

The DICOM standard for medical thermal imaging

by J. Ruminski*

**Department of Biomedical Engineering, Gdansk University of Technology, Gdansk, Poland*

Abstract

In imaging medicine the DICOM standard has become a widely accepted and implemented format for the exchange, storage and presentation of medical imaging data. Numerous imaging modalities are supported however there is not a dedicated solution for thermal infrared imaging. We designed and implemented a new proposal for DICOM Thermal Infrared Imaging (TII) using existing DICOM data structures and newly defined information objects.

4. Introduction

Medical applications of thermal infrared imaging are becoming more popular (e.g. [1]-[7]). There are different thermal imaging based modalities proposed however their success in medical practice depends (besides diagnostic value) on acceptable by healthcare professionals standard tools/formats used by those modalities. In medical imaging world the DICOM (Digital Imaging and Communication in Medical [8]) standard is the leading solution. The DICOM standard is widely accepted (e.g., it is also a European CEN standard: EN 12052) and mainly describes data structures, representation and exchange in the medical imaging context. Since its beginning the standard is under continuous development and currently almost every player on the medical imaging market produces a DICOM related software (including medical workstations). The role of the DICOM tools requires that every new medical imaging modality should be enriched with DICOM-related functionalities.

In DICOM every imaging modality is described by a data structure named Information Object Definition (e.g., CT Image IOD) and related services (e.g., CT Image Storage). Service Object Pair (SOP) is a pair of IOD and given service. The current DICOM version includes 18 parts. The biggest part – Part 3 (more than 1000 pages), specifies different Information Object Definitions. In 2008 standard version there are more than 30 image IODs (e.g., CT IOD, MR IOD) and non-image IODs, but there is no one dedicated to thermal infrared images. There were previous discussion on the DICOM application in thermal imaging. In 2004 we initiated a discussion about application of the DICOM in thermal infrared imaging during breakfast meeting which took place at IEEE EMBS 2004 Conference in San Francisco. Later, in [9] authors present results of preliminary studies on adopting the DICOM standard for medical infrared images however their proposals are deprecated in the current DICOM version.

In this work we would like to present the results of the research related to the application of DICOM for thermal infrared imaging. Currently thermal infrared images can be stored (i.e. using DICOM) only using one of the Secondary Capture (SC) IODs with the modality attribute set to "TG". We proposing further improvements to the current stage of the DICOM adopting for the thermal infrared imaging:

- single-frame SC Image IOD is retained in the DICOM standard so other SC IOD must be used;
- chosen IOD should supports 16 bits/pixel bits resolution;
- chosen IOD should supports multi frame format (for time sequences)
- private attributes should be defined to store information about thermal camera (e.g., calibration parameters), dynamic procedures (for active thermography), etc.;
- new Thermal Infrared Image IOD (TII IOD) should be proposed;
- the open software package should be prepared for universal conversion of thermal infrared formats to the DICOM format.

5. Method

In IOD designing for thermal infrared images it is important to analyze diversity of thermal cameras. They differ in detector types, operational wavelengths, calibration parameters, etc. The discussion is required to establish a consensus about a common set of attributes in the TII IOD. After many analysis we decided to propose two parallel solutions: first (temporary) using existing data structures in DICOM; second using own proposal of the new TII IOD (which we hope will be a base for normalization discussions).

In the thermal infrared imaging dynamic experiments are often proposed. This requires to store a sequence of frames, the time vector and the experiment descriptors (e.g., an excitation type, an excitation time period). The backward compatibility should be supported so the proposed solution should allows to generate a DICOM file in the previously accepted IOD format (e.g. SC IOD – to allow existing DICOM-based applications to work with thermal infrared imaging data) before the new TII IOD will be formally accepted.

