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PACS IN HEALTHCARE FACILITIES

Class Content Material

This document is part of a training materials collection developed within the Erasmus+ project “Smart healthcare engineering”, SHEng, project No. 2023-1-RO01-KA220-HED-000159985.

The collection is intended for engineering students and professionals working in the healthcare sector. It covers technical subjects relevant to hospital infrastructure, equipment, materials and support services, helping readers understand how engineering contributes to safe patient care and the reliable operation of healthcare facilities.

These materials support classroom teaching and independent study. They should be used alongside the project handbook and the presentations, courses and other learning resources available on the project website. Each document addresses a specific subject, while the collection provides a broader understanding of the responsibilities and practical challenges of healthcare engineering.

The content is educational. Its application in practice requires consideration of the conditions of each healthcare facility, the applicable standards and the instructions provided by equipment manufacturers.

Project website: www.smarthealtheng.com

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PACS IN HEALTHCARE FACILITIES

Picture archiving and communication systems: architecture, standards and operation

Introduction

A picture archiving and communication system (PACS) stores, transmits, retrieves and displays medical images. In a hospital it connects scanners, archives, reporting workstations, clinical viewers and the information systems that hold patient and order data. These parts have different demands. A scanner needs reliable image transmission, a reporting workstation needs a display that shows the image faithfully and an archive needs capacity, integrity and a plan for failure. **Treating a PACS as a single product that is bought and installed once is rarely justified.**

1. System fundamentals

What a PACS is

A PACS replaced the film library with a digital chain. Images are acquired by a modality, checked, sent to a server, stored and then displayed wherever they are authorised to be viewed. Typical benefits are simultaneous access, comparison with prior examinations and remote reporting. These benefits concern access and logistics. A PACS does not improve diagnostic quality by itself, because image quality still depends on acquisition, display and the reader.

The main components are shown in fig.1. Modalities create the images, an acquisition gateway or quality control step releases them, the PACS server and database keep the index of patients, studies and series, and one or more archives hold the pixel data. Viewers and integration interfaces complete the system. A weakness in any part can appear to the user as a problem of the whole PACS.

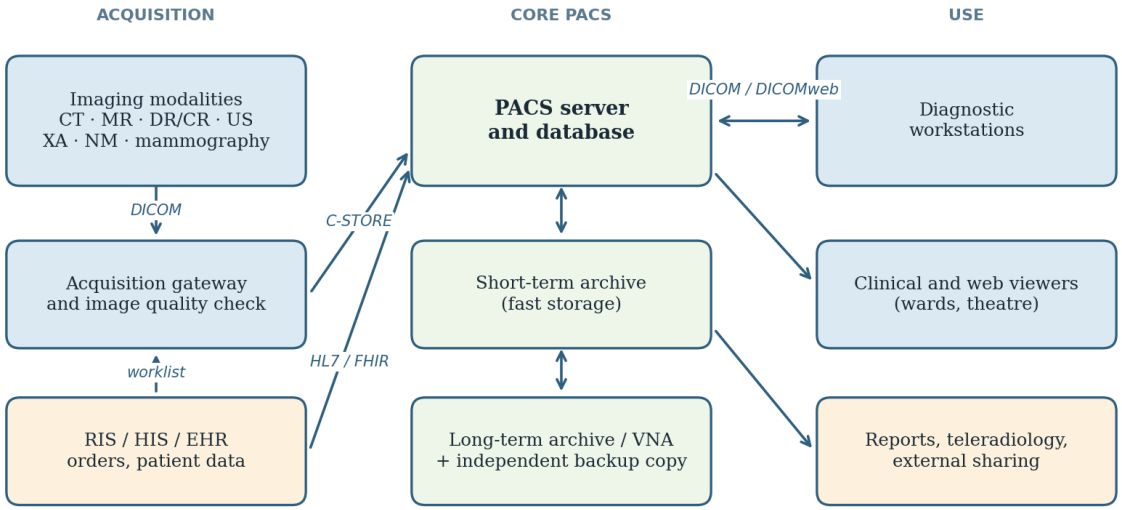

Figure 1. Main components and data flows of a PACS

Terms that should not be confused

Table 1. Terms used around PACS

Term	Meaning	Hospital example
PACS	System that stores, manages and distributes images	Server, archive and viewers used by the radiology department.
RIS	Radiology information system for orders, scheduling and reports	A request created by a ward appears on the CT worklist.
HIS / EHR	Hospital record of patients, admissions and clinical data	Source of the patient identity and demographics.
DICOM	Standard for image objects and image communication	Defines how a scanner sends a series to the archive.
VNA	Vendor neutral archive that stores images in standard form	Shared archive for several departments or sites.
Viewer	Software that displays images	A web viewer on a ward may not be suitable for reporting.

A viewer opens images, while a PACS manages them over time and controls who may see them. The word PACS is also used loosely for the whole imaging IT environment, so a contract should state which components are included.

2. DICOM and integration standards

How DICOM organises images

DICOM is both a file format and a network protocol. A DICOM object contains pixel data and a header with attributes describing the patient, the study, the equipment and the acquisition. Objects are organised as patient, study, series and instance, and each study, series and instance carry a unique identifier. An error in the header therefore travels with the image [1].

