CCFE–R(11)14

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Introduction

An IPX image file format was developed in 2003 and has been used since then as the main format for MAST images [1]. A number of standard image formats existing at that time could not satisfy requirements for effective and universal storage of image sequences produced by fast CCD cameras. For example, the most suitable candidate (TIFF) stores each image as a single entity; that means all meta-data common for the sequence must be repeated in each frame. Moreover, TIFF supports only “Zip” compression which is ineffective for images, and an additional license is required for access to compressed files in IDL (main analysis tool on MAST).

The IPX file is a simple container for image sequences; it contains a file header and one or more frames. The file header contains all common meta-data, camera settings for example. Each frame has a frame header with frame-specific information. The image data is stored in the frame as raw data or as a compressed file using JPEG2000 codec. The IPX file is specialized for image sequences produced by one camera; that means all images in the file must be similar: they have the same size, depth, and other meta-data.

The first version of IPX format has binary headers: both file and frame. Rapid progress in CCD cameras made this version obsolete; it was not flexible enough.

The second version of IPX format has a flexible text header both for the file and for each frame. The meta-data can be placed either in the file header or in the frame header. For example, the image exposure can be common for all frames (put in the file header) or different (put in the frame header). IPX2 can also store up to three reference frames: bad pixel table and two non-uniformity correction frames.

A number of file access and transformation tools have been developed including graphical viewer (**ipxview**) implemented in Windows and Linux. All tools support both versions of IPX format.

IPX1 format specification

The IPX1 file consists of a binary file header immediately followed by a sequence of image frames. The header has a set of mandatory fields; it has variable length and can be extended. All binary headers have little-endian format (less significant byte first).

The IPX1 supports only raw data and JPEG2000 codec which is most effective for CCD images. The data compression is implemented using the Jasper library [2]; there are two options: JP2 – lossless, and JPC – lossy compression.

Mandatory fields are (offset and length in bytes):

NAME	**OFFSET**	**LENGTH**	**TYPE**	**CONTENTS**
ID	0	8	string	“IPX 01”
size	8	4	unsigned	File header size; 286 bytes minimum
codec	12	8	string	“ ”, “JP2”, “JPC/N”. N is optional compression factor
date_time	20	20	string	File creation date and time, e.g. "07/09/2004 19:01:31"
shot	40	4	int	Shot number
trigger	44	4	float	Camera trigger time (s)
lens	48	24	strings	Camera lens
filter	72	24	string	Camera filter
view	96	64	string	Camera view
numFrames	160	4	unsigned	Number of frames
camera	164	64	string	Camera type, firmware, etc.
width	228	2	unsigned	Image width in pixels (after binning)
height	230	2	unsigned	Image height in pixels (after binning)
depth	232	2	unsigned	Image depth in bits
orient	234	4	unsigned	Image orientation
taps	238	2	unsigned	Number of digitizer channels
color	240	2	unsigned	Color scheme: 0 – gray; 1 – gbrg/rggb; 2 – gr/bg
hBin	242	2	unsigned	Horizontal binning; 0 – no binning.
left	244	2	unsigned	Window position (leftmost=1); 0 – not defined.
right	246	2	unsigned	Window position (leftmost=1); 0 – not defined.
vBin	248	2	unsigned	Vertical binning; 0 – no binning.
top	250	2	unsigned	Window position (topmost=1); 0 – not defined.

bottom	252	2	unsigned	Window position (topmost=1); 0 – not defined.
offset[0]	254	2	unsigned	ADC offset (black level) for first channel
offset[1]	256	2	unsigned	ADC offset (black level) for second channel
gain[0]	258	4	Float	ADC gain for first channel
gain[1]	262	4	Float	ADC gain for second channel
preExp	266	4	unsigned	First frame exposure in microseconds
exposure	270	4	unsigned	Each frame exposure in microseconds
strobe	274	4	unsigned	Strobe pulse position in microseconds
board_temp	278	4	Float	Board temperature in C
ccd_temp	282	4	Float	CCD temperature in K

The header size includes the file ID. The first frame immediately follows the file header; the header size is also the first frame offset.

Each frame contains a binary header and image data. The frame header has the following fields:

NAME	**OFFSET**	**LENGTH**	**TYPE**	**CONTENTS**
size	0	4	unsigned	Full frame size including frame header
timeStamp	4	8	double	Frame time in s.

The frame time is the end of exposure interval: this is a natural choice for CCD cameras - a “vertical sync” time; usually the cameras provide this signal as output and it can be registered for precise synchronization.

The image data immediately follows the frame header; it can be:

1) codec=0 - a raw pixel sequence (scan lines) starting from the top-left corner,

2) codec>0 - a JPEG2000 file including file header.

The frame position in the file can be counted as the following:

first_frame_offset = file_header_size;

frame_offset = previous_frame_offset + previous_frame_size.

IPX2 format specification

The IPX2 format has been developed as an extension of IPX1 to overcome limitations of the first version. There are two new features:

1) the file and frame headers are stored in text format;
2) the file can contain up to three reference frames: a bad pixel table and two frames for non-uniformity correction.

