A DICOM-based streaming service for the Digital Operating Room

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Abstract

In the Digital Operating Room there is a need to support data streaming to create advanced integrated surgical assist systems. In this paper we propose a DICOM-based streaming mechanism which leverages the interoperability definitions offered by DICOM to offer a common interface to manage all kinds of streaming data sources, while allowing data and application-specific protocols and infrastructure for the actual data access. We have implemented the proposed solution within the ASTMA project and have shown that thanks to the flexibility in choosing an appropriate streaming protocol we can achieve the necessary streaming quality while transmitting the context information required to create valid DICOM instances. This approach ensures an early integration of streaming data with the rest of the imaging information providing for a simpler data workflow.

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1 Introduction

In surgery, the wish to tackle more complex and information-intensive tasks and to optimally use existing resources demands tighter integration of existing and future surgical assist systems [1]. This integration ultimately creates a distributed surgical assist system whose functionalities are obtained by combining the appropriate components. Such integration represents a departure from the still today common situation of isolated monolithic surgical assist systems, exchanging more-or-less independent and self-contained units of information, which are processed once the complete data set has arrived. The new class of assist system, with distributed functionalities and tighter integration, will require increased continuous data transfer and processing among its components. To handle this type of data transmission, the system will have to support streaming of continuous data.

In [2] a general framework for the integration of data streams into the Digital Operating Room (DOR) has been presented. The approach provides a two-level design in which the management and supervision of the data producing and consuming devices is independent of the actual mechanisms used to transmit that data. This approach allows for the use of infrastructure and transmission mechanisms specially adapted to the specific needs of the streamed data. The applications wishing to use streaming services are offered a consistent high-level interface to set-up and control the streamed data. Figure 1 shows the UML deployment diagram depicting this situation (taken from [2]).

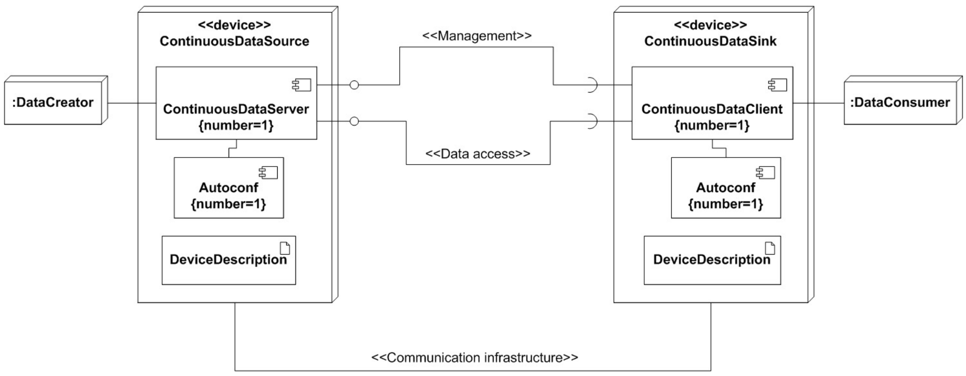

Figure 1 Deployment diagram.

In this paper we present a data streaming solution for the DOR based on the DICOM standard. This solution can be seen as an instance of the general framework presented in [2]. The mechanisms for interoperability offered by DICOM are used to implement the management layer, while appropriate protocols and infrastructure are employed for the data access layer. Already available methods in DICOM allow establishing a reference from the management layer to the specific protocols and infrastructure used for data access. We have implemented this solution in the context of the research project Automated Soft Tissue MAnipulation with mechatronic assistance using endoscopic Doppler guidance (ASTMA).

2 DICOM-based implementation of the general framework

Several technology alternatives are readily available to implement a streaming solution for distributing continuous signals in the DOR. However, in most cases the appropriate technology depends on the nature of the data being transmitted. Implementing such a system within DICOM would provide a common layer for the different technologies. Additionally, we believe that in surgery it would be of advantage to capture the data within DICOM as soon as possible, creating valid DICOM instances, to allow for easier integration of the streaming information with the rest of the imaging data into a richer patient model. Furthermore, keeping the streaming data within DICOM guarantees a smoother data workflow.

An analysis of the DICOM standard shows that it possesses the concepts necessary for implementing the general framework: (1) A client/server architecture (Service Class User/Service Class Provider); (2) A mechanism for querying and modifying capabilities of network peers (N-GET, N-SET) (3) A mechanism for reporting current status and changes (N-EVENT-REPORT) (DICOM standard part 7).