We decided to use the XML document standard [10] to configure destination DICOM attributes. The XML recommendation was recognized as a valuable standard for many medical applications. The HL7 ver. 3 [11] is one of the example. Designing the destination DICOM modules the corresponding XML elements are constructed in the XML elements of the configuration file, e.g., PATIENT XML element for the DICOM Patient module, SERIES XML element for the DICOM Series modules, etc. Every element related to the DICOM module has a set

of subelements. Each subelement defines corresponding attributes. In the listing 1 a part of the XML configuration file is presented.

Listing 1. A part of the extensible configuration file – all required parameters are defined using XML elements which can be added either as a standard DICOM attributes or as a private attributes

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- CONFIG FILE FOR THE AGEMA THV900SW/TE CAMERA -->
<DICOM>
  <PATIENT>
    <!-- ID -->
    <G GID="0010" EID="0020" M="M">1</G>
    <!-- PN -->
    <G GID="0010" EID="0010" M="M">Ruminski^Jacek</G>
    <!-- Birth date -->
    <G GID="0010" EID="0030" M="M">19701209</G>
    (...)
  </PATIENT>
  <STUDY>
    <!-- UID -->
    <G GID="0020" EID="000D" M="M">1</G>
    <!-- Date -->
    <G GID="0008" EID="0020" M="M">20070223</G>
    <!-- Time -->
    <G GID="0008" EID="0030" M="M">124312.01</G>
    <!-- Description -->
    <G GID="0008" EID="1030" M="M">test</G>
  </STUDY>
  (...)
  <EQUIPMENT>
  (...)
  </EQUIPMENT>
  <PROCEDURE>
  (...)
  </PROCEDURE>
</DICOM>
```

The simplified XML schema was used with common XML element <G></G> and its attributes. The “GID” attribute of the XML <G> element represents the group ID from the DICOM attribute TAG (TAG is composed by Group ID and Element ID). The “EID” attribute is used to define the second part of the TAG. The last XML <G> attribute “M” defines the mandatory status of the DICOM attribute (M-mandatory, O-optional). Optionally the <G> XML element can store a value, which will be treated as a default attribute value (e.g. a common for a module, like procedure description, etc.).

The configuration file should be created for each camera (majority of attributes will be the same, some of them can share data values). Update of the DICOM file attribute structure can be implemented easily with introducing of new <G></G> elements. The XML configuration file is a simple text document, so it can be edited outside the software code. It means that there is no need to modify application source code in case of format modification (in sense of attributes). The DICOM mandatory attributes must be present in the configuration file. Additional data, private attributes should be used to define required camera related parameters (e.g., calibration parameters). Currently we identify and use more than 20 such attributes (the description of which covers 3 A4 pages) but for standardization efforts they should be discussed between interested parties. The private attributes should be additionally identified as the future attributes of new modules in the working DICOM supplement (for Thermal Infrared Imaging IOD).

Majority of software programming languages support XML parsing so XML-based configuration file can be interpreted with any software package. The user of the designed transformation (raw data to the DICOM format) software can identify (choose) the source file (with data) and the appropriate XML configuration file. The configuration file can be easily prepared by Thermal Camera manufacturer or other party (and modified by a user if required e.g., to include default, user specific values).

Using Java programming language and Apache Xerces/Xalan (and JDOM) XML parsers we implemented a reference software for the proposed transformation method. The software requires DICOM Data Dictionary to identify attributes. The DICOM Data Dictionary (information about TAGs, attributes data types, multiplicity and names) is constructed (Java TreeMap object container that maps the TAG value to the data type, multiplicity and the name) using the DICOM Part 6 text and own set of new (private) attributes.

After specification of the required attribute set the final DICOM data container (IOD) is required. All existing IODs were analyzed and the Multi-frame Grayscale Word Secondary Capture Image IOD was chosen to represent original thermal imaging data. Required presentation formats (e.g., colors) can be defined using the DICOM Presentation Context parameters or “DERIVED” SC IOD formats. In case of a single image the chosen IOD is set to a number of images equal 1. The Multi-frame Grayscale Word Secondary Capture Image IOD can be used until the required TII IOD will be introduced.

Additionally further improvements can be used to simplify user operations. We propose to use in the XML configuration files the additional XML element (SOURCEFILE) which defines the default parameters to read raw data matrixes (and other parameters) from particular camera manufacturer file format. The example is presented in the listing 2.

Listing 2. The raw data conversion parameters for the specified camera

