A Novel Technology for Automatically Obtaining Digital Facial Photographs Near-Simultaneously with Portable Radiographs

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Abstract Our objective is to design, implement, and phantom-test a device to automatically obtain point-of-care patient photographs along with portable radiographs. Such photographs could help with detection of wrong-patient errors. Our device consists of a camera controller (CC) and a camera that can be mounted on a portable conventional radiography (CR) machine. Radiation from the CR machine triggers an identification module (IM) embedded in the CR cassette. The IM then sends the cassette identifier—*Plate_ID*—to the CC along with a trigger to activate the camera. This trigger ensures simultaneous acquisition of radiograph and photograph, and the *Plate_ID* along with a time stamp ensures binding of the two images. We conducted phantom tests to

determine if clinical portable radiography exposure settings (90 to 120 kVp and exposure time ranging from 0.63 to 8.0 ms) are sufficient to trigger the IM. Phantom experiments demonstrate acceptable sensor performance for clinical portable radiography exposures. Simultaneous acquisition of photographs is achieved by integrating a low-cost identification module containing a scintillator-detector into the radiographic cassette. Incident X-rays activate the scintillator-detector triggering photograph acquisition by a camera controller.

Keywords Patient identification · Electronic medical records · Medical imaging · Medical errors · Digital camera · DICOM · PACS

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Introduction

Wrong-patient errors—where one patient’s medical tests are placed in another patient’s chart—can seriously harm multiple patients. Despite widespread use of the Joint Commission mandated dual-identifier method [1], wrong-patient errors continue to occur in radiology. In 2009, the Pennsylvania Patient Safety Authority reported 196 events of serious patient injury due to wrong-patient errors [2]. While we do not know how many total imaging studies were performed in Pennsylvania in 2009, this is nevertheless an alarming number of preventable serious events. At our institution, we have noted near-miss wrong-patient error rates of ~0.01 %, which we are actively trying to reduce.

Hypothesizing that capturing point-of-care patient photographs along with radiographs increases the detection of wrong-patient errors, we previously described a picture archiving and communications system (PACS) enhancement that would permit automatic and simultaneous acquisition, transmission, storage, and viewing of photographs and radiographs [3]. Subsequently, through observer studies [4, 5], we

demonstrated that the addition of photographs to portable radiographs could significantly increase the detection rate of simulated wrong-patient errors. Note that our scheme will not prevent wrong-patient errors at the image acquisition level; rather, it is expected to lead to increased detection of such errors at the interpretation stage, thus resulting in decreased wrong-patient radiology reports. The error detection is possible if radiologists can see point-of-care photographs along with the radiographs from both the new and prior studies; if no prior similar studies with photographs are available, then a comparison could potentially be made with the patient's photograph in the electronic medical record (EMR).

To acquire point-of-care photographs, we developed our system for portable radiography. The motivation is that wrong-patient errors are more likely to occur with portable radiography than with other imaging modalities [6], most likely because portable examinations are performed outside the radiology department. Thus, our first prototype is focused on the design, implementation, and phantom-testing of low-cost optimized hardware to acquire point-of-care patient photographs along with portable chest radiographs. The purpose of this manuscript is to present this technical innovation.

Materials and Methods

The goal of our system is to automatically obtain and integrate patient photographs without any technologist intervention. The overall system is shown in Fig. 1 and the workflow steps are as follows: first, by incorporating an electronic sensor system that responds to X-ray radiation on a radiographic cassette, the cassette automatically transmits its identity (*Plate_ID*) via a radio frequency link when the patient is imaged. Second, processed by off-the-shelf computing hardware, the transmitted *Plate_ID* also triggers a webcam mounted on a portable X-ray machine. In turn, a digital

photograph of the patient is captured. Third, using the *Plate_ID* and a time stamp as the common link, customized integration software in an integration server (IS) converts the facial photograph of the patient into Digital Imaging and Communication in Medicine (DICOM) format. The necessary DICOM tags are added to establish the relationship between the digital photograph and the corresponding radiograph. Finally, this newly created DICOM folder, containing the patient photograph integrated with the radiograph, is then sent from the IS to the PACS for radiologists' review. Details of the identification module (IM) and the camera controller hardware are discussed below.

Radiographic Cassette Identification Module

We embedded our custom-built radiographic cassette IM in the most commonly used imaging cassette at our institution, a Fuji FCR standard IP Cassette type CC (14"×17") (Fujifilm, Tokyo, Japan). The most functional location to mount the IM is on the inner wall of the door panel (Fig. 2). The rear panel of the cassette is unsuitable since there is intervening lead shielding that prevents X-rays from reaching the detector. The external aspect of the front panel is also undesirable since the IM might protrude beyond the surface of the panel and cause patient discomfort. A miniaturized module was developed measuring 46 mm×25 mm×5 mm (Fig. 2) that maintained unobstructed operation of the film processor. We have illustrated one conventional radiography (CR) example. The footprint of this IM may have to be adapted to fit inside X-ray cassettes manufactured by other vendors.

