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SoRTS

System of Real-Time Systems

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V0.5	1-12-2016	Final draft to sign off by PMT members
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1 Introduction

This document reports on state-of-the-art of systems-of-systems in general and medical image-guided therapeutic real-time systems-of-systems specifically.

1.1 References

Number	Document ID	Name
1		Building Real-Time Systems of Systems. Wesselius, J. (2015), pp. 2-3 Retrieved from https://www.sigmaxg.com/uploads/2015/01/2015-01-whitepaper-sigmaxg.pdf
2		Architecting Principles for Systems-of-Systems. Maier, M. (1996). Retrieved from http://www.cesames.net/fichier.php?id=252
3		What is a System of Systems and Why Should I Care? Jo Ann Lane, Daniel J. Epstein (2013) Retrieved from: http://csse.usc.edu/TECHRPTS/2013/reports/usc-csse-2013-500.pdf
4		Modeling and simulation of system-of-systems timing constraints with UML-RT and OMNeT++ Michael, J.B. et al. (2004 Proceedings. 15th IEEE International Workshop on Rapid System Prototyping 2004.
5		SoRTS Exploitation plan – D5.10 Benschop, F.J.M. (2015)
6		http://www.viewray.com/system

2 State of the art

2.1 Systems of Systems

Wesselius has written a clear and concise overview of systems-of-systems [1]. Below are two quotes from this paper.

"Several definitions can be found in the literature. These definitions emphasize an important characteristic: systems of systems (SoS) consist of systems that were not initially designed to be part of a SoS. The systems from which the SoS is built serve a stand-alone function and can also be used outside the context of the SoS. By combining the individual systems, the SoS creates added value that the systems cannot offer by themselves."

"Since a SoS is created from stand-alone systems, it has specific characteristics which distinguish it from an ordinary system. Maier [2] gives the following five characteristics of systems of systems:
Operational Independence of the Elements:
If the system-of-systems is disassembled into its component systems the component systems must be able to usefully operate independently. The system-of-systems is composed of systems which are independent and useful in their own right.
Managerial Independence of the Elements:
The component systems not only can operate independently, they do operate independently. The component systems are separately acquired and integrated but maintain a continuing operational existence independent of the system-of-systems.
Evolutionary Development:
The system-of-systems does not appear fully formed. Its development and existence is evolutionary with functions and purposes added, removed, and modified with experience.
Emergent Behavior:
The system performs functions and carries out purposes that do not reside in any component system. These behaviors are emergent properties of the entire system-of-systems and cannot be localized to any component system. The principal purposes of the systems-of-systems are fulfilled by these behaviors.
Geographic Distribution:
The geographic extent of the component systems is large. Large is a nebulous and relative concept as communication capabilities increase, but at a minimum it means that the components can readily exchange only information and not substantial quantities of mass or energy."

Another good overview of SoS can be found in "What is a System of Systems and Why Should I Care?" [3]. Systems of systems are abundant. Especially in the field of defense/military systems but also in the field of healthcare:

“Enterprise-wide SoS: Most business enterprises contain one or more SoSs. For example, most businesses have integrated many of their back office systems such as employee systems, payroll systems, and accounting systems. In addition, they may also have an integrated set of customer-facing systems such as order-entry, pricing systems, billing, service monitoring, inventory management, and customer help. These types of SoS tend to be relatively static in that the systems are typically always connected and interoperating with each other to support the organization’s key business functions. An example of a customer-facing SoS is a healthcare SoS that integrates many of the patient care systems.”

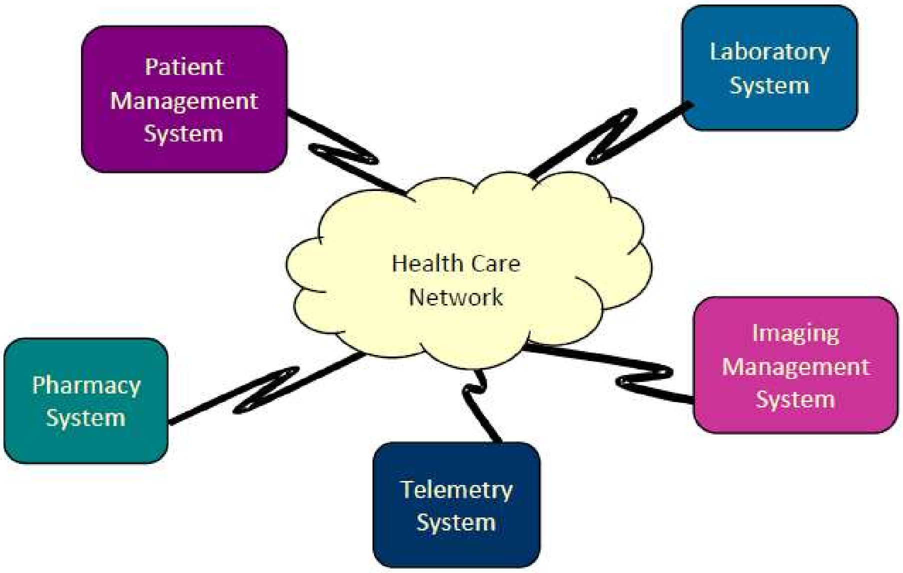

Figure 1. Example from Healthcare of an Enterprise System-of-systems. [3]

A recent trend has been the Internet of Things. At the start of SoRTS this was in its infancy, and not generally known. Today it has already penetrated many homes for example in the form of Nest thermostats and smoke detectors, or Philips Hue lighting and motion detection. Typical Home IoT systems support hundreds of “things” from multiple vendors, using various communication standards and formats. This way true Systems of Systems are formed. Today, the IoT-world drives the way we think of how to interface different systems. Once the communication and connectivity technology has been established many devices can be connected. Eventually the platform is just a given property, and users do not care anymore how it works, or where it is deployed. Here we see a clear link with Cloud applications. In this context the cloud basically means that it does not matter at which location the servers reside, as long as the services are provided at the location they are needed.

