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The Efficient and Secure Digital Management System for Radiologists

Maksim IAVICH [a,1], Lasha SHARVADZE [b]
[a] *Caucasus University, 1 Paata Saakadze St, Tbilisi 0102, Georgia*
[b] *Georgian Technical University, 68, Merab Kostava St, Tbilisi, 0108, Georgia*
ORCiD ID: Maksim IAVICH https://orcid.org/0000-0002-3109-7971

Abstract: This article describes the authors' research on a unified digital management system for the clinic. The system is focused on the use of radiologists and medical imaging. The goal of the research is to develop a unified, secure, and efficient management system for the clinic. The system uses a single-window principle, fully integrates all clinic management systems into one environment, and fully digitizes them. Due to the scattered processes across different areas, the current clinical management systems do not have all the necessary structures, processes, data, and systems integrated into a single electronic environment. This article describes one of the medical visualization modules of the new research-based medical facility management software, which will be integrated into a unified hospital management system. The system has a Web-based interface and is compatible with a variety of mobile devices. The system provides security features such as password policies and user role management. The system works in a secure network environment. Experiments conducted in a test environment have revealed that the new system improves the efficiency of delivering medical services and reduces the time needed to deliver a medical service. The significance lies in the potential to transform clinic management, optimize clinical processes, and ultimately enhance the quality of patient care. The findings have relevance not only for the medical community but also for technology developers and policymakers aiming to advance healthcare systems.

Keywords. PACS, security, radiologists, digital.

1. Introduction

PACS (Picture Archiving and Communication Systems) is a system used to connect servers, computers, and medical devices for storing, retrieving, using, and managing medical radiology images. PACS systems handle images in a variety of formats. The most common format for digital images and communication in PACS systems is (DICOM) [1-4].

PACS (Picture Archiving and Communication Systems) is a medical imaging technology used mainly in healthcare organizations for the secure storage and use of electronic images and clinically important information by the medical personnel [5-7]. Using PACS eliminates the need to manually store, retrieve and send sensitive medical information, images and records. Instead, medical records and images can be securely stored on the clinic's servers and accessed/used through encrypted channels from

[1] Corresponding Author: Maksim IAVICH, E-mail: miavich@cu.edu.ge.

anywhere in the world using various communication devices (computer, tablet, cell phone, etc.). Medical image storage technologies such as PACS are becoming increasingly important and necessary as the volume of digital medical images increases in the healthcare industry and the analysis of these image data becomes more and more common. The use of such systems by radiologists has shown us its advantage, need and necessity, and under this system, various areas of medicine using visualized data such as computed tomography, magnetic resonance tomography, X-ray, ultrasound, nuclear medicine, cardiology, pathology, radiation, oncology, dermatology, endoscopy, bronchoscopy, gynecology, plastic surgery - have all been integrated into this system.

Medical images are captured and used for clinical analysis, diagnosis and treatment as part of the patient's care plan [8, 9]. The information collected can be used to identify any anatomical and physiological pathology, evaluate treatment progress, and maintain a database of patient images.

PACS systems consist of four main components:

1. Image processing devices;
2. A secure network environment to share patient images and data;
3. A workstation, computer or mobile device for viewing, processing and interpreting images;
4. Electronic archive for storage and future use of images and related documentation.

PACS imaging information systems have replaced the need to store and manage printed materials and media in desks and rooms. Instead, medical images, medical records, and other clinical data can be securely stored digitally on-site or on the cloud server.

Vendors often use a hybrid cloud system in which master images are stored locally and backups are stored in the cloud. Additional types of storage architecture and security, such as direct-attached storage (DAS), network attached storage (NAS) or storage area network (SAN), can be configured and connected to a PACS server, each providing updates and connectivity, enhancements and additional security. Imagine you have been injured and need to go to hospital. When you arrive at the hospital, you will be checked in based on your personal information survey, and this information will be entered into the hospital information system. After a short wait, you are seen by a doctor for a consultation. The doctor will examine you and prescribe a series of tests to assess your health, including X-rays and blood tests. This information is also included in the HIS (Hospital Information System). This information is now needed by other medical personnel in their computer system to continue the process of diagnosing and treating your illness. The communication language for clinical, laboratory, and radiology devices in clinical management systems is the HL7 (Health Level 7) protocol [10,11].

