The Role of DICOM for Modular Perioperative Surgical Assist Systems Design

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Abstract

This document describes the role of DICOM as one major standard which will enable interoperability between systems used for surgical planning, intraoperative surgical assist systems and postoperative documentation. We first give an brief overview about DICOM and how it is constantly adapted and extended to cover the needs of new devices and application fields. We describe some of the recent additions which are relevant for image processing and intraoperative support in more detail, followed by a description of the current and future work of DICOM working group 24 “Surgery”.

Contents

1 Introduction to DICOM

Digital Imaging and Communications in Medicine (DICOM) is known as the major imaging and image communication standard in radiology. In 1985, the first version of the standard was published as ACR-NEMA Standards Publication No. 300-1985. Prior to this, most devices stored images in a proprietary format and transferred files of these proprietary formats over a network or on removable media in order to perform image communication – a situation which is comparable the situation in today's pre- and intra-operative systems design. In 1993, the "Version 3.0" was released, to reflect the major changes the name of the standard was changed to Digital Imaging and Communications in Medicine (DICOM).

The DICOM Standard specifies a network protocol based on TCP/IP, so called "Service Classes" which allow for higher level communication like image storage of query, and Information Objects which are uniquely identified. The information objects cover not only images but also patients, studies, reports, and other data groupings. The DICOM standard is freely available as multi-part document at http://dicom.nema.org.

The major application field of DICOM was radiology, but the standard's scope has been broadened within the last years to cover more use cases and application fields, like radiation therapy or pathology. It now aims on achieving compatibility and to improve workflow efficiency between imaging systems and other information systems in healthcare environments worldwide. A more detailed introduction and brief overview about the working principles of the DICOM Standard can be found in [1].

2 Motivation for using DICOM as standard for Surgical Assist Systems

Most surgical planning systems and many systems used intraoperatively are making use of radiology images. Those images are usually stored in a PACS (Picture Archiving and Communication System) in the DICOM format. In many applications it is desirable to store additional derived patient data, e.g. results of a surgical planning step, in the same location to facilitate integration of all data sources. In addition, if the PACS infrastructure allows for storage of those results, one can make use of the long term storage mechanisms already implemented in most PACS solutions – this solves the problem of maintaining different proprietary data formats for a long time. More use cases and rationales are given in a White Paper prepared by DICOM WG-24 "Surgery" [2].

Nonetheless, DICOM will not be the only standard used in the operating room (OR) of the future. It has no real time features; therefore it is not suitable for control tasks like control of a surgical instrument or robot. The scope of DICOM does not cover anesthesia with all its devices and it also does not support streaming data like live video transmission. Other standards will therefore complement the complete OR infrastructure of the future.

3 Extending DICOM

One common misunderstanding about DICOM is, that one can “implement version 3.0 which is the current one”. DICOM version 3 is constantly updated by supplements and modified by change proposals. Therefore, the annual version of DICOM (currently DICOM 2008) including the approved supplements finalized in 2009 is “the current version” of DICOM. There is no such thing like a DICOM 3.1 or 4.0. Extensions and modifications of DICOM are built in a sense that existing DICOM objects will remain valid and existing applications and devices will need no or just minor modifications to include the new features.

All systems claiming DICOM conformance must state in a so called “Conformance Statement”, which Service Classes and Information Objects they support. Therefore, it is not necessary to “implement DICOM” as a whole, one can focus on the things needed for a specific application. If new features are introduced by a supplement, each vendor can freely decide, whether those features are included in a product or not.

“Correction Proposals” (CP) aim on correcting minor errors in the existing text or reflect minor changes. If major additions, like new Information Objects or Service Classes, are introduced, a so called “Supplement” (Sup.) is prepared by one or more DICOM Working Groups (WG). To create a Supplement, the WG has to apply for a “Work Item” which describes the use cases and scope of the work. A comprehensive list of all Supplements and CPs is given by David A. Clunie at http://www.dclunie.com/dicom-status/status.html. All DICOM extensions and modifications must pass WG-06 (Base Standard) to ensure consistency of the overall DCIOM standard. Each supplement usually undergoes a “First Read”, optionally a “Second Read”, a preparation for the “Public Comment”-phase and a preparation for “Final Text”.