Table 2. DICOM services commonly met in hospitals

Service	Purpose	Typical use
Storage (C-STORE)	Sends an image object to another device	Scanner sends a series to the PACS server.
Query and retrieve	Searches for studies and retrieves them	A workstation fetches a prior examination.
Modality worklist	Gives the scanner the scheduled patient data	The operator selects a patient instead of typing.
Storage commitment	Confirms that the archive has taken responsibility	The scanner may then delete its local copy.
DICOMweb	Web based storage, query and retrieval	Browser viewers and cloud services.

Support for DICOM does not guarantee that two products will exchange every object. Each product publishes a conformance statement listing the object types, transfer syntaxes and roles it supports. Enhanced multi-frame CT or MR, structured reports and tomosynthesis are examples where a mismatch can occur. The statements should be compared before purchase and confirmed with real data from the actual scanners.

Communication with clinical information systems

Patient and order data normally reach the imaging system through HL7 messages. HL7 version 2 is still widespread for admission, order and result messages, and HL7 FHIR is increasingly used for newer interfaces and for imaging study references [3]. Integration profiles from IHE describe how these standards should be combined for a given workflow, for example scheduled workflow inside a hospital or document sharing between organisations [2]. A profile reduces ambiguity but must still be tested in each installation.

Patient identification deserves particular attention. The patient identifier, accession number and study identifier have different roles and are not interchangeable. Unidentified emergency patients are a known risk because temporary identities are later merged with permanent records, and the merge must update the images, not only the patient record.

3. Architecture, storage and data lifecycle

Architecture models

Table 3. Architecture models for image management

Model	Main feature	Selection point
Departmental PACS	Separate system for one department	Simple to run, but images may be isolated from other users.
Enterprise PACS	One system for several departments	Common viewing and shared priors across the hospital.
Vendor neutral archive	Archive separated from the viewing application	Eases replacement of viewers and migration between vendors.
Cloud or hybrid	Storage or services hosted outside the hospital	Useful for scaling and disaster recovery if governance is clear.

No model removes the need for governance. When images are hosted in a cloud service, the healthcare provider remains responsible for lawful processing, access control and retention. Data location, the cost of retrieving large volumes and the procedure for leaving the provider should be defined in the contract.

Image size and capacity

Study sizes differ widely. A digital radiograph is usually measured in tens of megabytes at most, a thin slice CT or MR examination may reach hundreds of megabytes or more than a gigabyte, and tomosynthesis or multi-frame studies can be larger still. Capacity planning should start from studies per modality, average size, expected growth and the retention period. For example, 100,000 studies per year at an average of 150 MB give about 15 TB of new data per year before any second copy is counted.

Capacity and throughput also use different units. Storage is expressed in bytes (MB, TB), while network links are expressed in bits per second (Mbit/s, Gbit/s). A 1 Gbit/s link cannot move more

than about 125 MB each second even under ideal conditions, so a link speed alone does not tell how quickly a large study will open.

Compression

Lossless compression allows the original pixel values to be recovered exactly, although the gain is usually modest. Lossy compression achieves higher ratios but discards information permanently, and its acceptable use depends on the modality, the clinical task and national professional guidance. A lossy copy should not silently replace the original diagnostic image.

Backup, archive and continuity

A backup is not an archive. An archive keeps images available for clinical use over their retention period, while a backup is an independent copy for recovery. Replication between two servers may copy a deletion or an encrypted file to the second server as well, so at least one copy should be independent, preferably off site and protected against modification. Recovery point and recovery time objectives should be agreed with the clinical departments, and restoration should be tested, not assumed. Retention periods are set by national law.

4. Image display and reporting environment

Diagnostic displays

A reporting workstation must reproduce the grey scale in a consistent way. Diagnostic displays are normally calibrated to the DICOM grayscale standard display function so that equal steps in pixel value give perceptually similar steps in brightness [1]. Resolution, maximum luminance, uniformity and ambient light all affect what the reader can see. Mammography generally calls for displays of higher resolution than general radiography. An office monitor or a tablet is not a substitute for a calibrated display in primary interpretation, even when the software on it is identical.

Viewer functions and their risks

Windowing, measurement and hanging protocols save time but depend on correct metadata. A distance measurement is valid only if the pixel spacing in the header is correct, and a projection radiograph shows magnification unless the system is calibrated. Laterality, orientation and the choice of prior studies should be checked by the user.

5. Clinical workflow and quality control

A typical examination follows an order, scheduling, selection of the patient from the worklist, acquisition, technical check, transfer to the PACS, retrieval of priors, reporting and distribution of the result. Errors enter mainly where data are typed by hand or where a step is bypassed to save time. Using the modality worklist reduces transcription errors, although it does not remove the need to confirm the identity of the patient at the scanner.

