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A novel approach to optimize workflow in grid-based teleradiology applications

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ABSTRACT

Background and objective: This study proposes an infrastructure with a reporting workflow optimization algorithm (RWOA) in order to interconnect facilities, reporting units and radiologists on a single access interface, to increase the efficiency of the reporting process by decreasing the medical report turnaround time and to increase the quality of medical reports by determining the optimum match between the inspection and radiologist in terms of subspecialty, workload and response time.

Methods: Workflow centric network architecture with an enhanced caching, querying and retrieving mechanism is implemented by seamlessly integrating Grid Agent and Grid Manager to conventional digital radiology systems. The inspection and radiologist attributes are modelled using a hierarchical ontology structure. Attribute preferences rated by radiologists and technical experts are formed into reciprocal matrixes and weights for entities are calculated utilizing Analytic Hierarchy Process (AHP). The assignment alternatives are processed by relation-based semantic matching (RBSM) and Integer Linear Programming (ILP).

Results: The results are evaluated based on both real case applications and simulated process data in terms of subspecialty, response time and workload success rates. Results obtained using simulated data are compared with the outcomes obtained by applying Round Robin, Shortest Queue and Random distribution policies. The proposed algorithm is also applied to a real case teleradiology application process data where medical reporting workflow was performed based on manual assignments by the chief radiologist for 6225 inspections.

Conclusions: RBSM gives the highest subspecialty success rate and integrating ILP with RBSM ratings as RWOA provides a better response time and workload distribution success rate. RWOA based image delivery also prevents bandwidth, storage or hardware related stuck and latencies. When compared with a real case teleradiology application where inspection assignments were performed manually, the proposed solution was found to increase the experience success rate by 13.25%, workload success rate by 63.76% and response time success rate by 120%. The total response time in the real case application data was improved by 22.39%.

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1. Introduction

The evolution of Picture Archiving and Communication System (PACS) and teleradiology starts with a simple PACS application where a single client can access the medical images, towards Enterprise PACS with several clients querying and retrieving inspections, to Web-Based [1–4] and Regional PACS [5–9] solutions. However, it can be concluded that Regional PACS solutions, which are usually utilized in nationwide studies produce vendor dependent infrastructures [5]. Therefore, the recent trends in teleradiology has been towards Virtual PACS solutions interconnecting several vendors and facilities on a cloud platform [10] and towards quest for standards [11–13] in order to integrate patient data into a complete electronic health record utilizing Digital Imaging and Communications in Medicine (DICOM) and Health Level Seven (HL7) standards defined in Integrating the Healthcare Enterprise (IHE) profiles or non-standard formats such as Resource Description Framework (RDF), Extensible Markup Language (XML) or Portable Document Format (PDF). The requirements have also evolved from accessibility to interoperability, compatibility [14] and workflow in the overall process [15]. In order to fulfill this requirement, technical solutions have evolved from regional VPN-based solutions to Grid-Based solutions [10]. These solutions which are also supported in parallel by the improvements in the content and information centric network solutions [16,17] propose the employment of a broker [18–20] or agent [21,22]. Accessibility solutions have been proposed by implementing PACS based on data grids [21,23,24] or web-based systems with faster image retrieval and processing capabilities [25]. RESTful interface solutions [19], JPEG2000 streaming architectures [26] have been proposed for image repositories to resolve compatibility issues as conventional DICOM viewer solutions are operating system dependent and often do not support mobile application usage.

Among the studies on teleradiology architectures or workflow optimization, only a few have implementations related to radiology reporting process. Benjamin et al. [27], proposed a teleradiology architecture in order to increase the efficiency of the teleradiology service. The system allows a radiology group serving multiple sites to access medical images on a global worklist. However, the implementation does not include a workflow optimization or contextual consideration. Huang et al. have implemented several studies on work distribution [28] and business process management [29,30]. These studies include mining the task distribution rules in the event log of CT-scan examination process. As a common approach, the rules are learned from the event log regardless of whether they are successful or not [30]. Reinforcement learning [29] and adaptive association [28] algorithms are applied and the results are compared based on response time and resource allocation efficiency. Expertise, subspecialty and quality of report are also critical parameters for teleradiology service delivery workflow. An inspection requiring subspecialty should be assigned to a radiologist with corresponding experience and high quality reports should be promoted in assignment process. In the proposed algorithm, subspecialties of radiologists are evaluated based on modality, anatomy, disease and body parts. Radiologist characteristics [31,32] and expert ratings are used as initial indicators and report quality feedback [33] is utilized to recalculate the corresponding ratings.

In previous research studies, multiple types of workflow optimization and semantic matching strategies are evaluated such as reinforcement learning [29,28], machine learning (SVM, Bayes) [34] and relation based negotiation [35]. In this study, a RBSM algorithm enhanced by ILP is utilized as RWOA to design medical image distribution strategy based on reporting workflow optimization.

The objective of this study is to design and implement a framework where multiple medical sites can outsource teleradiology services to multiple radiology groups and where radiology groups can access and report the assigned inspections from multiple sites on a single interface. In order to automize and optimize this mechanism, a reasoning component is implemented to direct the inspection to the optimum radiologist so that the inspection is reported in a short time, with high quality output and with optimum resource allocation.

2. Materials

2.1. *Inspections*

Radiology inspections are generated by the imaging modalities in the form of DICOM files. Modality, body part and anatomy examined, protocol requested, file size, resolution, series and slice numbers data can be extracted rendering the inspection files. These attributes are indicators for the radiologist demand criterias. Pre-diagnosis which is a manually determined inspection parameter, has a 10th revision of International Classification of Diseases (ICD-10) code and is used to determine subspecialty requirements together with modality, body part and anatomy attributes. Requested protocol id is used to determine the required effort and time for the reporting process using “Performance Point Documentation” (SUT) standard as a reference. SUT is a standardization for evaluation of medical processes published by Turkish Ministry of Health for performance assessment and payment measurements. Each process mapped to requested protocol id has a unique code and process indicators determined by Ministry of Health experts. “Point” is an indicator for resource and effort usage and used to estimate the payment for the corresponding operations as a function of “Risk”, “Technical Requirement”, “Work Required”, “Urgency”, “Presence of Alternative” and “Required Time”. RWOA utilizes normalized values of “Point” and “Required Time” in SUT standardization for Radiology. File size and resolution attributes are used to determine technical requirements such as bandwidth and resolution of medical monitors, respectively.

2.2. *Radiologists and reporting units*

In a context where multiple medical sites transfer inspections to multiple reporting units to receive radiology reporting service, each reporting unit is a supplier that present medical and technical capabilities in order to get the service order. Each inspection generated by each medical site is a demand