```
(...)
<!-- NOT FOR THE DICOM DESTINATION. -->
<SOURCEFILE>
  <!-- FILE HEADER -->
  <G GID="9999" EID="1001" M="M">128</G>
  <!-- IMAGE HEADER -->
  <G GID="9999" EID="1002" M="M">568</G>
  <!-- IMAGE FOOTER -->
  <G GID="9999" EID="1003" M="M">3840</G>
  <!-- BITS -->
  <G GID="9999" EID="1010" M="M">16</G>
  <!-- ENCODING LE-0, BE-1 -->
  <G GID="9999" EID="1011" M="M">1</G>
  <!-- SKIP TO TIME IN FILE [B] -->
  <G GID="9999" EID="1012" M="M">392</G>
  <!-- SWAP BE/LE -->
  <G GID="9999" EID="1013" M="M">>false</G>
  <!-- Camera implementation file -->
  <G GID="9999" EID="1020" M="M">org.cemte.jacek.thermo.FlirSC3000</G>
</SOURCEFILE>
```

In the end of the "SOURCEFILE" element the Java class name is specified which implements a set of methods (defined in the Java interface template) to read data matrixes and parameters from the source file. The parameters can be read automatically from the "SOURCEFILE" element or (if not supported) can be manually specified in the dialog window. In the dialog window the source file is chosen, then the XML configuration file. If the SOURCEFILE XML element is present in the configuration file, then all required parameters are copied to the dialog window (the 'No of images' is automatically calculated using existing parameters). After the user acceptance the new dialog window is activated. The content of this window is automatically constructed as a result of the XML configuration file processing (parsing).

In the figure 1 the example of a graphical user interface is presented which is dynamically build using the XML configuration files. All attributes can be modified as required.

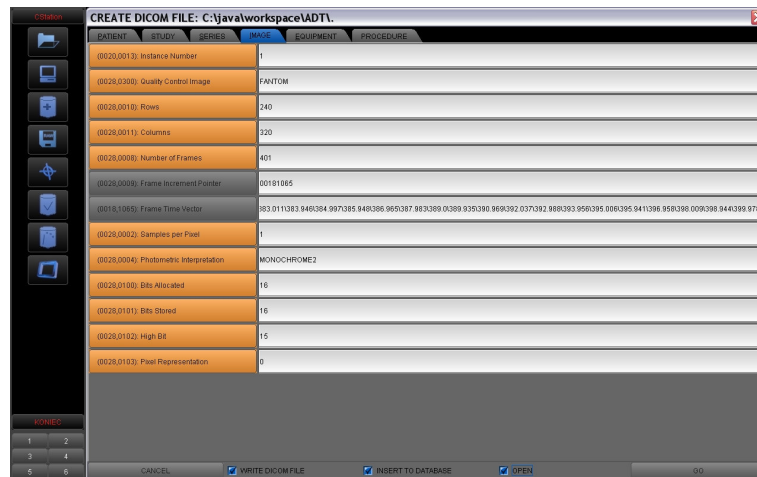


Fig. 1. Graphical user interface presents dynamically build form with attributes and possibility of quantitative analysis using original data stored in generated DICOM file

In the graphical user interface all attributes can be reviewed choosing a proper tab. The user can modify default values (correct DICOM data types are verified at the time of each modification). The mandatory DICOM attributes are presented using different colors. Finally the user can store a generated DICOM attribute set as a file or/and in a database (or open it for further analysis).

6. Results

The designed solution was implemented using Java programming language. The product enables to convert any kind of source data (original raw data) to the DICOM Multi-frame Grayscale Word Secondary Capture Image IOD using XML configuration file. If there are no modifications required in the GUI text fields the user can perform only 5 operations (identify the source file, the XML config file and chose 3 commands: GO, WRITE DICOM FILE, GO) to create the final DICOM file.

The private attributes were introduced and verified in the implemented software. Those attributes can be later used as the future TII IOD attributes. In fig. 2 the dialog window is presented with the private attributes (some of them have hidden description since so far they are only in polish language).

