FatFs Module Application Note

How to Port

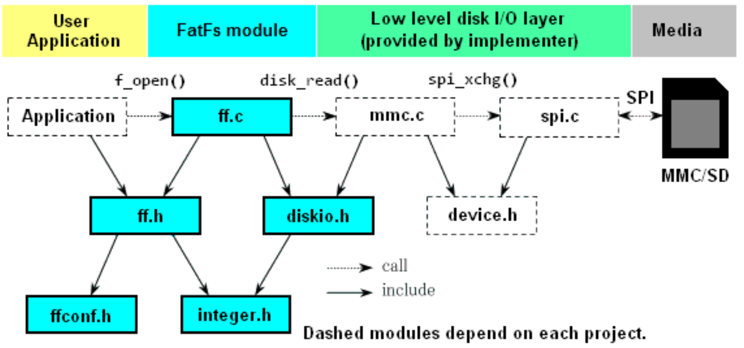
Basic considerations

The FatFs module is assuming following conditions on portability.

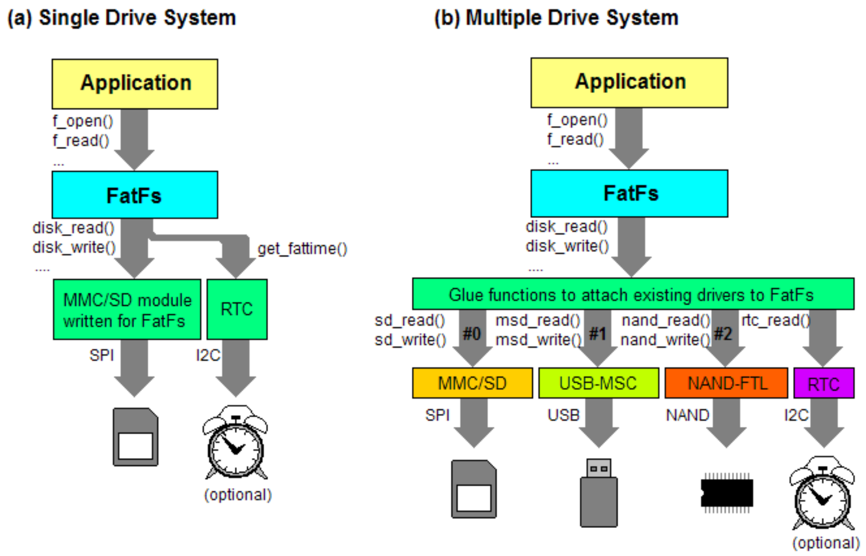
- ANSI C
  The FatFs module is a middleware written in ANSI C (C89). There is no platform dependence, so long as the compiler is in compliance with ANSI C.
- Size of integer types
  The FatFs module assumes that size of char/short/long are 8/16/32 bit and int is 16 or 32 bit. These correspondence are defined in `integer.h`. This will not be a problem on most compilers. When any conflict with existing definitions is occured, you must resolve it with care.

System organizations

The dependency diagram shown below is a typical configuration of the embedded system with FatFs module.



(a) If a working disk module with FatFs API is provided, no additional function is needed. (b) To attach existing disk drivers with different API, glue functions are needed to translate the APIs between FatFs and the drivers.



Which function is required?

You need to provide only low level disk I/O functions that required by FatFs module and nothing else. If a working disk module for the target is already existing, you need to write only glue functions to attach it to the FatFs module. If not, you need to port any other disk module or write it from scratch. Most of defined functions are not that always required. For example, disk write function is not required in read-only configuration. Following table shows which function is required depends on configuration options.