A DICOM Working Group consists of interested individuals representing vendors, manufacturers and end users of the respective domain. Everyone interested can participate in preparation of DICOM documents by joining a WG. From our point of view, the most relevant Working Groups for the field of Surgery are WG-02 and 12, both dealing with intraoperatively used imaging devices, 17 for storage of endoscope and microscope movies, 17 for image processing and modeling, 22 for dental and maxillofacial applications and 24 covering “surgery” as a whole. Two WGs play a special role: WG-10 considers issues and opportunities related to the strategic evolution of DICOM, WG-06 maintains the overall consistency of the DICOM standard. A complete list of WGs is given in Table 1.

WG-01: Cardiac and Vascular Information	WG-15: Digital Mammography and CAD
WG-02: Projection Radiography and Angiography	WG-16: Magnetic Resonance
WG-03: Nuclear Medicine	WG-17: 3D
WG-04: Compression	WG-18: Clinical Trials and Education
WG-05: Exchange Media	WG-19: Dermatologic Standards
WG-06: Base Standard	WG-20: Integration of Imaging and Information Systems
WG-07: Radiotherapy	WG-21: Computed Tomography
WG-08: Structured Reporting	WG-22: Dentistry

WG-09: Ophthalmology	WG-23: Application Hosting
WG-10: Strategic Advisory	WG-24: Surgery
WG-11: Display Function Standard	WG-25: Veterinary Medicine
WG-12: Ultrasound	WG-26: Pathology
WG-13: Visible Light	WG-27: Web Technology for DICOM
WG-14: Security	

Table 1 List of DICOM Working Groups (2009) [1].

4 DICOM Supplements relevant for modular perioperative Surgical Assist Systems

There are several DICOM Supplements which have been introduced within the last years which are having relevance for the field of Computer Assisted Surgery. The following table gives a short overview, supplements relevant just for one clinical speciality are omitted:

Supplement	***Year***	***Relevance***
47: Visible Light Video	2003	Storage of video files
67: Configuration Management	2003	Self-configuration of devices
73: Spatial Registration	2003	Introduction of fiducials and registration using affine transformations
85: Web Access to DICOM Objects (WADO)	2003	In case you don’t get native PACS access…
106: JPEG 2000 Interactive Protocol	2004	Interact with JPEG 2000 images using JPIP protocol
111: Segmentation	2006	Store segmentation results as labelled images
112: Deformable Spatial Registration	2006	Adds deformation fields to registration
116: 3D X-Ray	2007	Intraoperative imaging
43: Storage of 3D Ultrasound Images	2008	Intraopreative image acquisition, in device or patient coordinate system.
123: Structured Display	2008	Screen layout
132: Surface Segmentation	2008	Introduces surface meshes to DICOM end extends the formerly image based Segmentation SOP class.
96: Unified Worklist and Procedure Step	Frozen	Worklist and Workflow Management
118: Application Hosting	Comment	Plug-In mechanism for PACS software
131: Bone Mounted Implants	Comment	Introduces 2D and 3D Implant Templates for Surgical Planning
134: Implantation Plan	Comment[1]	Storage of Surgical Plans based on Supp 131
138: Crestal Implant	Cancelled	Use cases covered by Supp. 131

Table 2 Supplements relevant for Surgical Assist Systems. “Year” indicates the year the Supplement is introduced. “Comment” means, it’s in “Public Comment”-Phase, “Frozen” indicates a “Frozen Draft” which shall be tested by reference implementations before it is introduced in the standard.

[1] At time of publication of this article. Actual status: “work”.

5 DICOM Working Group 24 “Surgery”

In 2005, the DICOM Working Group 24 (WG-24) was installed with the goal to extend the DICOM standard towards applications in surgery. In contrast to other WGs, which are usually focused on one particular modality or application, WG-24 covers a broad range of applications and modalities. Therefore, it is organized in Clinical Project Groups which are responsible for the proper definition of clinical use cases and for ensuring the clinical relevance and applicability of the Supplements prepared by WG24. In addition, there Project Groups which are working on specific Supplements and Work Items. Those technical Project Groups are meeting based on their own schedule and report to the whole WG in bi-annual meetings. If a group or individual is interested in participating in the work of WG-24, they can contact the WG-24 chair or the respective PG-chair. DICOM WG-24 has currently over 100 members from industry, medical practice and academia.