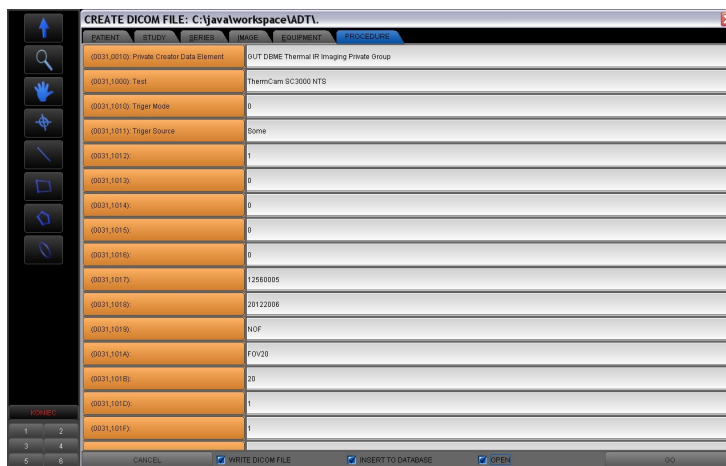


Fig. 2. The dialog window with private attributes

Different procedures were used to test the implemented software. In all tests two different thermal cameras (Agema THV 900SW and Flir SC 3000) were used. For each camera 10 different files were chosen (characterized by different number of frames, different frame resolutions, etc.). All tests were performed on the Pentium Dual Core (T2400) computer with 1GB RAM. The two parameters were measured: the conversion time and the DICOM conformance. The conversion time was calculated using the computer system clock in repeatable experiments. The DICOM conformance was tested using different, available DICOM applications.

The results of performance test were proportional (with a value between 1 and 2) to a disk read-write operations. Repeated tests (the time period was measures using the system time including: the conversion process – excluding dialog window user operations; the DICOM file disc operations; the converter logfile operations) produced the following results: sequences up to 3MB – 1ms < conversion time < 140ms; sequences up to 61MB – 640ms < conversion time < 2840ms.

Many DICOM conformance tests were performed using popular DICOM software (including HUG Osiris [12], ImageJ [13]). In all tested software there was no errors or exceptions; sequences were properly presented and interpreted (i.e. 16-bits values). The DICOM attributes were also readable. The screen copy of the ImageJ software running the constructed DICOM file is presented in fig. 3.

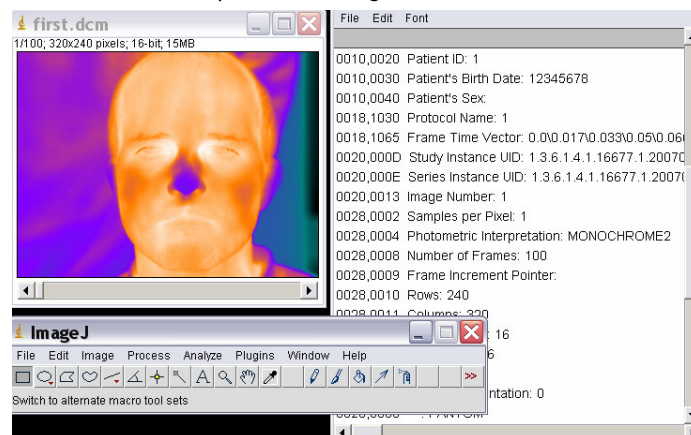


Fig. 3. The screen copy of the ImageJ software running the constructed DICOM file

Tests were also performed using our software for automatic burn diagnosis using the method proposed in [7]. In fig. 4 the screenshot is presented of the image read from the generated DICOM file.

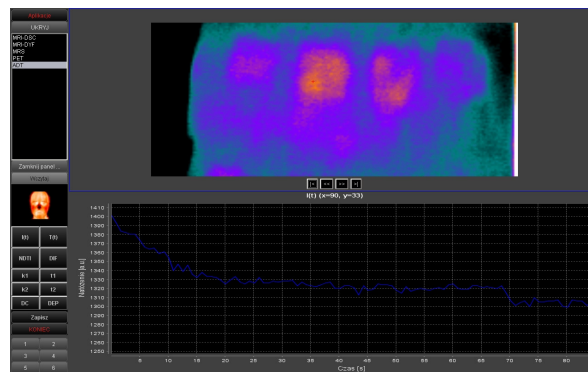


Fig. 4. The screenshot of the image read from the generated DICOM file

7. Discussion and conclusions

The adaptation of the DICOM structures for thermal infrared images was presented. Additionally the dedicated software was implemented and tested. The created software for conversion of thermal infrared imaging data to DICOM can be used as a standalone tool or as a part of the computer-aided diagnosis system. The conversion procedure is fast and the final DICOM files are readable by popular DICOM computer programs. This can be additionally used to produce DICOM databases of thermal infrared images for different medical applications.

Table 1. The proposed Thermal Infrared Image IOD (M – MANDATORY, C-CONDITIONAL, U-USER OPTION)

IE	Module	Usage
Patient	Patient	M
	Clinical Trial Subject	U
Study	General Study	M
	Patient Study	U
	Clinical Trial Study	U
Series	General Series	M
	Clinical Trial Series	U
Equipment	General Equipment	U
	Thermal Camera Equipment	M
Frame of Reference	Frame of Reference	C – Required if Pixel Measures or Plane Position or Plane Orientation Functional Group Macros Present