Function	Required when:	Note
disk_status disk_initialize disk_read	Always	Disk I/O functions. Samples available in ffsample.zip. There are many implementations on the web.
disk_write get_fattime disk_ioctl (CTRL_SYNC)	_FS_READONLY == 0	
disk_ioctl (GET_SECTOR_COUNT) disk_ioctl (GET_BLOCK_SIZE)	_USE_MKFS == 1	
disk_ioctl (GET_SECTOR_SIZE)	_MAX_SS != _MIN_SS	
disk_ioctl (CTRL_TRIM)	_USE_TRIM == 1	
ff_convert ff_wtoupper	_USE_LFN >= 1	Unicode support functions. Available in option/unicode.c.
ff_cre_syncobj ff_del_syncobj ff_req_grant ff_rel_grant	_FS_REENTRANT == 1	O/S dependent functions. Samples available in option/syscall.c.
ff_mem_alloc ff_mem_free	_USE_LFN == 3	

Limits

- FAT sub-types: FAT12, FAT16 and FAT32.
- Number of open files: Unlimited, depends on available memory.
- Number of volumes: Upto 10.
- File size: Depends on the FAT specs. (upto 4G-1 bytes)
- Volume size: Depends on the FAT specs. (upto 2T bytes at 512 bytes/sector)
- Cluster size: Depends on the FAT specs. (upto 64K bytes at 512 bytes/sector)
- Sector size: Depends on the FAT specs. (512, 1024, 2048 and 4096 bytes)

Memory Usage

	ARM7 32bit	ARM7 Thumb	CM3 Thumb-2	AVR	H8/300H	PIC24	RL78	V850ES	SH-2A	RX600	IA-32
Compiler	GCC	GCC	GCC	GCC	CH38	C30	CC78K0R	CA850	SHC	RXC	VC6
_WORD_ACCESS	0	0	0	1	0	0	0	1	0	1	1
text (Full, R/W)	10675	7171	6617	13355	10940	11722	13262	8113	9048	6032	7952
text (Min, R/W)	6727	4631	4331	8569	7262	7720	9088	5287	5800	3948	5183
text (Full, R/O)	4731	3147	2889	6235	5170	5497	6482	3833	3972	2862	3719
text (Min, R/O)	3559	2485	2295	4575	4064	4240	5019	2993	3104	2214	2889
bss	V*4 + 2	V*4 + 2	V*4 + 2	V*2 + 2	V*4 + 2	V*2 + 2	V*2 + 2	V*4 + 2	V*4 + 2	V*4 + 2	V*4 + 2
Work area (_FS_TINY == 0)	V*560 + F*550	V*560 + F*550	V*560 + F*550	V*560 + F*544	V*560 + F*550	V*560 + F*544	V*560 + F*544	V*560 + F*544	V*560 + F*550	V*560 + F*550	V*560 + F*550
Work area (_FS_TINY == 1)	V*560 + F*36	V*560 + F*36	V*560 + F*36	V*560 + F*32	V*560 + F*36	V*560 + F*32	V*560 + F*32	V*560 + F*36	V*560 + F*36	V*560 + F*36	V*560 + F*36

These are the memory usage on some target systems with following condition. The memory sizes are in unit of byte, *V* denotes number of volumes and *F* denotes number of open files. All samples are optimezed in code size.

```
FatFs R0.10a options:
_FS_READONLY     0 (R/W) or 1 (R/O)
_FS_MINIMIZE     0 (Full function) or 3 (Minimized function)
_USE_STRFUNC     0 (Disable string functions)
_USE_MKFS        0 (Disable f_mkfs function)
_USE_FORWARD     0 (Disable f_forward function)
_USE_FASTSEEK    0 (Disable fast seek feature)
_CODE_PAGE       932 (Japanese Shift_JIS)
_USE_LFN         0 (Disable LFN feature)
_MAX_SS          512 (Fixed sector size)
_FS_RPATH        0 (Disable relative path feature)
_FS_LABEL        0 (Disable volume label functions)
_VOLUMES         V (Number of logical drives to be used)
_MULTI_PARTITION 0 (Single partition per drive)
_FS_REENTRANT    0 (Disable thread safe)
_FS_LOCK         0 (Disable file lock control)
```

Module Size Reduction

Follwing table shows which API function is removed by configuration options for the module size reduction.