DICOM [3] offers services and objects, which are organized into Service-Object Pairs (SOP), with relationships among them to create a model of the real world corresponding to a specific service. A direct analogy with the existing Print Service Management Class (DICOM Standard part 4) can be established to guide the implementation of a Streaming Management Service Class.

The output of the Print Management Service Class is a Print Job. Such a job is a set of Film Sheets each of them containing zero or more image boxes holding an image and annotations. If we take a film sheet containing many image boxes and order them sequentially, and instead of printing them, we show them on a display one by one at a fixed rate, we will have a video stream. Figure 2 shows this analogy by relating the SOPs of the Print Management Service Class to SOPs of the proposed Stream Management Service Class. The concept of frame can easily be generalized to any kind of data yielding the ability to transmit streams of any kind.

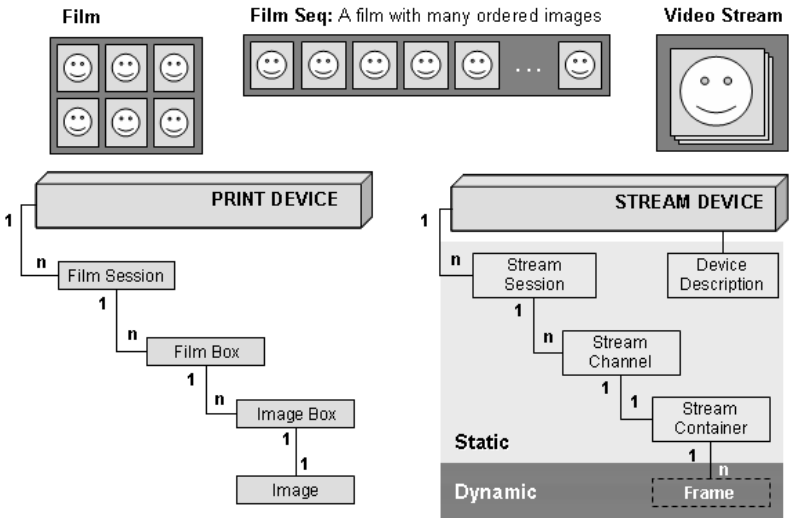

Figure 2 Analogy established between the DICOM print service and the proposed DICOM-based streaming service.

The Stream Device has a Device Description. This description is a snapshot of the hierarchy of objects deployed in the Stream Device (figure 2). One Stream Session holds information common to all Stream Channels it manages, e.g. stream session type, number of stream channels. Each Stream Channel is defined by the network information needed for streaming, e.g. network protocol, routing scheme. One Stream Channel is related to only one Stream Container. The Stream Container's attributes describe how to encode, decode and present each Stream Frame. Finally, the Stream Frame defines the content each transmitted frame should have which basically consists of an acquisition time stamp and the actual data, e.g. frame pixels in the case of video frame.

In general, each transmitted frame is an instance of the stream frame that defines it. It is encoded and decoded according to the attribute values specified in the stream container it belongs to. It is transmitted using the network information of the stream channel its container is related to and according to the specifications of the corresponding stream session.

As it is also shown in figure 2, the Stream Session, Channel and Container, together with the Device Description build the static part of the model of the world: their values do not change during the execution of the application. Moreover the Device Description is sent from the server to the client to expose its streaming capabilities. Additionally, the device description contains the context of the transmitted frames, e.g. equipment information, transformations, annotations as required to create DICOM valid instances. On the other hand, the Frame constitutes the dynamic part of the model of the world: the frame contains the actual data changing continually over time.

The DICOM standard specifies that communication between DICOM Application Entities (AE) should be accomplished via the TCP/IP protocol (DICOM Standard part 8). In our case this is appropriate for the management channel, since the device description and other event notifications will only be exchanged sporadically. For this, we use the offered DICOM Message Service Elements (DIMSE): N-GET, N-SET, N-ACTION and N-EVENT-RPT.