The custom IM consists of an X-ray detector (scintillator and photodiode), low-power microcontroller, memory, radio-frequency (RF) transceiver, and a 3-V coin cell battery (Fig. 2). The X-ray detection circuitry serves to generate a trigger signal when X-rays are incident on the module, i.e., when the patient is imaged. The trigger signal is converted to a digital representation indicating the detection of X-rays. A

Fig. 1 Block diagram of improved camera device and identification module (IM). The IM is housed in the radiographic cassette. Incident X-rays on the IM are converted to a voltage by the scintillator and photodetector diode. Once a voltage threshold has been reached, the IM sends the *Plate_ID* to the camera controller through the radiofrequency (RF) transceiver. The RF transceiver on the camera controller activates the camera to obtain the patient photograph. The controller transmits the

photograph along with the *Plate_ID* to the integration server (IS) through the existing hospital wireless network. The IS then obtains the corresponding radiograph from the picture archiving and communication system (PACS), integrates the photograph with the radiograph and sends the combined folder back to PACS. The radiograph-photograph combination can be viewed together on a PACS viewing workstation

Fig. 2 Identification module (IM), highlighted in red, embedded in a standard radiographic (CR) cassette. The enlarged view of the IM shows the scintillator-photodetector unit, the memory unit, the microcontroller, the radiofrequency (RF) transceiver, and the impedance-matched trace antenna. Housed on the underside of the IM is a 3-V (100 mAh) coin cell battery that can power the module for over 4 years if up to ten patients are imaged daily using the cassette

low-power 8-bit microcontroller acts upon this digital signal to transmit the pre-programmed Plate_ID via a low-power RF transceiver. Further details of each module component are described in detail below.

The scintillator screen is a small patch from a Kodak Min-R 2000 cassette (CareStream Health Inc., Shelton, CT, USA) in the X-ray detection circuitry and emits visible light at 540 nm. This light is converted into a voltage by a large area (7.5 mm²) PIN photodiode (BPW21R, Vishay Semiconductor, Shelton, CT, USA). This matched photodiode has peak sensitivity at 540 nm ensuring maximal energy transfer. Optical grease (Radiation Measurement Technologies, CA, USA) improves optical coupling between the scintillator screen and the photodiode.

The voltage generated by the photodiode is fed to a low-noise instrumentation amplifier (LNA 2126, Texas Instruments, Dallas, TX, USA), which amplifies the voltage by a factor of 25. The amplified analog signal is passed to an onboard comparator in the low-power Atmel 8-bit microcontroller (ATtiny84, Atmel Corporation, San Jose, CA, USA). The comparator uses a preset reference voltage, which was determined empirically, to compare the input signal. When X-rays are detected, the comparator is set, raising a hardware interrupt, which calls the service routine to transmit the pre-programmed Plate_ID information via the RF circuitry.

The low-power RF transceiver (nRF24L01, Nordic Semiconductor, Norway) offers automatic packet handling and cyclic redundancy check ensuring retransmission of data packets in case of transmission error. As a result, a reliable wireless communication link to the camera controller hardware is guaranteed. An impedance-matched trace antenna

provides the necessary link for wireless communication (Fig. 2).

Modified Camera and Computing Platform

The camera hardware is mounted on a CR machine, operates independently, and uses a cost-effective and sensor-friendly microcontroller platform (Figs. 2 and 3). In contrast to the earlier design [3] that actively requested identification information from a radiofrequency identifier (RFID) tagged cassette, the new design is fully automatic. The IM wirelessly transmits its Plate_ID when the patient is imaged. When the Plate_ID is received by the camera controller's RF transceiver, a hardware interrupt is generated, which triggers the camera to capture a facial photograph of the patient, and the controller then pairs it with the received Plate_ID. Once successful, the camera controller automatically transmits this information along with a time stamp to the IS via the existing hospital-wide wireless network for further processing. A buzzer is connected to the device, to provide an audible confirmation of receipt of the Plate_ID from the cassette.

Our new cost-efficient camera device uses the Raspberry Pi (Raspberry Pi Foundation, Cambridgeshire, UK) since it costs

Fig. 3 Camera device (red oval (a)) and adjustable webcam (red circle (b)) mounted on the CR machine. Also shown is the experimental setup with an anthropomorphic chest phantom (c) placed over a radiographic cassette

less than US\$35. This device provides native support via USB for a 5 Megapixel Omnivision 5647 Camera (Omnivision Technologies, Santa Clara, CA, USA) or similar cameras, support via USB for Wifi, and SPI interface to connect to the RF transceiver. Thus, this inexpensive platform, with components costing less than US\$100 in total, integrates sensors with ease.