Function	_FS_MINIMIZE				_FS_READONLY		_USE_STRFUNC		_FS_RPATH			_FS_LABEL		_USE_MKFS		_USE_FORWARD		_MULTI_PARTITION	
	0	1	2	3	0	1	0	1/2	0	1	2	0	1	0	1	0	1	0	1

f_mount											
f_open											
f_close											
f_read											
f_write				x							
f_sync				x							
f_lseek			x								
f_opendir		x	x								
f_closedir		x	x								
f_readdir		x	x								
f_stat	x	x	x								
f_getfree	x	x	x	x							
f_truncate	x	x	x	x							
f_unlink	x	x	x	x							
f_mkdir	x	x	x	x							
f_chmod	x	x	x	x							
f_utime	x	x	x	x							
f_rename	x	x	x	x							
f_chdir						x					
f_chdrive						x					
f_getcwd						x	x				
f_getlabel								x			
f_setlabel				x				x			
f_forward										x	
f_mkfs				x					x		
f_fdisk				x					x		x
f_putc				x	x						
f_puts				x	x						
f_printf				x	x						
f_gets					x						

Long File Name

FatFs module supports LFN (long file name). The two different file names, SFN (short file name) and LFN, of a file is transparent on the API except for `f_readdir()` function. The LFN feature is disabled by default. To enable it, set `_USE_LFN` to 1, 2 or 3, and add `option/unicode.c` to the project. The LFN feature requiers a certain working buffer in addition. The buffer size can be configured by `_MAX_LFN` according to the available memory. The length of an LFN will reach up to 255 characters, so that the `_MAX_LFN` should be set to 255 for full featured LFN operation. If the size of working buffer is insufficient for the input file name, the file function fails with `FR_INVALID_NAME`. When enable the LFN feature under re-entrant configuration, `_USE_LFN` must be set to 2 or 3. In this case, the file function allocates the working buffer on the stack or heap. The working buffer occupies `(_MAX_LFN + 1) * 2` bytes.

LFN cfg on ARM7TDMI

Code page	**Program size**
SBCS	+3.7K
932(Shift_JIS)	+62K
936(GBK)	+177K
949(Korean)	+139K
950(Big5)	+111K

When the LFN feature is enabled, the module size will be increased depends on the selected code page. Right table shows how many bytes increased when LFN feature is enabled with some code pages. Especially, in the CJK region, tens of thousands of characters are being used. Unfortunately, it requires a huge OEM-Unicode bidirectional conversion table and the module size will be drastically increased as shown in the table. As the result, the FatFs with LFN feature with those code pages will not able to be implemented to most 8-bit microcontrollers.

Note that the LFN feature on the FAT file system is a patent of Microsoft Corporation. This is not the case on FAT32 but most FAT32 drivers come with the LFN feature. FatFs can swich the LFN feature off by configuration option. When enable LFN feature on the commercial products, a license from Microsoft may be required depends on the final destination.

Unicode API

By default, FatFs uses ANSI/OEM code set on the API under LFN configuration. FatFs can also switch the character encoding to Unicode on the API by `_LFN_UNICODE` option. This means that the FatFs supports the True-LFN feature. For more information, refer to the description in the file name.

Re-entrancy

The file operations to the different volume is always re-entrant and can work simultaneously. The file operations to the same volume is not re-entrant but it can also be configured to thread-safe by `_FS_REENTRANT` option. In this case, also the OS dependent synchronization object control functions, `ff_cre_syncobj(), ff_del_syncobj(), ff_req_grant() and ff_rel_grant()` must be added to the project. There are some examples in the `option/syscall.c`.

When a file function is called while the volume is in use by any other task, the file function is suspended until that task leaves the file function. If wait time exceeded a period defined by `_TIMEOUT`, the file function will abort with `FR_TIMEOUT`. The timeout feature might not be supported by some RTOS.

There is an exception for `f_mount(), f_mkfs(), f_fdisk()` function. These functions are not re-entrant to the same volume or corresponding physical drive. When use these functions, all other tasks must unmount the volume and avoid to access the volume.

Note that this section describes on the re-entrancy of the FatFs module itself but also the low level disk I/O layer will need to be re-entrant.

Duplicated File Access

FatFs module does not support the read/write collision control of duplicated open to a file. The duplicated open is permitted only when each of open method to a file is read mode. The duplicated open with one or more write mode to a file is always prohibited, and also open file must not be renamed and deleted. A violation of these rules can cause data colluption.