However, for the data access channel, implementing the actual streaming, this protocol is not the best option. The two-layered structure of the general framework (figure 1) allows for using specific protocols, supporting real-time transfer, for the actual data access. The DICOM standard supports such concept since the introduction of supplement 106 [4]. In that supplement a mechanism for streaming very large still pictures was introduced which exploits the concept of indirection: instead of including the real pixel data, the DICOM image contains a reference to the URL where the source of the data can be found. The required data can then be streamed as needed, avoiding the transmission of a very large file. In supplement 106 it is further specified that the protocol to be used for such a streaming transmission is the JPEG 2000 Interactive Protocol.

In our case, we borrowed this idea to specify that the protocol for accessing the real data is user-defined, but must be specified as an attribute of the stream device description, specifically under the Stream Channel structure. This structure also contains an attribute for the location of the data. The client can then obtain the actual data from that source using the specified protocol.

3 The ASTMA project implementation

We have used the introduced DICOM-based streaming solution within the research project Automated Soft Tissue MAnipulation with mechatronic assistance using endoscopic Doppler guidance (ASTMA).

The ASTMA system is a distributed system whose purpose is to semi-autonomously assist the surgeon during the harvesting of the internal thoracic artery (ITA) in coronary artery bypass grafting (CABG) surgery. The mechatronics component, with a combination of ultrasound probe and mono-polar blade electrode as end effector, follows the ITA, guided by intraoperatively obtained ultrasound Doppler images. Ultrasound images and control information are continuously sent over the network to a control station for processing.

Figure 3 shows The ASTMA system with its main components: 1) the control station; 2) the combination of ultrasound probe and mono-polar blade electrode, mounted on a universal medical robot.

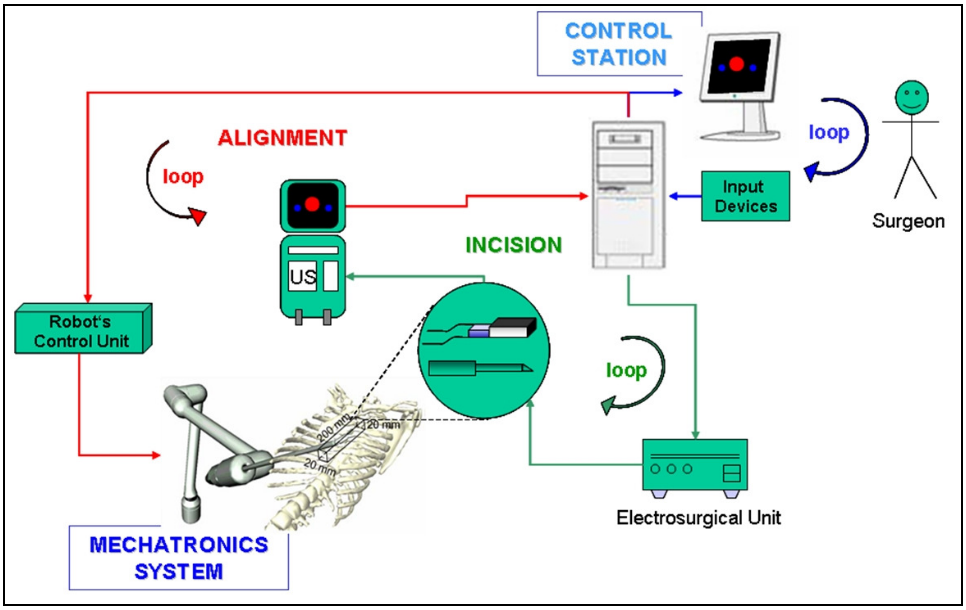

Figure 3 ASTMA system deployment

From the streaming point of view the mechatronics system can be seen as a provider of video and control streams. The control station plays the role of stream consumer; it receives both stream types to combine them in a way that guarantees temporal consistency. Furthermore DICOM secondary capture image and multiframe objects can be stored and retrieved.

The component diagram of the ASTMA system is shown in figure 4. As mentioned before, the StreamServer component is deployed on the mechatronics system, whereas the StreamClient is deployed on the control station. ASTMA implements three main interfaces: Management, Video Access and Control Access. The management interface defines a new DICOM Service Class called “DICOM Stream Management Service Class”. It is responsible of the communication establishment and negotiation between the ASTMA stream user and the ASTMA stream provider as well as of the status reports (it corresponds to the management channel in figure 1). The Video Access interface guarantees the ultrasound Doppler video stream, while the Control Access interface maintains the stream of control frames (they correspond to the data access channel in figure 1). It is worth mentioning that the video data is actually captured via a video converter (Imaging Source converter). Currently, no ultrasound device can provide an image stream with the additional context required. Thus in ASTMA only DICOM secondary captured objects can be created from the video data stream.