	Synchronization	U
Image	General Image	M
	Image Pixel	M
	Contrast/excitation	C – Required if contrast media or other type of excitation was used in this image.
	Cine	C – Required if Frame Increment Pointer (0028,0009) is Frame Time (0018,1063) or Frame Time Vector (0018,1065)
	Multi-frame	M
	Frame Pointers	U
	Multi-frame Functional Groups	U
	Multi-frame Dimension	U
	Thermal Camera Calibration	U
	TI Image	U
	TI Multi-frame Image	M
	TI Multi-frame Vector	C – Required if Number of Frames is greater than 1
	Multi-frame Overlay	U
	Modality LUT	U
	VOI LUT	C – Required if the VOI LUT stage is not an identity transformation
SOP Common	M	

However general Secondary Capture formats are limited in case of modality-related attributes. Private attributes will not be accessible for many DICOM applications. Concluding we are proposing to create a new

Thermal Infrared Image IOD (the proposed structure, proper for the DICOM standard, is presented in Tab.1) and the already described Multi-frame SC IOD to use as an intermediate solution. The following new modules are proposed for the TII IOD: TI Image, TI Multi-frame Image, TI Multi-frame Vector (all similar to those in the Multi-frame Grayscale Word Secondary Capture Image IOD), Thermal Camera Equipment, Thermal Camera Calibration and Contrast/Excitation module. The Thermal Camera Equipment module (in the Equipment IE) is a composition of camera related attributes (e.g. type of lens, calibration constants, calibration dates, a detector type, detector wavelength range, etc.). The Thermal Camera Calibration module (in the Image IE) is a composition of image related calibration attributes including local environment properties during image acquisition (e.g. ambient temperature, relative humidity, target emissivity, etc.).

The last proposed module (Contrast/Excitation) is a set of attributes describing introduced contrast (e.g., pharmacological excitation) or other internal/external excitation (e.g., heating, cooling, etc.). Finally, we are proposing the new Service Object Pair class as UID=1.2.840.10008.5.1.4.1.1.77.1.6; Thermal Infrared Image Storage, where the UID (Unique Identifier) can be changed (if the DICOM standard will be updated with new SOP Classes before the TII one).

The final set of attributes should be defined by a proper working group. The new working group for Thermal Infrared Image IOD should be created and the final set of attributes (in the proposed modules – Tab. 1) should be specified. The working group should start the initiative to update (e.g., the IOD, the SOP, Data Dictionary) the actual DICOM standard (after discussion with formal authorities) in reference to the new SOP Class (and TII IOD). In case of the successful introduction of the TII IOD to the DICOM each provider of the thermal infrared imaging application should prepare the DICOM conformance statement document. The document should describe how the camera and software implements the DICOM standard according to the DICOM Part 2 requirements.

