WILEY

Description of a low-cost picture archiving and communication system based on network-attached storage

Dario Costanza ⓘ | **Pierpaolo Coluccia** | **Erica Castiello** | **Adelaide Greco** | **Leonardo Meomartino**

Interdepartmental Center of Veterinary Radiology, University of Napoli "Federico II", Napoli, Italy

Correspondence
Dario Costanza, Interdepartmental Center of Veterinary Radiology, Università di Napoli "Federico II", Via Federico Delpino 1, 80137, Napoli, Italy.
Email: dario.costanza@unina.it

[Correction added on 14 May 2022, after first online publication: CRUI funding statement has been added.]

Abstract

High costs for installing, maintaining, and updating a standard picture archiving and communication system (PACS) can be prohibitive for small/medium-sized veterinary facilities. The aims of this prospective, exploratory study were to describe the design, implementation, and author experiences for 1 year's use of a low-cost PACS based on network-attached storage. The system described here was easily installed and resiliently stored redundant copies of data. It excellently balanced data recovery, system speed, security, and available memory for storage. A virtual private network also allowed off-site data review. This system can also be used for future off-site backup of data in the cloud.

KEYWORDS
DICOM, digital storage, NAS, RAID

1 | INTRODUCTION

Advances in the digital technologies used in diagnostic imaging have increased the requirements of physical storage for each image or image series.[1] The resulting large amounts of data require systematic archiving to allow quick retrieval when necessary. In addition to being clinically useful, a long-term archiving system could have legal, research, and didactic applications; it must be reliable, secure, fast, and affordable.[2–6] A large and complex facility such as a hospital or large veterinary practice will involve multiple operators, multiple imaging techniques, and a large workflow. Such facilities entrust evaluation, exchange, and archiving of the generated data to a picture archiving and communication system (PACS), which allows the simultaneous evaluation of data acquired on different workstations using different imaging modalities. The PACS also handles files' long-term storage.[4] However, the setup of such a system can be complex and require a multidisciplinary collaboration of radiologists, technicians, and health informatics specialists.[3–5,7–9] Moreover, a PACS must allow off-site access to files and interface with the hospital information system (HIS).[3,4] The currently available PACSs have high costs for purchase and maintenance, precluding their widespread use in veterinary practices.[3,5] Small/medium-sized veterinary practices have therefore tended to use optical media (compact discs, CDs; digital versatile discs, DVDs; and Blu-ray discs) or mass storage devices (hard-disk drives, HDDs). None of these alternative storage systems are free from potential data loss. A further impediment is the difficulty of cataloguing and searching libraries of optical media to retrieve specific files.[2,3] Therefore, a medical imagery archive must store redundant copies.[2–4] Network-attached storage (NAS) adopts a redundant array of independent disks (RAID), whereby stored data are split into sections (stripes) of equal length and written on different discs to improve the system's

Abbreviations: AET, application entity title; CD, compact disc; DICOM, digital imaging and communications in medicine; DoS, denial of service; DVD, digital versatile disc; HDD, hard disk drive; HIS, hospital information system; HTTPS, hypertext transfer protocol over secure socket layer; IP, Internet protocol; LAN, local area network; NAS, network-attached storage; OS, operating system; PACS, picture archiving and communication system; RAID, redundant array of independent disks; SMART, self-monitoring, analysis, and reporting technology; SSD, solid-state drive; UPS, uninterruptible power supply; VPN, virtual private network.

speed, data redundancy, or both.[2] The RAID scheme makes the system resilient to the loss of one or more physical drives, and allows the replacement of a failed disk without interrupting the workflow. Add-ons can allow backup on external HDDs or off-site cloud platforms. Decreasing hardware costs, increasing availability of high-bandwidth networks, and advances in open-source software have allowed the creation of affordable PACSs that have shown good reliability.[5–7,10] Aims of this study were to describe the design, setup, and results from 1 year's use of a low-cost PACS based on NAS.