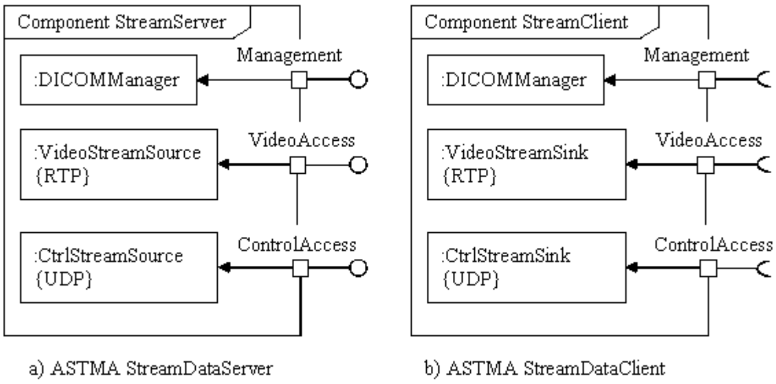

Figure 4 ASTMA system component diagram.

As an example of using the DICOM-based streaming within the ASTMA system, we now discuss in detail the important use case "get video stream": a correctly set-up and functioning process (the primary actor) in the ASTMA control station wishes to obtain the video stream offered by the ASTMA stream provider. Figure 5 shows the UML communication diagram modelling this use case. As a precondition, it is assumed that the client component is aware of the available streaming servers on the network (for this, discovery services such as DICOM-supported DNS Service Discovery could be used).

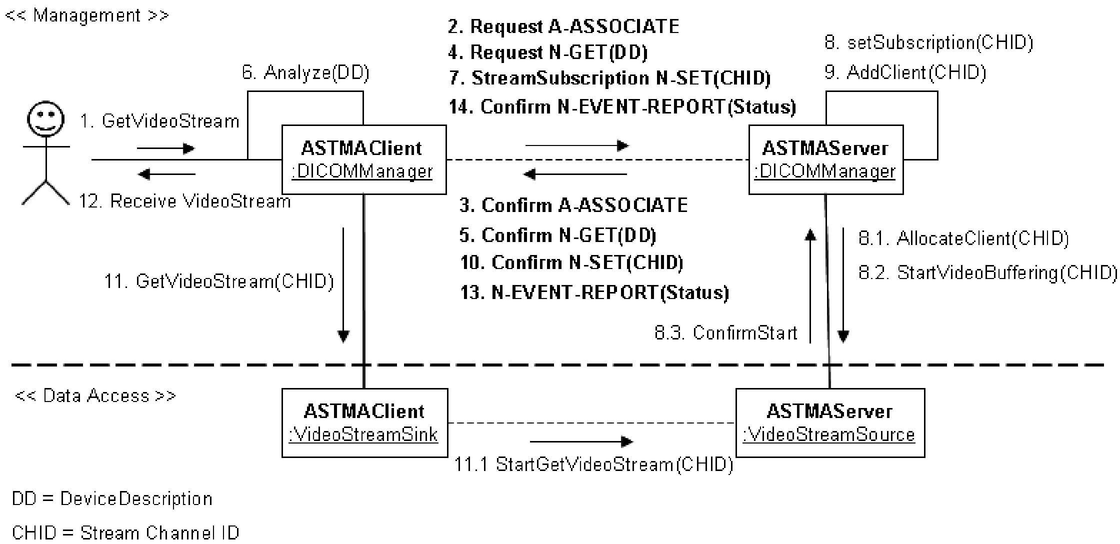

Figure 5 Communication diagram of the ASTMA use case "get video stream data".

The main steps of the use case are steps four and five. In step four, the client requests the device description (DD) of the server using the DIMSE message N-GET(DD). In step five, the server sends back the DD codified as a DICOM dataset. An excerpt of the codified device description is shown in figure 6. Once the DD is received, the ASTMA client process analyzes it (step six), requests a subscription to the video channel (step seven) and starts getting the video frames (step 11) encoded as Video Frame DICOM datasets. The transmission of the actual data frames takes place directly between the VideoStreamSource and the VideoStreamSink over the data access channel.

