Robotic Nursing Assistants: Human Temperature Measurement Case Study

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ABSTRACT

In this study, we present a human temperature measurement case implementation for hospital patients using a mobile robotic platform (PR2). The main focus of the study is to apply computer vision methods, specifically optical character recognition (OCR) with template matching, in order to read a non-contact thermometer screen while PR2 is measuring patient's temperature. Parameter analysis is done for thermometer digit detection, and parameters with best results are selected for human tests. The tests are designed including human subjects as patients, a tablet for human-robot interaction (HRI), and the PR2 robot. Human subject test are performed with 8 volunteers over 2 days in Assistive Robotics Laboratory at the University of Texas at Arlington Research Institute (UTARI). Results and observations of human subject tests are provided. These activities are a part of a larger effort to establish adaptive robotic nursing assistants (ARNA) for physical tasks in hospital environments.

Keywords

Assistive Robotics, Service Robotics, Computer Vision, Optical Character Recognition (OCR), Template Matching, Human-Robot Interaction.

1. INTRODUCTION

There are nearly three million registered nurses employed in the United States, making them the largest pool of healthcare providers in the country. Our goal is to provide next-generation assistive robots to support the activities of hospital-based registered nurses (RNs). We focus on the creation of new design tools that can configure the hardware and software of adaptive robotic nursing assistants (ARNA). ARNA will specifically designed to assist nurses in healthcare facilities with simple tasks such as delivery of everyday lightweight objects (medicine, medical wearable equipment), or taking vital sign measurements, e.g. measuring temperature, and providing continuous observation of patients and feedback to and from nurses. The design and engineering innovations resulting from insights gained in this study may have great value deployed as products in broader consumer markets in addition to hospitals. Examples include in-home service and assistive robots, robots for assistance in public venues, and co-Robot manufacturing where humans are in close proximity to robot workers. The improved understanding of human-robot and nurse-robot interaction could represent enabling technology that will facilitate research breakthroughs and increase productivity and social acceptance of robotics.

Robotics in healthcare and/or service field is widely studied in the literature. There are many examples of applications and robotics platforms, we want to mention some of them here, such as "Flo" robot which is a personal service robot for elderly [1], "Keepon" robot that is developed for autism therapy [2], "Gestonurse" is a robotic surgical nurse for handling surgical instruments in the operating room [3], and the robotic system which is designed to measure patient's temperature [4]. Considering our aimed application, some example studies in which template matching based optical character recognition is used are worth mentioning here. Wallich [5] presents a system consist of a camera and a weather station in which system detects characters and numbers on the screen of the weather station. Vijayarani and Sakila [6] introduce a word searching method in document images using template matching. Application of number detection from plates is presented by Ferhat et al. [7], and optical character recognition using template matching improved with back propagation algorithm is introduced by Singh and Desai [8].

Toward to our bigger goal of developing ARNA platforms, our main focus in this paper is to study one specific applications: "patient temperature measurement task". The results gained from this study will be a part of development efforts for ARNA platforms. In this paper, we present developed algorithms, parameter analysis, and test results of thermometer screen digit detection. We attempt to apply computer vision methods to read thermometer screen that is also patient's temperature.

The remainder of the paper is organized in the following sections. Section 2 presents optical character recognition (OCR) using template matching method used in this study. Developed algorithms are explained in Section 3. Descriptions of overall system and parameter analysis are given in Sections 4 and 5, respectively. In Section 6, human subject test design and results are provided. The conclusion is presented in Section 7.

2. OPTICAL CHARACTER RECOGNITION (OCR) USING TEMPLATE MATCHING

In our study, we adopt template matching based OCR. Template matching technique can be described as finding matching portions of two images; an input image and a reference (template) image [9]. In algorithms, the input image is first processed to find contours for each recognizable characters. Then, each contour is compared to each and every character in the template (reference) image [10]. The aim is to find matches with highest score values. If we call input image as "*I(x,y)*" and template (reference) image as "*T(x,y)*"; the goal is to find highest matching pairs by checking the function "*s(I,T)*". Most common functions used in template matching applications are [10]