Developing of the new DICOM Supplement requires “a dedicated effort over a period of several months to effect a change in the Standard” [14]. We hope that our previous and current work will help in this process.

8. Acknowledgment

This work was supported by R13 027 01 scientific grant from the Polish Ministry of Science.

I would like to thank my colleague, dr Mariusz Kaczmarek, for his help in preparation of test files from different thermal cameras.

REFERENCES

- [1] Vainer B.G., FPA-based infrared thermography as applied to the study of cutaneous perspiration and stimulated vascular response in humans, *Phys. Med. Biol.* 50 R63-R94, 2005.
- [2] A. Renkielska, A. Nowakowski, M. Kaczmarek, M.K. Dobke, J. Grudzinski, A. Karmolinski, W. Stojek, “Static thermography revisited – an adjunct method for determining the depth of the burn injury,” *Burns*, 31, pp. 768-775, 2005.
- [3] Anbar M: Contact Thermometry. In Anbar M. Quantitative dynamic telethermometry in medical diagnosis and management. CRC Press Inc. Boca Raton, FL. 1994.
- [4] Fujimasa, T. Chinzei, K.Mabuchi, Converting algorithms for detecting physiological function changes from time sequential thermal images of skin surface, *Proc. Of Engineering in Medicine and Biology Society, IEEE 17th Annual Conference*, p:1709-1710 vol.2, 1995.
- [5] Merla A., Donato L. Di., Romani G. L., Rossini P.M., Infrared functional imaging evaluation of the sympathetic thermal response, *Proc. 2nd European Medical and Biological Engineering Conference-EMBEC02*, p. 1610-1611, 2002.
- [6] Renkielska A., Nowakowski A., Kaczmarek M., Ruminski J., Burn depths evaluation based on active dynamic IR thermal imaging-A preliminary study. *Burns*. 2006 Nov ;32 (7):867-75, 2006.
- [7] Ruminski J., Kaczmarek M., Nowakowski A., Renkielska A., Thermal parametric imaging in the evaluation of skin burn depth, *IEEE Trans Biomed Eng.* 2007 Feb ;54 (2):303-12, 2007.
- [8] NEMA, Digital Imaging and Communication in Medicine standard, 2008, Available: <http://medical.nema.org/dicom/2008/>
- [9] Schaefer G, Huguet J, Zhu SY, Plassmann P., Ring F., Adopting the DICOM standard for medical IR images, *Proc. of 28th Annual Int. Conf. Of the IEEE in Medicine and Biology Society (EMBC06)*, pp. 236-239, USA, 2006.
- [10] World Wide Web Consortium, eXtensible Markup Language XML. Available: <http://www.w3.org/TR/2006/REC-xml11-20060816/>
- [11] Health Level Seven, Inc., HL7 standards. Available: http://www.hl7.org/Library/standards_non1.htm
- [12] Digital Imaging Unit (UIN), HUG, Osiris – viewer for DICOM images, Available: http://www.sim.hcuge.ch/osiris/01_Osiris_Presentation_EN.htm.
- [13] National institute of Health, ImageJ – Image processing and analysis in Java, Available: <http://rsb.info.nih.gov/ij/>
- [14] NEMA, How to Develop a Supplement to the DICOM Standard, 2002, Available: http://medical.nema.org/dicom/handbook/WG-06/How_to_Prepare_a_Supplement_2002-09-16.doc