2 | MATERIALS AND METHODS

2.1 | Experimental design

This study was a prospective, exploratory design. A low-cost PACS system based on NAS was installed at the Interdepartmental Centre of Veterinary Radiology of the University of Naples Federico II, a medium diagnostic imaging facility with a caseload of about 1000 new cases per year.

2.2 | Original workflow

The relevant equipment at the center consisted of a 16-slice CT scanner (GE BrightSpeed, GE Healthcare, Milwaukee, WI, USA), a workstation used for the evaluation of CT images (Philiphs Extendend Brilliance Workspace vers. 4.5.51035, Philips Healthcare Nederland B.V., The Netherlands), an ultrasound device (Esaote Class C, Esaote S.p.A., Genova, Italy), a computed radiography system (Agfa CR-30, Agfa HealthCare, Mortsel, Belgium), a CD/DVD duplicator and printer (EPSON Discproducer PP-100II, Seiko Epson Co., Suwa, Japan), and a workstation used for databasing radiographic images (Merlino, Theorem@ S.r.l., Salerno, Italy). All files were temporarily archived on the respective workstation, before regular twice monthly backing-up on to CD/DVD or HDD. The CD/DVD duplicator and printer was used only to print discs' labels containing the patient's information and the study description (Figure 1).

2.3 | New hardware and software setup

The system powering the PACS was an NAS (Synology DiskStation DS1621+; Synology, Inc., Taipei, Taiwan) with a proprietary operating system (DiskStation Manager DSM vers. 6.2), a four-core, 2.2 GHz, 64 bit CPU, and 4 GB DDR4 RAM. The device had a maximum noise of 25.2 dB, and given its size (16.6 cm height, 28.2 cm width, 24.3 cm depth) and weight (5.1 kg) was placed in a room with restricted access. Its uninterruptible power supply (UPS) unit (EPYC Neon UPS, Vicenza, Italy) guaranteed ~40 min of autonomous running. The NAS storage memory consisted of six HDDs, 4 TB each (Seagate ST4000VN008, Seagate Technology PLC, Cupertino, CA, USA), in RAID 6 configuration. Of the 24 TB total memory, 14.5 TB was effectively available for storage and 9.5 TB was reserved for mirroring. Self-monitoring analysis and

reporting technology (SMART) was used to detect and prevent HDD malfunction. A PACS add-on was downloaded from a proprietary package centre (PACS vers. 5.11.0-0154; http://www.dcm4che.org). This application embedded several programs for the installation and running of the PACS server by the NAS. In detail, the PACS resided within a paravirtualization of the system (Docker, vers. 18.09.8, Docker Inc, Palo Alto, CA, USA). The application server (WildFly, vers. 3.4.0 Red Hat Inc, Raleigh, NC, USA) allowed the running of applications (JAVA, Oracle Corp, Redwood City, CA, USA). The deployment (Keycloak vers. 12.0.4, Red Hat Inc, Raleigh, NC, USA) guaranteed access and security management. Open-source PACS software (DCM4CHEE dcm4chee-arc-light vers. 5.11.1, http://www.dcm4che.org) with an integrated DICOM viewer (Weasis vers. 3.7.0, https://nroduit.github.io/en/) and software (MariaDB vers. 10, MariaDB Foundation, DE, USA) was used for databasing. All images were stored in native DICOM format, while the ultrasound videos were stored as MPEG-4 V2 (30 fps). Finally, to restore the system—in case of simultaneous failure of three or more disks or critical errors—automatic backups were made daily using integrated software (Hyper backup; Synology, Inc., Taipei, Taiwan) on an external hard drive (My Book Duo; Western Digital Corp. San Jose, CA, USA) connected via USB to the NAS and configured in RAID 1 with 8 TB of storage memory available.