$$s(I,T) = \sum_{i=0}^{w}\sum_{j=0}^{h} |I(i,j) - T(i,j)| \tag{1}$$

$$s(I,T) = \sum_{i=0}^{w}\sum_{j=0}^{h} (I(i,j) - T(i,j))^2 \tag{2}$$

$$s(I,T) = \sum_{i=0}^{w}\sum_{j=0}^{h} I(i,j)T(i,j) \tag{3}$$

In this study, we use "correlation coefficient matching" type of template matching. The equation for this type is given as [11]

$$s(I,T) = \sum_{i=0}^{w} [T'(x',y') \cdot I'(x+x',y+y')]^2 \tag{4}$$

where *T'* and *I'* are defined as

$$T'(x',y') = T(x',y') - \frac{1}{(w \cdot h)\sum_{x'',y''} T(x'',y'')} \tag{5}$$

$$I'(x+x',y+y') = I(x+x',y+y') - \frac{1}{(w \cdot h)\sum_{x'',y''} I(x+x'',y+y'')} \tag{6}$$

3. THERMOMETER DIGITS DETECTION ALGORITHMS

The developed system utilizes an optical character recognition (OCR) software called Tesseract [12]. This library breaks down an input image's region of interest (ROI) into a contour description that can be compared to a library of characters for recognition. Before using OCR, we must first find a ROI to pull characters from. Our ROI is selected from multiple filters specific to the application. The image of the thermometer is captured by a camera at a known position and the thermometer is held in the robot's gripper that is also in a known position. By using the robots odometery, we can estimate the position of the thermometer screen from the camera's perspective. The image can, then, be cropped to only show this region plus a buffer area on each edge. A Blackhat (black top-hat transform [13]) morphological operation is preformed to expose a dark foreground (the LCD characters) away from a light background (the backlit screen), then edge detection is preformed to create a binary image of foreground details. A fill operation is used to connect the various character edges into a larger blob. If multiple blobs are found, they are filtered by minimal size, maximum size, and aspect ratio to find a blob of the expected size to the characters we are attempting to read. The original images is, then, cropped according to the area of this final blob to be passed to OCR.

Character recognition is performed using a character library that comes with Tesseract including several fonts and languages. However, that library does not particularly include "seven segment numerals" like those used by the thermometer. A royalty free image [14] is used for a seven segment display font. This adds benefit of both recognition accuracy and decreased processing time by not comparing to a multi font full numeric and alphabetical character library. Our modified reference font can be seen in Fig. 1.

Figure 1. Reference Image used in Digit Detection Algorithms

During initial implementations, both reference fonts and characters of input image are modified as the contour description can only be applied to continuous characters and not segmented characters. Separate horizontal and vertical fills are applied to connect the segments of individual characters without merging different characters together. This is done to the reference image and input image identically. Each character in the input file is scored for its contour similarity to each character in the reference image by the OCR algorithm using template matching method (Section 2) to determine the character estimation. Further details about the specific implementation can be found in [15].

4. OVERALL SYSTEM DESCRIPTION

The Personal Robot 2 (PR2) is selected as the mobile platform in this study. The PR2 has two grippers, two 7 degrees of freedom (DOF) arms, a pan-tilt head (Fig. 2). Robotic operating system (ROS) based packages are used in order to program the PR2. A hospital room scene is created in the Assistive Robotics Laboratory at the University of Texas at Arlington Research Institute (UTARI). For human robot interaction, an android tablet is used, and a custom app is developed. Further details about overall system can be found in our previous research [16, 17].

For reading the thermometer, a high-resolution camera with a zoom able lens is mounted to the robot shoulder as seen in Fig. 3 (a). This camera is positioned at an angle to read the thermometer lens while reducing glare as much as possible and an additional glare reduction film is added to the thermometer screen. A portable speaker is connected to the robot's opposite shoulder as seen in Fig. 3 (b) to allow the robot to both read out loud the subject's (patient) temperature verbally and inform them of its actions to increase comfort while working near them.

Figure 2. PR2 Robotic Platform

An off the shelf non-contact thermometer (SinoPie Forehead Thermometer) seen in Fig. 3 (c) is used to read the subject's body temperature. The thermometer is modified with a styrofoam foot to allow it to stand upright and with an AR tag for quick and easy recognition as seen in Fig. 4. While the internal circuit board is not intended for modification or expanded applications, it can be modified to be triggered from an external source electrically. Therefore, we connect the internal electrical triggering switch to the digital output of a Bluetooth enabled microcontroller. The microcontroller used is an Adafruit Feather 32u4 Bluefruit LE as seen in Fig. 3 (d). This allows the robot to connect to and trigger the thermometer digitally. Due to the internal circuit boards lack of expendability, it is chosen not to read the temperature value from the circuit itself, but to read the screen using computer vision methods.