Mounting the Camera Controller Device

The camera controller is mounted on the frame of the CR machine such that it does not interfere with movement of the telescoping arm (Fig. 3). Both the controller and the camera are placed directly on the collimator. Each can be moved along the axis of the collimator and can be rotated from left to right. Only a one-time device setup process is needed. During this process, the camera focus is adjusted so that any imaged subject's face is visible in all possible collimator positions while acquiring chest or abdominal radiographs.

Phantom-Based Experimental Testing

The IM was phantom-tested in a parametric study to assess the IM's reliability in detecting all energy levels of X-rays used by portable CR machines, i.e., various combinations of kilovoltage (kVp) and milliamperes-second (mAs) settings. The ability to send the accompanying trigger to the camera controller was also tested on the IM.

In our experimental setup (Fig. 3), the X-ray tube of the CR machine exposes an anthropomorphic cardio CT thoracic phantom (Cardio; QRM, Mohrendorf, Germany), which mimics the attenuation and density characteristics of an adult human thorax. The radiographic cassette with the integrated IM was placed behind the phantom. This setup simulates the patient experience during a regular CR examination.

The peak voltage applied across the X-ray tube was varied from 90 to 120 kVp in steps of 10 kVp. The tube current was held constant at 250 mA. The exposure time was indirectly controlled by the tube current-time product expressed in mAs. For every X-ray tube voltage, the time of exposure as controlled by the mAs setting was varied from 0.63 to 8.00 ms.

Results

The voltage generated by the photodiode, (V_{pd}), is increased proportionally with an increase in the energy level of the incident photons (Fig. 4). An increase in exposure time does not lead to an increase in voltage generated by the photodiode, as evidenced by the relative flatness of the plots for each energy level. The raw signal (V_{pd}) generated is amplified by the low-noise circuitry and then passed to the threshold

Fig. 4 Photodiode performance at different energy levels as measured by an oscilloscope. Using a threshold of 50 mV would ensure that only exposure from the X-ray tube would trigger the detector and background radiation would not trigger the detector

detector. The high amplification factor (25) saturates the output of the amplifier to the maximum possible voltage and is substantially higher than the threshold. A high amplification factor was chosen to ensure the detector's sensitivity to lower energy levels. A trigger was reliably generated in this parametric study for every possible combination of tube voltage and mAs setting used clinically in chest and abdominal radiography.

Discussion

Wrong-patient errors are preventable and continue to plague medical imaging [2]. Such errors can cause serious patient harm. To increase the detection rate of wrong-patient errors in portable radiography, we have developed a technology that automatically obtains point-of-care patient photographs and, using the combined radiographic Plate_ID and time stamp, ensures that the photograph and radiograph are tightly coupled in the PACS. When radiologists or other interpreting physicians view these photographs along with the corresponding radiographs in comparison with prior studies (which also contain photographs), any wrong-patient error would become obvious [4, 5]. If there are no prior studies with photographs, then a comparison could be made between the photograph in the current imaging study and photographs in the patient's EMR.

The chief advantage of our custom design is that it requires no technologist intervention. In a previous design [3], the device used a RFID tag on the cassette. While this passive RFID device required no battery power, it had the drawback of requiring an additional step for the technologist—the requirement to scan the cassette at the RFID reader. While this additional step may be trivial, if not performed properly, it would prevent the patient facial photograph from being

correctly associated with the corresponding medical image. Additionally, the original design required a separate trigger for acquisition of the facial photograph to be generated by the CR machine. This was accomplished by obtaining a trigger signal from the X-ray exposure hand switch, requiring hardware modifications to this switch. Our new design obviates both the technologist intervention and hardware modifications to the X-ray exposure switch.

Our experimental results demonstrate that the IM is triggered throughout the entire range of X-ray exposures that can be expected for pediatric and adult portable radiographs.

One limitation of our current design is the battery requirement for the IM. Our calculations show that such a battery would last for more than 4 years in operation. Technologists will need to ensure that this battery has not drained during daily or weekly quality control procedures. In the future, it is conceivable that a method to recharge the batteries in the identification modules when not in use could be developed.

A second limitation of this system is that it only helps with detection of wrong-patient errors after they occur and does not prevent the initial occurrence. However, the detection of the wrong-patient errors at the time of interpretation can help prevent the occurrence of wrong-patient dictations.

Finally, the position of the camera on the CR machine determines if patients' faces are consistently acquired. We have found that most digital cameras have a wide enough angle to capture the face and most of the upper body when placed next to the X-ray source. However, if the patient's position were to be reversed, i.e., the position of the feet and head interchanged, the face may not be captured. This may require placement of two cameras on both sides of the source; alternatively, a camera with a steerable mount may be required.

Conclusion

In summary, we have developed and validated a low-cost IM that integrated point-of-care patient photographs with their radiographs. This device can be easily integrated into existing

CR machinery and cassettes. The improved automatic functionality of the IM will not necessitate any additional work from the technologist or alter workflow. Further studies are needed to evaluate this technology in a clinical setting.

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