2.4 | Network configuration

Each workstation or device was connected through a 1 Gbps ethernet connection to the department's local area network (LAN). A static Internet protocol (IP) address, a communication port, and a unique application entity title (AET) were assigned to allow a DICOM association between devices. To prevent unauthorised access and hacking attempts, only the public ports needed for essential services were kept open, the NAS's built-in firewall was configured to refuse any incoming connection from IP addresses other than those of the connected devices. Furthermore, to increase system security, it was embedded into a virtual private network (VPN; Open-VPN, OpenVPN Inc, Pleasanton, CA, USA), a time expiration passphrase and a multi-factor authentication process were enabled to access in the system configuration. Finally, the Denial-of-Service (DoS) protection and the Hypertext Transfer Protocol over Secure Socket Layer (HTTPS) protocols were enabled. The DICOM message service elements were enabled between the different AETs and the PACS to allow the exchange of files between all the units present in the network and the PACS. Finally, any critical error triggered an automatic alert email addressed to the system administrators.

3 | RESULTS

The total cost for the new system was €1552.00, including tax. Author experiences during the period of July 2020 to July 2021 were as follows. Radiographic, CT, and ultrasonographic exams were temporarily stored on workstations or ultrasound device, and automatically archived on the PACS. If necessary, files could be retrieved by these
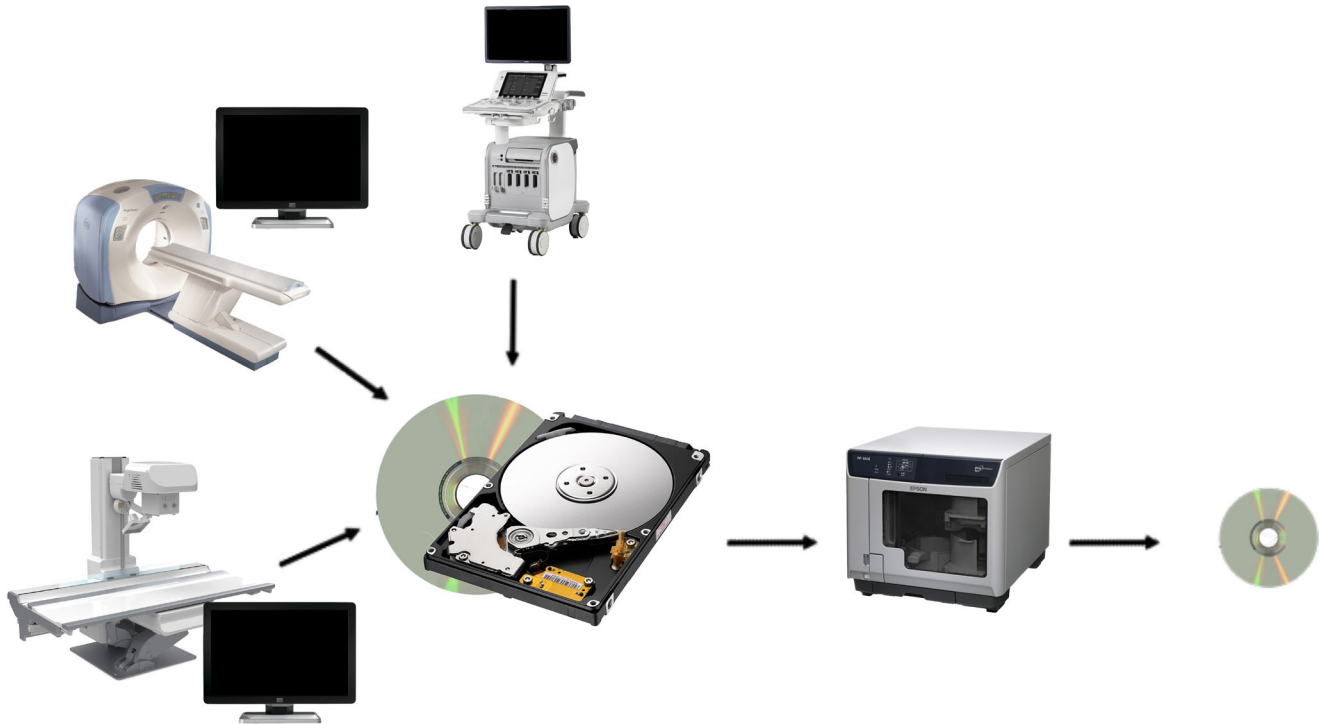
FIGURE 1 Schematic organization of the old configuration: all the imaging files required twice monthly backup on CDs/DVDs or HDDs from each workstation. The CD/DVD duplicator and printer were only used to print the discs' labels [Color figure can be viewed at wileyonlinelibrary.com]