The text headers eliminate the need for endian conversion; they become more flexible. The IPX2 format supports new camera capabilities, for example, variable exposure in the frame sequence. The image meta-data can be stored in the file header (common for all frames) or in the frame header (frame-specific).

The file header consists of a fixed-size part and a text string. The fixed part has the following fields:

NAME	OFFSET	LENGTH	TYPE	CONTENTS
File ID	0	8	string	“IPX 02”
Header size	8	4	string	Length in bytes: zero padded hex number

The rest of the file header is a text string consisting of fields: “tag=value” pairs (without spaces). The header fields start with and are delimited by the ‘&’ symbol. This symbol is not allowed in both tag and value. If the value contains spaces it must be enclosed in a pair of double or single quotes. The fields can be stored in any order. There are three categories of header fields: mandatory – must be present in any IPX2 file; common – present in most files and accessed by common tools; optional – used in special files and accessed by specialized tools.

There are only four (five for compressed files) mandatory fields (tags):

TAG	TYPE	VALUE
codec	string	Compressed files only: “jp2” or “jpc/N” (N is optional compression factor).
width	integer	Image width in pixels (after binning)
height	integer	Image height in pixels (after binning)
depth	integer	Image depth in bits
frames	unsigned	Number of image frames in the file; not including reference frames

The following fields are present in most files; if found they are interpreted by common data access tools as described in the table:

TAG	TYPE	VALUE
exposure	float	Common exposure for all image frames in microseconds.
taps	integer	Number of digitizer channels
color	string	Color scheme: “gbrg/rggb” or “gr/bg”
hbin	integer	Horizontal binning; 0 – no binning.
left	integer	Window position (leftmost=1); 0 – not defined.
right	integer	Window position (leftmost=1); 0 – not defined.
vbin	integer	Vertical binning; 0 – no binning.
top	integer	Window position (topmost=1); 0 – not defined.
bottom	integer	Window position (topmost=1); 0 – not defined.
offset	float or string	ADC offset (blacklevel): one value for one channel or comma-separated values for each channel
gain	float or string	ADC gain: one value for one channel or comma-separated values for each channel
preexp	float	First frame exposure in microseconds
strobe	float	Strobe pulse position in microseconds
boardtemp	float	Board temperature in C
ccdtemp	float	CCD temperature in K
lens	string	Camera lens
filter	string	Camera filter
view	string	Camera view

The file access tools should use at least 4 bytes both for integer and float values.

The image meta-data can be either in the file header or in the frame headers. For example, when the exposure is common for all image frames it must be specified in the file header; if this field is absent or equals 0 the exposure must be specified for each frame. The file header has precedence: if it contains the common value then frame header values are ignored.

Reference frames

The reference frames, if present, must immediately follow the file header; the first frame offset equals the header length.

Three reference frames are supported: a bad pixel table, and one or two frames for non-uniformity correction. In compressed files all reference frames use only lossless JP2 codec. All reference frames must be the same size as image frames. The bad pixel table consists of single byte pixels. The NUC frames must be the same depth as image frames.

The reference frames can have application-specific implementation. The graphical viewer (**ipxview**) uses the following algorithm (V is the pixel value):
ref0 (bad pixel table): non-zero value means bad pixel, it is replaced by mean value of nearest good pixels;
ref1 (1 point NUC): $V_{corrected} = V_{raw} - V_{ref1} + mean(V_{ref1})$;
ref2 (2 point NUC): $V_{corrected} = G * (V_{raw} - V_{ref1}) + mean(V_{ref1})$,

$G = (mean(V_{ref2}) - mean(V_{ref1})) / (V_{ref2} - V_{ref1})$ if $V_{ref2} > V_{ref1}$,

$G = 1$ if $V_{ref2} <= V_{ref1}$.

The reference frame header must start with two hex digits: the header length in bytes. The rest of the header is a string consisting of "tag=value" pairs; the pairs are delimited by '&' symbol. The reference frame header has only two mandatory fields:

TAG	TYPE	VALUE
ref	Int	0 – bad pixel table, 1 – 1 point NUC, or 2 – 2 point NUC frame
fsize	unsigned	Frame (image) size in bytes without header. It may be omitted in uncompressed file.

The reference image follows the header. Next frame offset can be calculated as: frame_offset + frame_header_length + fsize.

Image frames

The image frames follow the file header or the reference frames. Each frame consists of a header and an image. The frame header must start with two hex digits: the header length in bytes. The rest of the header is a string consisting of "tag=value" pairs; the pairs are delimited by '&' symbol. There are three common fields (supported by file access tools) in the frame header:

TAG	TYPE	VALUE
ftime	double	Frame time in s; must be present in the image frame header.
fsize	unsigned	Frame (image) size in bytes without header. It may be omitted in uncompressed file.
fexp	float	Frame exposure in microseconds. It is used when "exposure" in the file header is omitted or equals 0.

The frame time is the end of exposure period.

Next frame offset can be calculated as: frame_offset + frame_header_length + fsize.

References

[1] S. Shibaev and MAST team, Software for fast cameras and image handling on MAST, Fusion Eng. Des. 83 (2008) 667–671.

[2] M.D. Adams, JasPer library, http://www.ece.uvic.ca/~mdadams/jasper.