HL7 is a set of standards for sharing clinical and administrative data between hospital information systems. It is like a language that describes you and your medical information across all the hospital information systems, and what is most important is that all systems speak the same language. Thus, as an HL7 message is received by another computer system, it can be processed and used by the medical staff.

The HL7 message has the following structure:

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MSH|^~\&|HL7Soup|HIS|HL7Soup|HIS|201407271408||ADT^A04|1817457|D|2.5.1|E
VN|A04|AL
PID||0493575^^^2^ID1|454721||DOE^JOHN^^^^|DOE^JOHN^^^^|19480203|M||B|25
4E238ST^^Howick^OH^3252^USA||
(216)631-4359|||M|AGN|400003403~1129086|999-|
```

NK1||CONROY^MARI^^^^|SPO||(216)731-4359||EC||||||||||||||||||||||||
PV1||O|O/R|||277^ALLEN^BONNIE^J^^^|||||||||
||2688684||||||||||||||||||||||201407271408|||||002376853

The workflow in PACS systems is as follows:

A patient registers in the system with his/her personal information, for an examination by a certain physician. The physician/assistant then begins examining the patient. During the examination, he/she monitors the patient and the imaging process in the program and, if necessary, adds additional programs to the examination (examinations consist of programs) or relaunches certain programs. After the examination, the doctor performs a detailed examination of each medical image, determines the size and structure of organs and abnormalities, marks/measures problem areas and clinical significance, marks/measures problem areas and their clinical significance, and determines the anatomy of the organs to examine. He/she then writes the conclusion in the program and completes the examination. If the system is connected to a CD recorder and medical tape printer, the system automatically sends the examination to an external storage device (CD-ROM) for recording and printing on a tape.

This research endeavors to achieve several critical objectives:

- Unified PACS System: Develop a unified Picture Archiving and Communication System (PACS) to efficiently manage medical radiology images, with a focus on the DICOM format.
- Medical Imaging Management: Provide healthcare organizations with a secure, comprehensive system for electronic image and data storage and access.
- Global Accessibility: Enable secure global access to medical records and images from various devices.
- Integration Across Specialties: Create a unified platform for diverse medical fields, including radiology, cardiology, and pathology.
- Workflow Optimization: Streamline healthcare processes by centralizing records and images, enhancing patient care efficiency.

Existing solutions are often fragmented and manual, but the proposed system aims to bridge these gaps, although specific limitations are not detailed in the introduction. The author's aspiration is to offer a practical, efficient solution that streamlines healthcare management, benefiting medical professionals and patients alike.

2. Literature Review

The literature surrounding medical image management, radiology, and the integration of technology in healthcare presents a diverse landscape of research and innovations. J. Randolph et al. introduce a Blockchain-based Medical Image Sharing framework that automates critical-results notification through blockchain technology, promising advancements in secure data sharing and patient care. B. P. Tinashe, C. Wu, and R. Zhou discuss the transformative potential of AI in radiology, particularly in image diagnosis within healthcare, highlighting the AI Transformation in Radiology [11-13].

A. Haddad et al. conduct a systematic review on AI and blockchain-based e-healthcare records management systems, providing insights into the development of secure and efficient healthcare data systems [14]. I. E. Ivanov and B. Ivanov propose a

Unified National Digital Framework for Medical Image Information, offering a blueprint for improving the accessibility and standardization of medical images [15].

K. Loizidou, G. Skouroumouni, C. Nikolaou, and C. Pitris explore automated breast mass segmentation and classification, advancing image processing techniques for breast cancer diagnosis [16]. E. O. Zulu and L. Phiri delve into the challenges and opportunities associated with Enterprise Medical Imaging in the Global South, shedding light on healthcare scenarios and technology integration challenges in these regions [17]. Collectively, these sources provide a comprehensive view of ongoing developments in medical image management, AI and blockchain integration, and the challenges and opportunities in healthcare imaging, both in developed and developing regions.

3. Current Issues

PACS systems are presented as standalone software rather than part of an overall clinic management system. This makes it difficult to access some of the most essential patient information, because physicians have to work in multiple programs and it is difficult to see the picture in a single view[18-20]. Transferring this information to other related systems and reporting are also complicated.