workstations from the PACS. Another workstation (RadiAnt DICOM Viewer, vers. 2020.2. Medixant, Poznan, Poland,) was used for the evaluation of studies performed outside the Veterinary Radiology Centre. Images to be externally delivered to owners or referring colleagues were sent from the PACS to the duplicator and CD/DVD printer. Finally, through the VPN, it was possible to access the studies from the web (Figure 2). The new archiving and imaging system's adoption subjectively quickened the workflow and reduced the possibility of operator-related error during archiving. At the time of this publication, the system had archived 4237 studies (from mid-2015 to July 2021), including older studies still present on the workstations, using storage of ~1 TB. Whenever necessary, the studies were easily found using different search criteria. The NAS showed no service interruptions or critical errors. Minor errors encountered and notified were due to short interruptions in the electrical supply, for which the UPS successfully compensated. Furthermore, to avoid power outages, the UPS and NAS were also interconnected via USB to communicate about the battery state of charge. If the residual battery charge dropped below 15%, the NAS shut down and automatically rebooted when the main power returned.

4 | DISCUSSION

Although some studies have demonstrated the reliability of open-source PACS software,[5–7,10] no previously published report describes the use of NAS as the basis for a PACS. We chose NAS, because it

is designed to create copies of data automatically and, in case of one or more hard disks failing, to allow their replacement without interrupting the normal workflow. NAS can also be securely connected to a network via the integrated firewall and VPN.[2,8] The configurations for this are intuitive and do not require substantial knowledge of network configuration and data storage. The type of RAID significantly influences the system's speed, fault tolerance, data redundancy, and available memory. Although many similar systems[2,5] use a RAID 1 or RAID 5 configuration, we chose to adopt a RAID 6 given the availability of a large amount of memory provided by the six HDDs installed in the NAS; the configuration adopted tolerates the loss up to three disks concurrently.