The file lock control can be enabled by `_FS_LOCK` option. The value of option defines the number of open objects to manage simultaneously. In this case, if any open, rename or remove that violating the file shareing rule that described above is attempted, the file function will fail with `FR_LOCKED`. If number of open objects, files and sub-directories, is equal to `_FS_LOCK`, an extra `f_open(), f_optndir()` function will fail with `FR_TOO_MANY_OPEN_FILES`.

Performance Effective File Access

For good read/write throughput on the small embedded systems with limited size of memory, application programmer should consider what process is done in the FatFs module. The file data on the volume is transferred in following sequence by `f_read()` function.

Figure 1. Sector misaligned read (short)

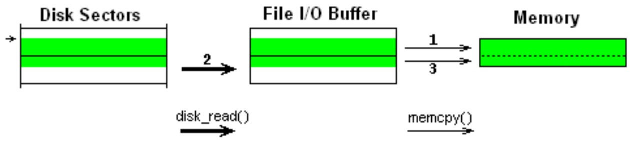


Figure 2. Sector misaligned read (long)

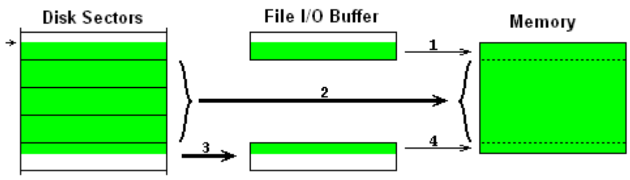
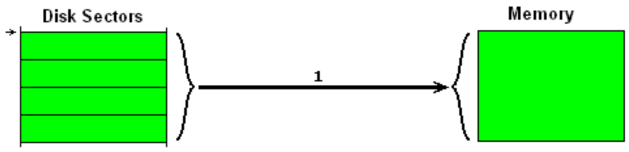


Figure 3. Fully sector aligned read



The file I/O buffer is a sector buffer to read/write a partial data on the sector. The sector buffer is either file private sector buffer on each file object or shared sector buffer in the file system object. The buffer configuration option `_FS_TINY` determins which sector buffer is used for the file data transfer. When tiny buffer configuration (1) is selected, data memory consumption is reduced `_MAX_SS` bytes each file object. In this case, FatFs module uses only a sector buffer in the file system object for file data transfer and FAT/directory access. The disadvantage of the tiny buffer configuration is: the FAT data cached in the sector buffer will be lost by file data transfer and it must be reloaded at every cluster boundary. However it will be suitable for most application from view point of the decent performance and low memory comsumption.

Figure 1 shows that a partial sector, sector misaligned part of the file, is transferred via the file I/O buffer. At long data transfer shown in Figure 2, middle of transfer data that covers one or more sector is transferred to the application buffer directly. Figure 3 shows that the case of entier transfer data is aligned to the sector boundary. In this case, file I/O buffer is not used. On the direct transfer, the maximum extent of sectors are read with `disk_read()` function at a time but the multiple sector transfer is divided at cluster boundary even if it is contiguous.

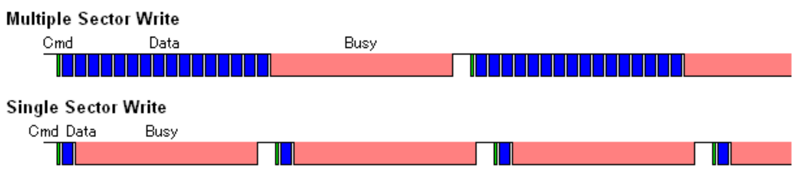
Therefore taking effort to sector aligned read/write accesss eliminates buffered data transfer and the read/write performance will be improved. Besides the effect, cached FAT data will not be flushed by file data transfer at the tiny configuration, so that it can achieve same performance as non-tiny configuration with small memory footprint.

Considerations on Flash Memory Media

To maximize the write performance of flash memory media, such as SDC, CFC and U Disk, it must be controlled in consideration of its characteristitcs.