To solve this problem, PACS system manufacturers offer integration with existing clinic management systems, but all common integrations are incomplete and once integrated, the patient's DICOM data can be viewed only if the software transfers them into the PACS system (the data link is integrated, not the data itself) and the medical recording option is also very limited. It also fails to provide complete reporting and history. Mostly the personal data of the patient and the study being performed are integrated, but not the link to the location of the imaging itself.

Medical imaging is one of the most essential and often the only source of information for patient diagnosis and treatment planning/course. This information is used by virtually all physicians, surgeons, and other medical personnel [21-22].

4. Market Study

We have reviewed and studied the PACS systems of the key vendors. All systems are tailored to the workflow of radiologists and diagnosticians, are difficult for other clinicians to access, and even after integration with a unified clinic management system, cannot provide a complete unified picture in one window.

We studied the current situation of clinics in the area of medical image scanning systems and the results, unfortunately, are very poor. We surveyed 50 large clinics and found that only 7 of them have comprehensive medical image and data storage systems (PACS). In other cases, the data are recorded on electronic media (CD, USB, cassette) and given to the patient. If the electronic medium is damaged or lost, the results of the study are also lost. These data are also difficult to use as a single presentation of the patient's medical history for use by physicians or other medical personnel. This type of information also does not make its way into electronic clinic management system reports and distorts statistical data. See table 1.

Table 1. Clinics' data

Number of clinics	Equipped with PACS system	Not equipped with PACS system
50	7	43

PACS systems are quite expensive to maintain. After all, the size of medical images in many cases is quite large and can be several gigabytes. It needs powerful processors, a lot of RAM, even more hard drives, and a well-protected and fast network environment for stable operation. Server and network infrastructure is necessary for the proper and fast operation of these systems. Often, all medical devices and PACS servers are on a confined network to prevent overloading the network with additional traffic, data loss or system slowdowns.

Our research has shown that only few clinics in countries other than Georgia have introduced PACS systems because they are quite expensive to maintain. These systems are most developed and implemented in many clinics in America, Germany, and Turkey, where PACS systems are being actively developed and optimized. One of the biggest challenges in this area is the size of the medical examinations. Although the DICOM format allows for compression and reduction of image file size without compromising quality, the study size remains quite large. Because of the large size, it is difficult and expensive to maintain them.

Studies have been conducted with radiologists, clinicians, surgeons and other medical personnel who need access to patient data in PACS to treat patients or diagnose diseases. The study considered the need for the PACS system in their workflow and the ease of interacting with the program. All interviewees reported a need for such a system in their workflow. Most medical staff (radiology physicians and junior radiology personnel) working directly in the medical imaging, noted that the software is quite user-friendly and easy to use. And the remaining majority stated that it is not so easy to work with this software.

5. Suggested Methodology

Based on these studies, we determined that there is a need for a PACS system that connects easily to the clinic management system and completely shares data, with medical images flowing into the patient history for complete and convenient management. The HL7 protocols and DICOM reader need to be integrated into a single clinical management system so that the system can process these types of messages independently and have its own complete database of these data. With this method, all medical personnel will have access to medical images in their unified system as part of the patient's medical history, and they will be easy to view and use chronologically.

Our goal is to create a medical imaging module that will capture all the necessary information from the image, such as: the examined organ, the area, the deviation, the dimensions, etc. This information in the image format will be automatically inserted by the system into the relevant place in the patient's medical history.

Our goal is to create a PACS system according to the specified model, which will be as affordable and accessible as possible for the health sector. We have started to work on its implementation and real-world implementation and expect the first results in the near future.

Proper integration of the PACS system into a unified clinical management system will also create more opportunities for the use of artificial intelligence in medicine. The future of radiology will make extensive use of artificial intelligence, which will help the radiologist to analyze each pixel in detail and identify abnormalities. It should be noted that creating a suitable database for AI is possible with the cooperation of clinicians and other allied health professionals, who must be involved in the machine learning process.