6 DICOM Supplements prepared by WG-24

WG-24 has been strongly involved in the development of DICOM Supplement 132 “Surface Segmentation Storage SOP Class”. It introduces the Surface Segmentation IOD (Information Object Definition) which describes segmented surfaces in patients. The main contribution of this supplement is a module for the representation of surface meshes, i.e. piecewise bilinear approximations of surfaces. There are several use cases for surface meshes in CAS systems which go beyond the representation of segmentation results, as we discussed in [3]. Thus, the surface module which is specified within Supplement 132 was specified in way that facilitates re-use of this module in other IODs developed for other use cases.

The surface module contains mechanisms to describe a set of points P in 3D space, a set of vectors which represent the surface normal in each point, and one or more surfaces in the form of polygonal meshes with the points P as vertices. The surfaces are constructed from surface mesh primitives, such as triangles or planar polygons (facets).

While supplement 132, which was developed under the leadership of Working Group 17 (3D) is not aiming at a surgical use case *per se*, Supplements 131 “Implant Templates” and 134 “Implantation Plan SR Document” focus on a workflow which is definitely related to surgery: preoperative implantation planning.

Originally, implantation planning was performed using 2D drawings of implants printed on translucent slides which were manually overlaid to X-ray images. Such techniques were widely used, e.g. for the preoperative selection of the best-fitting implant for partial or total hip joint replacement. Along with adoption of digital acquisition and display of X-ray images, planning software which uses digital templates instead of the printed drawings emerged. Once detached from the plastic foils, implantation planning systems began to use 3D images and 3D templates where 2D information was insufficient, e.g. in dental surgery.

The availability of digital templates depicting the implant is a prerequisite for an implantation planning software to generate plans which make use of an implant. With no standardized format for digital templates available, the extension of planning software or the communication of plans between different systems is difficult and error-prone. Supplement 131 specifies the generic implant templates IOD which is intended for the description of digital templates. The IOD allows the description of 2D and 3D templates, and includes mechanisms to describe how multi-component implants can be assembled and how anatomical landmarks can be used to find the optimal position of the implants.

Supplement 134 specifies a data structure for the storage and exchange of planning results. The implantation planning SR document is an instance which references all data which was used for or created during the procedure of planning an implantation for one patient. Figure 1 shows the structure of this document. The aim of the implantation plan defined by this Supplement is to provide vendor-independent information about the most important planning steps and results. It is not meant to replace the file handling and storage of a specific planning software since there might be several software and vendor specific information which shall not be stored in a public file format. Supplement 134 is based on the DICOM Structured Report (SR) document which allows to parse a tree-like structure of elements.