5. PARAMETER ANALYSIS

A parameter analysis is performed to determine the best set of the parameters for thermometer screen digit detection in 15 cases varying the following parameters: threshold to be applied to average score (Th), aspect ratio (AR) for detected contours, size limits for detected contours (Cntr Limits - Width and Height), size of the structural element: rectangle (Rect) and square (Sq), morphological operation to fill the gaps (Fill), full image or cropped image (Crop). The list of the 15 cases with the values of these parameters is given in Table 1.

The results of the analysis are evaluated considering three values; detection rate (DR), and number of detected contours (#Cntr), and average matching score (AS). The detection rate equals to the number of digits that algorithm detects from actual digits over the total number of actual digits. The number of contours gives the total of contours detected which may include false positive detections. The results are given in last three columns of Table 1.

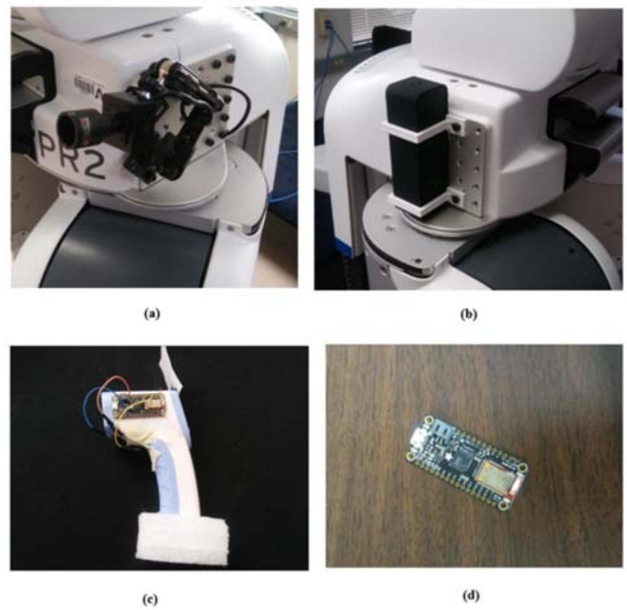

Figure 3. (a) Camera used in Digit Detection (b) Bluetooth Speaker (c) Non-contact Thermometer with Bluetooth trigger (d) Bluetooth Development Board

Figure 4. Thermometer with AR tag

Figure 5 shows sample case outputs from analysis. As seen from the Table 1 and Fig. 5, the cases are given in an increasing performance manner. The performance of the detection algorithm increases with higher detection rate and contour number equals to

Table 1. Parameter Analysis Cases

			Cntr Limits		Struct Size						
	Th	AR	Width	Height	Rect	Sq	Fill	Crop	DR	#Cntr	AS
Case 1	No	0,1.5	0,150	10,200	5,5	5,5	1,1	No	33.33%	29	21345722.64
Case 2	No	0,1.5	0,150	10,200	5,5	5,5	1,1	Yes	33.33%	5	20020376.20
Case 3	No	0,1.5	0,150	10,200	5,5	5,5	25,25	Yes	0.00%	5	19322476.00
Case 4	No	0,1.5	0,150	10,200	5,5	5,5	50,50	Yes	33.33%	5	23890805.00
Case 5	No	0,1.5	0,150	10,200	5,5	5,5	75,75	Yes	33.33%	5	25687678.40
Case 6	No	0,1.5	0,150	10,200	5,5	5,5	100,100	Yes	33.33%	5	24408772.20
Case 7	No	0,1.5	0,150	10,200	10,10	5,5	75,75	Yes	100.00%	8	27724953.75
Case 8	No	0,1.5	0,150	10,200	10,10	10,10	75,75	Yes	100.00%	8	27822773.50
Case 9	No	0,1.5	0,150	10,200	15,15	10,10	75,75	Yes	100.00%	9	29880588.00
Case 10	No	0,1.5	10,150	20,200	15,15	10,10	75,75	Yes	100.00%	7	29329435.71
Case 11	No	0,1.5	20,150	30,200	15,15	10,10	75,75	Yes	100.00%	6	27701941.00
Case 12	No	0,1.5	30,150	40,200	15,15	10,10	75,75	Yes	100.00%	6	27701941.00
Case 13	No	0.5,2	30,150	40,200	15,15	10,10	75,75	Yes	100.00%	6	27701941.00
Case 14	No	0.5,3	30,150	40,200	15,15	10,10	75,75	Yes	100.00%	6	27701941.00
Case 15	Yes	0.5,3	30,150	40,200	15,15	10,10	75,75	Yes	100.00%	3	37202478.67