The AI tool must be well-trained. There must be a back-up monitoring and testing mechanism to ensure strict quality control. AI tools are difficult to control, so they need to be implemented through process authorization. Implementing strict quality control will increase the reliability of the clinical and analytical data being processed and give us the opportunity to develop it. Artificial intelligence will assist medical personnel in making medical decisions. Finding the best and latest treatments for a patient's specific case and providing the right care requires a lot of resources from physicians. Using artificial intelligence-based technologies, medical professionals can simplify the process of retrieving relevant information from the latest biomedical data and electronic medical records. Some tools have natural language processing capabilities, allowing physicians to ask questions just like their medical colleagues and receive quick and reliable answers.

In diagnostics, the use of artificial intelligence to analyze medical images is also important. A typical clinical trial can accumulate thousands of images of data that need to be analyzed one by one. Artificial intelligence facilitates their decoding and the detection of certain patterns. In addition, such technologies are also used in everyday processes in the medical field, when analyzing the results of CT or MRI scans and making a diagnosis. With the help of artificial chatbots, users can get relevant answers to various health-related topics, such as payment processes, diseases, and symptoms. Virtual health assistants are responsible for such things as managing patient medical information, hiding sensitive data, scheduling appointments with doctors, sending reminders, etc.

The mathematical model for the system can be introduced as following:

Patient data structure: P = {Demographics, MedicalHistory, MedicalImages} (1)

Demographics = {Age, Gender, etc.} (2)

MedicalHistory = {Diagnosis, Treatments, Medications, etc.} (3)

MedicalImages = {Image1, Image2, ..., ImageN} (4)

PACS System Model:

A mathematical representation of PACS might include: (5)

Image storage: PACS_storage(image) = StorageLocation (6)

Data retrieval: PACS_retrieve(PatientID, ImageID) = MedicalImage (7)

Data extraction: ImageProcessing(MedicalImage) = ExtractedData (8)

Clinical Management System Model:

Patient record storage and retrieval: CMS(PatientID) = PatientRecord (9)

Integration of PACS data into the patient record:

CMS(PatientID).MedicalImages = MedicalImages (10)

AI Model: A representation of AI model is offered as:

AI_model(MedicalImage) = Diagnosis (11)

AI_train(Data, Labels) = ModelParameters (12)

Integration Model: Data flow between systems:

CMS(PatientID).MedicalImages = PACS_retrieve(PatientID, ImageID) (13)

AI_model(MedicalImage) = Diagnosis (14)

CMS(PatientID).Diagnosis = Diagnosis (15)

Cost and Resource Model:

Cost = HardwareCost + SoftwareCost + PersonnelCost (16)

HardwareCost is calculated based on the number of servers, storage capacity, etc.

SoftwareCost could involve licensing fees and software development costs.

PersonnelCost considers salaries and maintenance costs.
Quality Control Model:
Quality metric: QC(Diagnosis, GroundTruth) = QualityScore (17)
Threshold for acceptable QualityScore: ThresholdQualityScore (18)
Natural language interaction is user model:
NLP(UserQuery) = AI_response (19)

AI_response involves a response to a medical query. In this model, we consider two key aspects of scalability: data scalability and user scalability.
Data Scalability: Data scalability refers to the system's ability to handle increasing volumes of medical data, including images and patient records.
Let D represent the current data capacity of the system (e.g., storage capacity in terabytes). Let D_max represent the maximum data capacity the system can handle without a significant drop in performance. A formula for data scalability can be written as follow:
Data_Scalability = D_max / D (20)

This formula provides a ratio that indicates how close the system is to reaching its maximum data capacity. A higher value indicates better data scalability.

User Scalability: User scalability focuses on how the system can accommodate more users, such as medical professionals accessing patient records and AI algorithms. Let U represent the current number of concurrent users. Let U_max represent the maximum number of concurrent users the system can support without degradation in response times.

A formula for user scalability can be written as follows:

User_Scalability = U_max / U (21)

This formula provides a ratio indicating how many more concurrent users the system can handle before performance starts to decline.Optimization Objectives:
Objective function to maximize: Maximize(DesiredObjective)
The proposed methodology aligns with the research objectives by integrating HL7 protocols and DICOM readers into a unified clinical management system. This integration automates data entry, improving accuracy and accessibility. The research aims to create a cost-effective PACS system, promoting affordability and accessibility for healthcare facilities. The methodology also integrates artificial intelligence, enhancing image analysis and diagnosis. Quality control mechanisms ensure data reliability. This approach is grounded in data integration, automation, cost-effectiveness, AI utilization, and quality control, all contributing to improved healthcare services and patient outcomes.

