mobile terminals.

We will continue to carry forward development of mobile terminals that can achieve attractive services and functions, with the aim of expanding the FOMA services further in the future.

ABBREVIATIONS

AMP: AMPlifier (transmission power amplifier part)
API: Application Program Interface
ASV: Advanced Super View
CPU: Central Processing Unit
DAC: Digital Analog Converter
DoJa: DoCoMo Java
EL: Electro-Luminescence
FOMA: Freedom Of Mobile multimedia Access
HRTF: Head Related Transfer Function
LCD: Liquid Crystal Display
MFi: Melody Format for i-mode
MIDI: Musical Instrument Data Interface
NTSC: National Television Standards Committee
SMS: Short Message Service
STN: Super Twisted Nematic liquid crystal
TFT: Thin Film Transistor liquid crystal