Using Mutiple-Sector Write

Figure 6. Comparison between Multiple/Single Sector Write



The write throughput of the flash memory media becomes the worst at single sector write transaction. The write throughput increases as the number of sectors per a write transaction. This effect more appers at faster interface speed and the performance ratio often becomes grater than ten. This graph is clearly explaining how fast is multiple block write (W:16K, 32 sectors) than single block write (W:100, 1 sector), and also larger card tends to be slow at single block write. The number of write transactions also affects the life time of the flash memory media. Therefore the application program should write the data in large block as possible. The ideal write chunk size and alighment is size of sector, and size of cluster is the best. Of course all layers between the application and the storage device must have consideration on multiple sector write, however most of open-source disk drivers lack it. Do not split a multiple sector write request into single sector write transactions or the write throughput gets poor. Note that FatFs module and its sample disk drivers supprt multiple sector read/write feature.

Forcing Memory Erase

When remove a file with `f_remove()` function, the data clusters occupied by the file are marked 'free' on the FAT. But the data sectors containing the file data are not that applied any process, so that the file data left occupies a part of the flash memory array as 'live block'. If the file data is forced erased on removing the file, those data blocks will be turned in to the free block pool. This may skip internal block erase operation to the data block on next write operation. As the result the write performance might be improved. FatFs can manage this feature by setting `_USE_TRIM` to 1. Note that this is an expectation of internal process of the flash memory storage and not that always effective. Also `f_remove()` function will take a time when remove a large file. Most applications will not need this feature.

Critical Section

If a write operation to the FAT volume is interrupted due to any accidental failure, such as sudden blackout, incorrect disk removal and unrecoverable disk error, the FAT structure on the volume can be broken. Following images shows the critical section of the FatFs module.

Figure 4. Long critical section

```
f_mount(...);

f_open(...);          //Create  file

// any procedure

do {
    t = get_adc(...);

    // any procedure

    f_write(...);    // write file

    delay_second(1);

} while (...);

// any procedure

f_close(...);         // close file
```

```
f_mkdir(...);

f_rename(...);

f_unlink(...);
```

Figure 5. Minimized critical section

```
f_mount(...);

f_open(...);          //Create  file
f_sync(...);
// any procedure

do {
    t = get_adc(...);

    // any procedure

    f_write(...);    // write file
    f_sync(...);
    delay_second(1);

} while (...);

// any procedure

f_close(...);         // close file
```

```
f_mkdir(...);

f_rename(...);

f_unlink(...);
```

An interruption in the red section can cause a cross link; as a result, the object being changed can be lost. If an interruption in the yellow section is occured, there is one or more possibility listed below.

- The file data being rewrited is collapsed.
- The file being appended returns initial state.
- The file created as new is gone.
- The file created as new or overwritten remains but no content.
- Efficiency of disk use gets worse due to lost clusters.

Each case does not affect the files that not opened in write mode. To minimize risk of data loss, the critical section can be minimized by minimizing the time that file is opened in write mode or using `f_sync()` function as shown in Figure 5.

Extended Use of FatFs API

These are examples of extended use of FatFs APIs. New item will be added whenever a useful code is found.

1. Open or create a file for append
2. Empty a directory
3. Allocate contiguous area to the file
4. Function/Compatible checker for low level disk I/O module
5. FAT image creator

About FatFs License

FatFs has being developped as a personal project of author, ChaN. It is free from the code anyone else wrote. Following code block shows a copy of the FatFs license document that included in the source files.

```
/*----------------------------------------------------------------------------/
/  FatFs - FAT file system module  R0.10c                    (C)ChaN, 2014
/-----------------------------------------------------------------------------/
/ FatFs module is a generic FAT file system module for small embedded systems.
/ This is a free software that opened for education, research and commercial
/ developments under license policy of following trems.
/
/  Copyright (C) 2014, ChaN, all right reserved.
/
/ * The FatFs module is a free software and there is NO WARRANTY.
/ * No restriction on use. You can use, modify and redistribute it for
/   personal, non-profit or commercial products UNDER YOUR RESPONSIBILITY.
/ * Redistributions of source code must retain the above copyright notice.
/
/-----------------------------------------------------------------------------/
```

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