In conclusion, today we see a rapid fusion of concepts like Systems-of-Systems, Internet-of-Things and Clouds.

2.2 Real-time systems

A real-time system can been described as one which "controls an environment by receiving data, processing them, and returning the results sufficiently quickly to affect the environment at that time." Systems used for many mission critical applications must be real-time, such as for control of fly-by-wire aircraft, or anti-lock brakes on a vehicle, which must produce maximum deceleration but intermittently stop braking to prevent skidding. Real-time processing fails if not completed within a specified deadline relative to an event; deadlines must always be met, regardless of system load.

Obviously real-time does not mean real-fast as such. Usually speed is a wanted property, but more important is that the system delivers in a predictable manner. Real-time systems, as well as their deadlines, are commonly classified by the consequence of missing a deadline:

- Hard – missing a deadline is a total system failure.
- Firm – infrequent deadline misses are tolerable, but may degrade the system's quality of service. The usefulness of a result is zero after its deadline.
- Soft – the usefulness of a result degrades after its deadline, thereby degrading the system's quality of service.

2.3 Real-time system-of-systems

As both real-time systems and systems-of-systems are common in daily life, as well as in the medical device domain, the combination of the two is a different story. A literature search on real-time system-of-systems indicates that these are virtually no-existent today. No specific examples came up in the search. What can be found is publications around the real-time extensions of UML. The articles have modeling of real-time systems-of-systems as subject. See for example [4].

Actually this is not surprising. As discussed above, systems in a SoS are developed as stand-alone systems. In their design process it was not decided upfront that there should be real-time capabilities in interacting with the outside world. On the other hand, real-time systems are always developed around the real-time requirements. So making a RT-SoS out of a set of systems is a challenge. A challenge that has been picked-up by the SoRTS consortium.

2.4 Real-time System-of-systems in Healthcare

Just like in the Internet-of-things world, also in the healthcare domain various systems are combined to compose an integrated function. For example in the operating theater or cath labs, many instruments may be connected to facilitate workflow automation.

Imaging equipment is used during a procedure in an operating theater/cath lab (X-Ray, ultrasound, endoscopes etc.). Combining live image streams from the imaging equipment creates powerful new tools. In some cases, the systems need to exchange raw images (for instance directly from the X-ray detector); in other cases, the processed images need to be exchanged. What is needed is flexibility to select the data and to distribute it from the imaging equipment to other equipment in the SoS.

A characteristic of these systems is that those are soft real-time systems. In displaying a video stream of the procedure being performed, for example placing a stent, low-latencies are required, but a certain amount of jitter is acceptable. In the extreme case of a hick-up of one second, the cardiologist can hold the tube position for a short moment. In the dose-delivery domain the real-time requirements can be more stringent. When gating dose delivery based on organ position, a one-second hick-up can lead to unintended tissue damage.

2.5 Real-time System-of-systems in Therapy

In the image-guided therapeutic market we are not aware of real-time systems-of-systems. As described in the Exploitation plan (D5.10)[5] of the SoRTS project, there is one competitor offering similar products (ViewRay [6]). No information is available on the real-time aspects of the ViewRay system.

The SoRTS project has been working on the real-time capabilities of diagnostic MRI equipment and various therapeutic devices. It has resulted in a low-latency platform of data and image exchange between the various systems in the system-of-systems. In a therapeutic RT-SoS it is difficult to give safety guarantees. SoRTS taught us that by time-stamping the images and other data objects, the systems within the SoS are enabled to make their own decisions to determine whether their operation is still within the safety limits. In this way the safety risk related to (soft) real-time communication between the systems is addressed. The catch-all safety mechanism of system-wide time-stamping of images and data is used in therapy dose control, motion detection and in the near future organ-tracking. The demonstrators from SoRTS are examples of real time systems of systems.

Trends in Imaging systems

The SoRTS project focused on Magnetic Resonance Imaging. Since the start of the project the most notable developments in MRI, both at SoRTS partner Philips and at the competition is a further development towards robustness of imaging and ease of use. A major SoRTS contribution in robust imaging is for example the mDIXON-XD technology, resulting in a good separation of water and fat images in even the most difficult anatomies and also close to the edges of the homogeneous magnetic field. A new trend is that advanced reconstruction techniques are shifting focus away from pulse sequence domain to reconstruction and image processing domain. Examples are: Iterative reconstructions, the mDIXON reconstruction, and in the near future developments like Spiral imaging They will have a high contribution to innovations in image quality, speed and diagnostic value.

Trends in Therapy systems

In the past three years one of Elekta's Linac competitors, Viewray, has started the clinical implementation of their low field MR cobalt based guided RT [6]. Although this create challenges to the high field MR Linac it also shows that this combination is feasible, safe, valid and can provide a lot of benefits to cancer patients. In general the role of MRI in RT has also increased a lot as well as the research on usage of MR only treatment planning workflow. Philips has recently obtained FDA clearance for use of MR-only MRCAT for prostate cancer therapy planning. This represents the first FDA approved MR only treatment planning workflow with other companies following suit. Other anatomies such as brain and head and neck are active research topics for several research groups. Other area of interest include contouring guidelines (as the heterogeneity in contour delineation by a physician is still the biggest source of error in RT treatments), deformable image registration tools including dose accumulation and treatment planning workflow automation. Last but not least, analysis of "big data" and registry programs and their implementation complexity are also an important topic of discussion.