[2] As these systems are designed for data archiving, the OS allows easy restoration of system integrity in case of critical error or attempted hacking. In terms of security, the open-source, multi-platform PACS DCM4CHEE has been demonstrated to be reliable as a commercial PACS.[5–7,10,11] The network community that supports this system can help overcome difficulties that could be encountered during particular circumstances, thus demonstrating the system's greater flexibility than a proprietary PACS.[5,6,10] Furthermore, the simple user interface and easy set-up of DICOM association between the various AETs allow its use even by inexperienced people.[5,10] The possibility of off-site access to the archive has proved to be very useful, with restrictions on medical staff's presence on-site during the COVID-19 outbreak. The setting up and configuration of the NAS was easy, because once the HDDs were physically inserted, a wizard helped the system administrator to configure the OS. Moreover, this NAS-based PACS can be easily expanded either by installing new
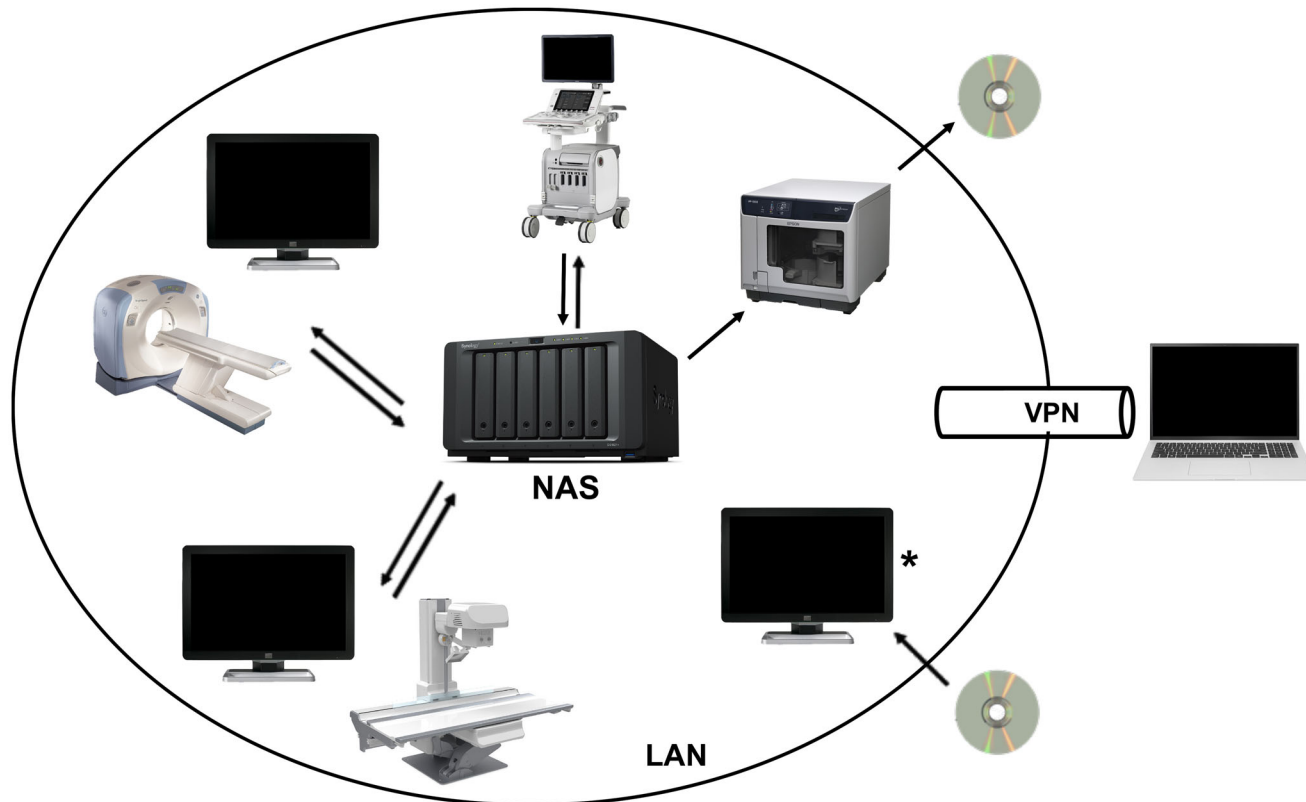
FIGURE 2 Schematic organization of the new picture archiving and imaging system based on network-attached storage (NAS-PACS): all the files are first temporarily stored on their own workstation, and then automatically sent to the NAS. If further evaluation is needed, they can be retrieved from the PACS. A further workstation (*) is used for evaluating studies performed outside the Centre. Images to be delivered to owners or referring colleagues are sent to the duplicator and CD/DVD printer. The VPN allows access to the PACS from the web [Color figure can be viewed at wileyonlinelibrary.com]

higher-capacity disks or by connecting via USB another NAS with a similar configuration.