The analysis of the capabilities of the StreamServer is done on the basis of the obtained device description offered by the mechatronics system. As mentioned before, in the case of the ASTMA project, the server maintains two streams: a video stream and a control stream. Figure 6 shows, for the ASTMA project, the most important attributes contained in the device description. The attribute StreamSessionType determines the type of data contained in the stream (VIDEO or DEVICE_CONTROL). This would be the first attribute checked by the client to decide which stream session to use. Focusing on the video stream and further down in the hierarchy (compare figures 6 and 2), the structure VideoStreamChannel includes details regarding the protocol for data access (StreamProtocol) and the URL of the data source (ProviderURL). The structure SCVideoContainer informs the client of the video format employed (FrameFormat), the encoding (TransferSyntax) and of the resolution (Rows, Columns). Finally, VideoFrame represents the static structure of the transmitted frames, it lets the client know that each frame will contain an acquisition time stamp (AcquisitionDateTime) followed by the actual pixels.

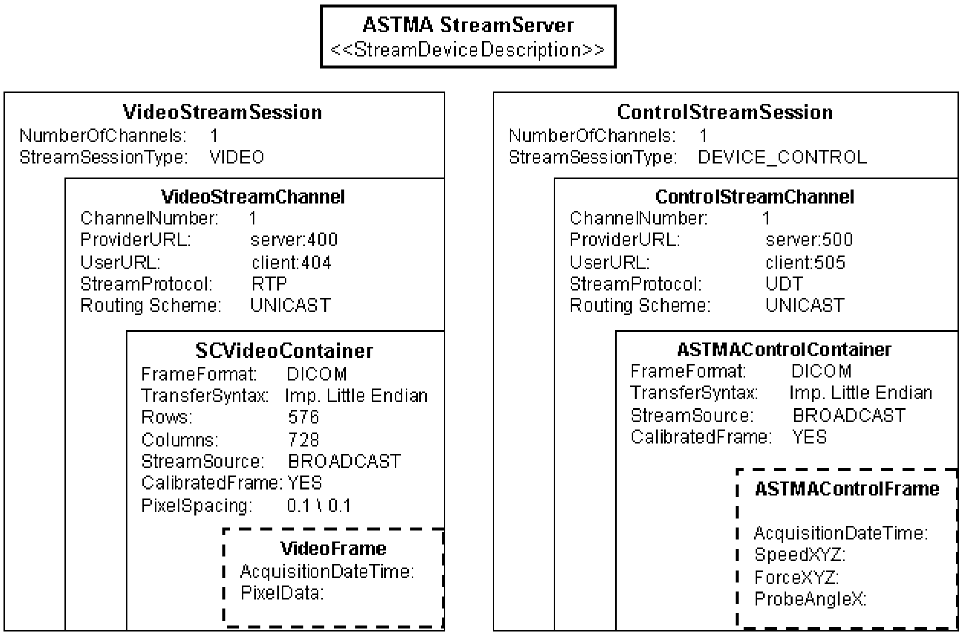

Figure 6 Excerpt of the ASTMA stream server description. Only the most relevant attributes are shown.

Using this proposed scheme we have been able within the ASTMA system to transmit video and control streams with the desired quality to allow for detection (using image processing) and following of the ITA. Additionally, since the required context information is exchanged during the transmission of the device description and is available to the client before the actual data are streamed, we can directly create valid DICOM instances thus simplifying the data workflow and making tighter integration possible.

4 Conclusions

In the Digital Operating Room there is a need to support data streaming to create advanced integrated surgical assist systems. In this paper we propose a DICOM-based streaming mechanism which leverages the interoperability definitions offered by DICOM to offer a common interface to manage all kinds of streaming data sources, while allowing data and application-specific protocols and infrastructure for the actual data access.

We have shown the feasibility of such an approach by implementing this solution on the distributed ASTMA system. The ASTMA system relies on the real-time transmission of video and control streams using RTP [5] and UDT [6] protocols over a conventional Ethernet network. Both streams are managed through the same management channel based on a common device description and on DIMSE messages.

Further work in the ASTMA implementation of the streaming solution will involve having more channels per session, for example offering different video resolutions or different data sampling frequencies, and making the client dynamically change channels during the execution to test the server internal administration of resources.

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