number of digits on the screen. Contour number greater than actual digit number indicates false positives. The best case desired is when the detection rate is 100% and the contour number is 3, because the actual temperature reads 94.1 in the parameter analysis (Fig. 5). In many cases, the detection rate is 100%, but the contour number is higher than 3. The last case, Case 15, has the parameters which give the best results; 100% detection rate and no false positives. These parameters are used for human subject tests.

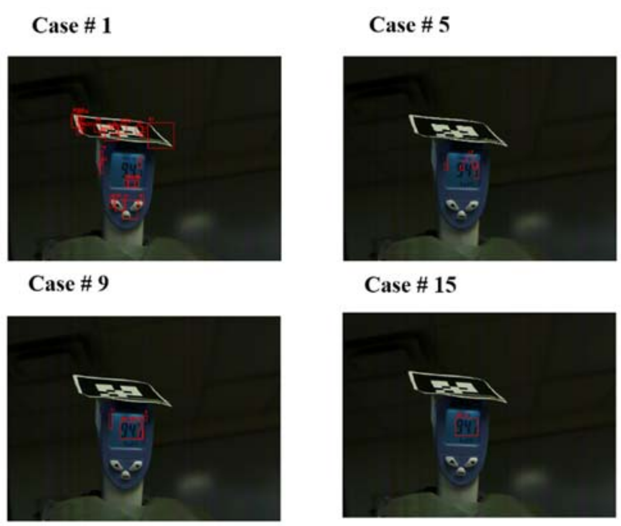

Figure 5. Examples of Parameter Analysis Results - Selected Cases #1, #5, #9, and #15

6. HUMAN SUBJECT TESTS AND RESULTS

Human subject tests are performed with 8 volunteers over 2 days, and test are done in Assistive Robotics Laboratory at UTARI. The designed test scenario is as follows. A human subject is asked to lay on a hospital bed (pretending to be a patient in a hospital). The human subject is asked to use buttons on an android tablet to interact with the PR2 robot during the experiment. Once the PR2 receives the temperature measurement task request, it navigates 20 feet to a desk to pick up the thermometer (Fig. 6), navigates back next to the patient, finds the patient's face in order to direct the thermometer, and move its arm with thermometer to the calculated position (Fig. 7). Then, thermometer is triggered by a Bluetooth module. Finally, the PR2 moves its arm with thermometer close to the high definition camera and a single image is saved for detection purposes.