Finally, the system we adopted was inexpensive (in our case, the total cost was €1552.00, including tax). Although the system had a backup system to restore its integrity in case of critical errors, the system's limits included the possibility of data loss in case of a catastrophe such as earthquake, flood, or fire. To avoid losses from such unlikely events, we have planned a further improvement to implement daily off-site backup, linking the NAS to cloud platforms to enable data recovery. However, where continuity of workflow is essential, while waiting for the data to be restored, a solution could be to connect the PACS to another off-site system with a similar configuration that would act as a hot-swap unit, taking over in the event of a malfunction of the main until it is restored.

In conclusion, after 1 year of utilization, the NAS-based PACS has improved the workflow in our center in terms of speed and security; its performance has exceeded expectations, and it seems unlikely to experience service interruptions or critical errors.

LIST OF AUTHOR CONTRIBUTIONS
Category 1
(a) Conception and Design: Costanza, Meomartino
(b) Acquisition of Data: Costanza, Coluccia, Castiello
(c) Analysis and Interpretation: Costanza, Greco, Meomartino

Category 2
(a) Drafting the Article: Costanza, Meomartino
(b) Revising the Article for Intellectual Content: Greco, Coluccia, Castiello

Category 3
(a) Final Approval of the Completed Article: Costanza, Coluccia, Castiello; Greco, Meomartino

Category 4
(a) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Costanza, Coluccia, Castiello, Greco, Meomartino

PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

This work has not been previously presented.

EQUATOR NETWORK DISCLOSURE

No EQUATOR network or other reporting checklist was used.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

ORCID

Dario Costanza 🄳 https://orcid.org/0000-0001-7310-0246

REFERENCES

1. Dandu R. Storage media for computers in radiology. *Indian J Radiol Imaging*. 2008; 18:287. https://doi.org/10.4103/0971-3026.43838
2. Wallack S, Digital image storage. *Vet Radiol Ultrasound*. 2008;49:37-41. https://doi.org/10.1111/j.1740-8261.2007.00332.x
3. Armbrust LJ. PACS and image storage. *Vet Clin North Am - Small Anim Pract*. 2009; 39:711-718. https://doi.org/10.1016/j.cvsm.2009.04.004
4. Robertson ID, Saveraid T. Hospital, radiology, and picture archiving and communication systems. *Vet Radiol Ultrasound*. 2008; 49:138-144. https://doi.org/10.1111/j.1740-8261.2007.00329.x
5. Iotti B, Valazza A. A reliable, low-cost picture archiving and communications system for small and medium veterinary practices built using open-source technology. *J Digit Imaging*. 2014; 27:563-570. https://doi.org/10.1007/s10278-014-9692-1
6. Valeri G, Zuccaccia M, Badaloni A, et al. Implementation, reliability, and feasibility test of an Open-Source PACS. *Radiol Medica*. 2015; 120:1138-1145. https://doi.org/10.1007/s11547-015-0560-y
7. Marcheschi P, Ciregia A, Mazzarisi A, Augiero G, Gori A. A new approach to affordable and reliable cardiology PACS architecture using open-source technology. *Comput Cardiol*. 2009; 36:537-540.
8. Ballance D. The network and its role in digital imaging and communications in medicine imaging. *Vet Radiol Ultrasound*. 2008; 49:29-32. https://doi.org/10.1111/j.1740-8261.2007.00330.x
9. Huang HK. Chapter 7 - Picture archiving and communication system components and workflow. In: Huang HK, ed. *PACS Imaging Informatics*. 2nd ed. John Wiley & Sons, Inc.; 2009;217-235. https://doi.org/10.1002/9780470560525.ch7
10. Warnock MJ, Toland C, Evans D, Wallace B, Nagy P. Benefits of using the DCM4CHE DICOM archive. *J Digit Imaging*. 2007; 20:125-129. https://doi.org/10.1007/s10278-007-9064-1
11. Erickson BJ, Langer S, Nagy P. The role of open-source software in innovation and standardization in radiology. *J Am Coll Radiol*. 2005; 2:927-931. https://doi.org/10.1016/j.jacr.2005.05.004