Table 4. What an observed problem may mean

Observation	Possible explanation	What to check
Study under the wrong patient	Identity entered by hand or incorrect merge	Worklist use, accession number and audit trail.
Images missing at the workstation	Routing rule or failed transfer	Modality send log, PACS receive queue and storage commitment.
Empty worklist at the scanner	Interface down or wrong device name	HL7 channel status, network address and device settings.
Large CT opens slowly	Bandwidth, server load or retrieval from slow storage	Network path, prefetch rules and storage tier.
Image appears darker than expected	Display calibration or presentation settings	Calibration record, viewer presets and ambient light.

Do not correct the record before documenting it. Note the original values, the examination and the time of discovery. A change to patient data or images must follow an authorised procedure that preserves the audit trail, and an error that reached a report should be handled as a patient safety incident. A PACS does not communicate urgent findings by itself, so the escalation route must be defined separately.

6. Applications in healthcare facilities

Radiology and other departments

Radiology is the main user and drives most performance requirements, because CT, MR and mammography produce large studies that must open quickly and be compared with priors. Echocardiography, catheterisation and vascular ultrasound often produce cine loops and measurements that rely on specific DICOM objects. Ophthalmology, endoscopy and dental imaging may run on separate systems. Radiotherapy uses additional objects for plans and

structures. Digital pathology slides are extremely large and usually need dedicated storage and viewers, so including them in an existing PACS should not be assumed.

Wards, theatre and sharing between sites

Clinicians outside radiology need fast and simple access, often through a web viewer, and in an operating theatre the display location can matter as much as the software.

Remote reporting and transfer between hospitals depend on secure transmission, agreed identity matching and clear responsibility for the report. Cross-organisation sharing can use IHE document sharing profiles or national platforms [2]. Portable media such as discs remain in use, but importing them needs malware checks and identity verification.

Algorithms for triage, detection or measurement are increasingly connected to the PACS. A tool must be validated for the local equipment and population, and its output should be identifiable as machine generated. A flag in the worklist does not replace the report by a qualified reader.

7. Security, privacy and regulation

Medical images contain personal data in the header and sometimes in the pixels, for example burned-in names on an ultrasound frame. Security should therefore be planned as part of the design. Table 5 lists common measures and their limits.

Table 5. Common security measures and their limits

Measure	Purpose	Limitation
Role-based access	Restrict viewing and editing to authorised users	Roles need regular review when staff change.
Audit trail	Record who accessed or changed a study	Useful only if the logs are reviewed and protected.
Encryption	Protect data in transit and in storage	Does not stop misuse by an authorised account.
Network segmentation	Limit the spread of an incident	Legacy modalities may still need controlled access.
Patching and monitoring	Reduce known vulnerabilities	Some medical devices cannot be updated without the manufacturer.

Older modalities that run unsupported operating systems are a frequent difficulty. If they cannot be patched, compensating controls such as isolation and restricted communication should be agreed

with the manufacturer and recorded in a risk management process, for instance one based on IEC 80001-1 [6].

Software that is intended for diagnosis is generally regulated as a medical device, for example under the EU Medical Device Regulation [5]. The intended purpose stated by the manufacturer matters. Using a product outside this purpose or combining components in a way the manufacturer did not foresee, can change the responsibility of the hospital. Personal data protection rules such as the GDPR also apply to images, including lawful basis, minimisation and retention [4].

De-identification for research or teaching needs more than removal of the name from the header. Burned-in text, dates and free-text fields may remain, and head CT or MR data can allow the reconstruction of a recognisable face. DICOM defines confidentiality profiles, but the output must still be checked [1].

8. Implementation, maintenance and continuity

Specification and acceptance

A specification should describe functions, interfaces, performance and service levels, not only a product name. Requirements should come from radiographers, radiologists, referring clinicians, IT and information security staff. Acceptance testing should use real images and real workflows, and it should include failure cases as well as normal operation. Evidence from each stage, such as conformance statements, test records, migration counts and training records, should be kept for later audit and troubleshooting.

Migration and continuity

Migration from an old archive should preserve the unique identifiers and map patient and accession data in a controlled way. Counts of studies, series and images should be compared before and after, with a sample reviewed visually, and the old archive should not be decommissioned until the results are verified. Downtime procedures must also be planned. They should cover local storage on the modalities, emergency access to images, the order in which services are restored and the way that studies acquired during the outage are reconciled.

Routine tasks include monitoring of failed transfers, storage growth, certificate expiry and the clocks of all devices, since wrong timestamps can place images in the wrong order. Critical

workflows should be retested after each update, and the service agreement must state who is responsible for the interfaces between products of different suppliers.

References and standards

[1] NEMA. Digital Imaging and Communications in Medicine (DICOM) Standard, PS3 (also published as ISO 12052). Includes PS3.14 (grayscale display), PS3.15 (security profiles) and PS3.18 (web services).

[2] IHE International. IHE Radiology Technical Framework, including Scheduled Workflow and cross-enterprise document sharing for imaging (XDS-I.b).

[3] HL7 International. HL7 Version 2 messaging standard and HL7 FHIR (including the Imaging Study resource).

[4] Regulation (EU) 2016/679 (General Data Protection Regulation).

[5] Regulation (EU) 2017/745 on medical devices.

[6] IEC 80001-1. Application of risk management for IT-networks incorporating medical devices.

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