Figure 6. PR2 Robot Picks Up the Thermometer during an

Figure 7. Snapshot of a Human Temperature Measurement

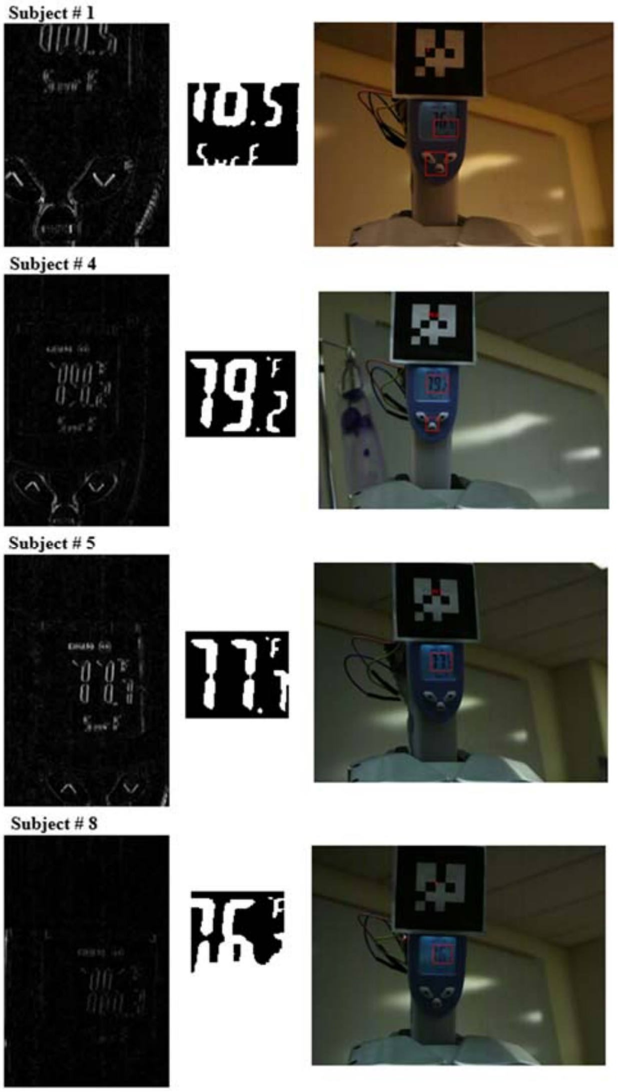

Figure 8. Examples of Human Subject Test Results - Selected Tests #1, #4, #5, and #8

The list of observations during human subject experiments are given below:

- 2 times subject patients lay down quiet low on the bed. It takes longer for PR2 to find subject's face.
- 3 times subjects push button twice.
- One time PR2 hits the table when lifting the arm during thermometer pick up phase.
- One subject removes glasses while PR2 points thermometer.
- Human subjects comment during the tests. Some examples of those comments are:
    - "It looks like the robot from the Jetsons."
    - "The speed of the robot is too slow and that the tablet interface can be improved."
    - "Can the supplies be put on the robot?"

The thermometer digit detection results from human subject test are given in Table 2. In two out of eight human subject cases, the system reads the thermometer screen 100% correct with no false positive contour. The system also has 100% for two more cases, however there are 1 and 3 false positive detections in those cases, respectively. Three out of remaining four cases ends up with 33% detection rate, and there is one case with 66% detection rate. Some examples of resulting images from human subject tests are shown in Fig. 8. When the parameter analysis is performed, we defined a ROI in the image using known locations of the arm of PR2, the camera, and the thermometer. During human subject tests, we realize that, depending how PR2 picks up the thermometer, the orientation of the thermometer in the gripper may change. Even though that orientation difference is very small, it highly affects the performance of detection algorithm. Also, lighting conditions may contribute the high false positive rate. The possible solutions to improve detection include (i) modifying thermometer to allow PR2 to pick it up exact same way every time, (ii) adding LED lights around the camera to improve visibility of the digits, and (iii) defining dynamic and adaptive ROI using visual markers around thermometer screen.

7. CONCLUSION

In this paper, we present human temperature measurement task study using an assistive robot (PR2). Our focus in this study is to use OCR with template matching for detecting digits on the non-contact thermometer. Parameter analysis is performed and parameters with best results are selected to be used in the human subject tests. In the experiments with human subjects, two out of eight cases, the developed system detects the thermometer digits and reads patient's temperature with 100% detection rate and without false positives. For the remaining cases, in some of them, there are false positives, in other cases, the detection rate is below 100% due to the environment effects. The hardware part of the system is open to advance improvements such as adding LED lighting. Furthermore, the detection algorithm can also be improved by adding adaptive ROI selection. This study is a part of larger research effort in which the system is aimed to be integrated on an adaptive robotic nursing assistant (ARNA) platform.

8. ACKNOWLEDGMENTS

This work was supported by the National Science Foundation (NSF) Partnerships for Innovation: Building Innovation Capacity (PFI: BIC) grant (Award Number: 1643989).

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Table 2. Human Subject Test Results

	Actual Temp.	System Output	Detection %	Correct Digit %	# of False positives
Subject 1	76.5	215.151	33%	0%	5
Subject 2	73.2	2	33%	0%	0
Subject 3	72	72.1	66%	66%	1
Subject 4	79.2	79.2	100%	100%	0
Subject 5	77.7	77.7	100%	100%	0
Subject 6	76.3	43.7631	100%	0%	3
Subject 7	77.9	77.191	100%	66%	2
Subject 8	76.3	7	33%	0%	0

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