6. Results and Discussion

The implementation of the PACS system integrated with HL7 protocols and DICOM readers has shown significant promise. Medical images now seamlessly merge into unified patient records, improving accessibility for medical personnel, reducing manual errors, and saving time. This approach aligns with our research goal of creating a cost-effective and accessible system for healthcare facilities. Initial real-world trials have yielded positive results, with ongoing implementation expected to reinforce its efficacy. Additionally, the introduction of artificial intelligence into medical image analysis demonstrates great potential for enhancing diagnostic accuracy and efficiency. AI models, when trained on comprehensive medical image datasets, exhibit promise in identifying abnormalities and assisting healthcare professionals in making diagnoses. Our stringent quality control measures contribute to the reliability of clinical and analytical data, ultimately elevating healthcare service quality.

In summary, our proposed methodology, emphasizing data integration, automation, cost-efficiency, AI utilization, and quality control, presents a substantial opportunity for improving healthcare services and patient outcomes. The initial results are encouraging, and ongoing endeavors are likely to validate the methodology's effectiveness.

7. Experiments

The experiments were conducted in a test environment. First, we calculated the time in an existing decentralized environment for a physician who needs to see the results of an imaging study to find a medical image of a patient, and then manually transfer this data to the patient history in another system and analyze the patient history as a single picture. It was found that this process takes 30-45 minutes, and then, according to our methodology, we automatically transferred the data of the simulated test image into a single patient history.

The experiment revealed that this time was reduced by a factor of 6 at best. This was because the processes were scattered across different programs and it was necessary to find and analyze the patient data in all systems separately.

8. Conclusion

The needs throughout the study are that all digital clinic management systems should be integrated into one large complete clinic management system, and it should integrate the major areas of medicine and data in an appropriate chronology and sequence. In this process, it is very important that the information the system collects around patient care be sorted chronologically, adapted to the various management or peripheral devices. The system should provide accurate, consistent, and convenient reporting in all areas.

Creating such a system and adapting it to such simple portable equipment as a tablet and a cell phone greatly simplifies and speeds up the process of monitoring and treating patients. Storing patient medical images, creating a history, and accessing them from the brain allows for faster and better disease diagnosis, shorter treatment times, minimization of errors, and avoidance of unnecessary examinations. Digital systems also increase the security of a patient's personal data and reduce the time it takes to receive medical services. The need for improving the patient's medical history data gives us an opportunity to create a platform for the widespread use of artificial intelligence in medicine. The combination of properly structured electronic data and electronic production of calculations has improved the quality of care, the reliability of information, and dramatically accelerated the time for diagnosis and establishment of a treatment regimen. Physicians were able to easily monitor the patient's condition in one window and learn about all the necessary data and patient results. The system has been updated, refined, and improved several times, and research and innovation are still underway.

The system is constantly evolving and expanding. The research, development and optimization of this project is done intensely with the medical staff. At this stage, the aforementioned system has been updated/optimized several times, and we are still researching, implementing new systems and expanding the system in the direction of digitalization of processes and data. In conclusion, our research significantly advances healthcare informatics by introducing a unified digital clinic management system. This addresses the need for integrated patient data across medical domains, improving efficiency, security, and access to information. The system's potential extends to various healthcare applications and paves the way for AI integration in healthcare decision-making. It provides a foundation for future healthcare informatics developments. This innovative approach enhances healthcare systems, benefiting medical professionals and patients. Ongoing research and system expansion will further improve healthcare delivery and patient outcomes.

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