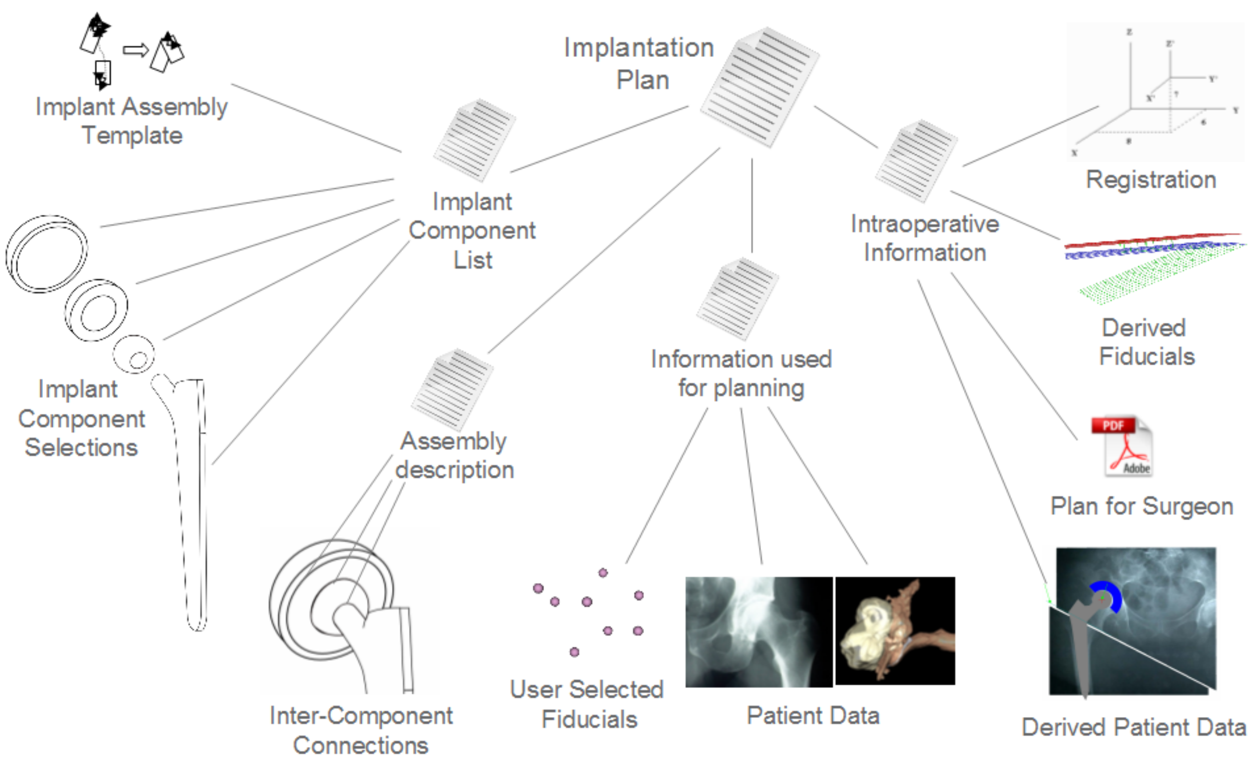

Figure 1 Structure of the Implantation Planning SR Document

7 Future enhancements of DICOM

WG 24 will continue to pursue the standardization of data exchange in computer assisted surgery. Thereby, one task will be to identify the borders of a meaningful extension of DICOM. There will be use cases which technically can not be solved with DICOM (e.g., DICOM is not suitable when it comes to real-time communication). In addition, there might be others which could technically be solved with DICOM but appear not to be in the scope of DICOM since they are covered other standards such as HL7.

The strength of DICOM is its affinity to PACS, which is *the* infrastructure for the exchange and long term archival of images and image-related information. The authors foresee that DICOM will very likely be used to specify data exchange in use-cases where the primary requirements are: preoperative planning of interventions, intraoperative handling of patient models, and postoperative storage of information for surgery reports.

For the near future, WG 24 is planning to address the following subjects:

- Patient Specific Implants: Based on the Information Objects and Services introduced by Supplement 131 and 134, implantation procedures were patient specific implants are planned, crafted and implanted shall be supported. An IOD is required, which combines some of the attributes from the Generic Implant Template IOD from Supp. 131 with the Patient Module, which is used in DICOM to refer an instance to one patient.

- Scanned Surfaces: Supplement 132 covers segmented surfaces, i.e. surface meshes which are created as the boundaries of regions in three-dimensional images. Yet, there are other ways to generate surface-data of patients, like surface scanners which use laser or structured light to acquire surface information. WG-24, jointly with other interested WGs like WG-22 “Dentistry”, is preparing a work item description for the use case of patient surfaces which are acquired by such devices.

- Parameters on Surfaces: An extension of the surface module is planned which allows attaching parameter vectors other than a normal vector to the points of a surface. Use cases for such a data structure are the representation of simulation results and the distribution of measurements which were acquired at different locations on a surface.

- Coordinate Systems: There are several coordinate systems used by different modalities, but no unified and commonly accepted one which shall be used to integrate the different information about the patient. Especially intraoperative images and patient position can not be treated in one coordinate system. The aim of this work is to either propose a mechanism to link the different coordinate systems, e.g. by registrations, or to establish a new world coordinate system which can be used during all stages of therapy as a reference.

8 Conclusion

DICOM has the potential to play a major role as interoperability standard for surgical planning and intraoperative data exchange. It can be enhanced to meet the needs of many Surgical Assist Systems with moderate effort, e.g. it took roughly two years to introduce Surface Meshes. The benefits of a common standard in this field will be manifold: cost reduction, increased patient safety due to clearly defined interfaces, re-use of existing applications or integrated patient data presentation and handling. We strongly encourage the Computer-Assisted-Therapy-Community to participate in the standardization process and to implement the resulting Standard.

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Reference

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