Patient Pathway Optimization in Hospitals using Convolutional Neural Network and m-Artificial Bee Colony Algorithm

Jyoti R Munavalli[1], Priya R Sankpal[2], Sumathi A[3]
[1]Department of ECE, BNM Institute of Technology, Bangalore, India
Email: jyotirmunavalli@bnmit.in
[2]Department of ECE, BNM Institute of Technology, Bangalore, India
Email: priyarsankpal@bnmit.in
[3]Department of ECE, BNM Institute of Technology, Bangalore, India
Email: sumathia@bnmit.in
Corresponding author: Department of ECE, BNM Institute of Technology, Bangalore, India
Email: jyotirmunavalli@bnmit.in

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Abstract. *Patients, either scheduled or unscheduled, have to be put on pathways depending on their clinical conditions. These pathways when assigned to patients, at times result in prolonged waiting times. The patient pathway has to be selected in such a way that their waiting times is minimized. To accomplish this, real-time optimization of workflow is required. In this study, we propose 2-fold solution, first to use image processing techniques to capture system status of all departments in the hospital. A Convolutional Neural Network is trained to recognize the patients. The number of patients waiting for the care in each department is identified and the database is updated in real time. Second, to use this real-time system status, to select optimal pathways using modified Artificial Bee Colony (m-ABC) algorithm. Image processing technique captures and provides more accurate system status for real-time workflow optimization. The ABC algorithm is modified by incorporating the precedence constraints that clinical workflows have. By selecting optimal pathway through m-ABC, the waiting times of patients is minimized.*

Keywords*: Image Processing, pathway optimization, cycle time, waiting times, Convolutional Neural Network, Artificial Bee Colony algorithm*

1. Introduction

Operations management is an important aspect in hospital operations. It deals with managing of patients and resources like doctors, nurses, staff, layout and equipment. Hospitals are systems that have heterogeneous departments that are managed and controlled independently, yet they are connected. Often, patients move across these departments to complete their treatment. During this process, patients wait for care at most of the departments. Waiting time is the result of poor planning, scheduling and controlling of the activities, and at times it is because of layout design [1]. There exists a lot of literature on scheduling of patients and resources. Generally, appointment systems are used to schedule patients [2-6]. Few patient scheduling models also consider walk-in patients [7, 8]. Various scheduling models are proposed for resource scheduling [9, 10]. Most of the time, resources are planned and scheduled beforehand. There are few studies that have scheduled resources that match with patient demand and have also incorporated rescheduling of resources based on real-time changes in patient demand [11, 12]. Though patients are scheduled beforehand via appointment systems, it is observed that sometimes patients arrive too early or too late. This results in patients' waiting for their care. Additionally, patients are not aware of the care process and the departments they have to visit to complete their care process. Because of this, few departments are overloaded and patients experience prolonged waiting times whereas few departments are unfilled and this results in non-utilization of resources [5, 11]. It means in few departments patients wait for care and in other departments resources wait for patients. This is optimized with identifying patient pathways and routing patients to the optimal pathway [8].

There is uncertainty and variability in patient demand and the care processes. The care process differs from patient to patient and the care process has sequential procedures. But few of the procedures in the care do not have sequential constraints and such procedures could be altered. For this, real-time system status of all the departments in a hospital is essential. The study in [8] have proposed an integral patient scheduling that captures the real time status of the departments in an outpatient clinic and schedule the patients to optimal pathways using hybrid ant agent algorithm. Capturing the system status in real-time accurately is a significant factor in pathway optimization. It is a challenging task and can be captured using different ways. There is enormous potential for real-time planning and control and to dynamically construct pathways and acquiring accurate data in real-time would optimize the hospital operations [13].

Image processing and neural networks have been used in various applications and healthcare is a prominent one. It has been used to identify and predict the disease onset, medical imaging, and biometric, elderly care, MRI, ophthalmology and many more [14-18]. From literature, it is observed that operations management like planning, scheduling and control have not been performed using image processing techniques. In this paper, we present a simulation study that captures the patient load or the system status in real-time, for all the departments of a hospital which is further used for pathway optimization. We propose 2-fold solution, one to capture the real-time patient load more accurately using image processing techniques and second to schedule patients to optimal pathways. We implement Convolutional Neural Network to identify/recognize the patient load in all the departments. Using this system status, a modified Artificial Bee Colony algorithm is implemented considering precedence constraints in clinical workflow. The organization of the paper is as follows: Section 2 presents Materials and Methods in which we explain a sample workflow process in a hospital, recognition model and implementation, and the modified-Artificial Bee Colony algorithm for identifying optimal patient pathway. Section 3 presents the Results and Conclusion is presented in Section 4.

2. Material and Methods

In this section, first we explain the generic workflow in hospitals, then the proposed method of capturing the department status through CNN model and the modified-Artificial Bee Colony algorithm. Finally their implementation is explained.

2.1 Workflow

A hospital is a collection of different departments to which patients have to visit. A simple workflow of a hospital is as shown in Figure 1. The hospital has five departments, D1, D2, D3, D4 and D5 with average service times 3 minutes, 5 minutes, 8 minutes, 10 minutes and 5 minutes respectively. Most of the departments need to be visited in sequence (precedence constraint) except the order of visiting departments D3 and D4 can be interchanged. All the queues in the hospital follow First Come First Serve (FCFS). D1 is the registration department. A patient pathway starts from D1 and ends at department D5. The possible pathways are D1-D2-D3-D4-D5, D1-D2-D4-D3-D5, D1-D2-D3-D5 and D1-D2-D4-D5.

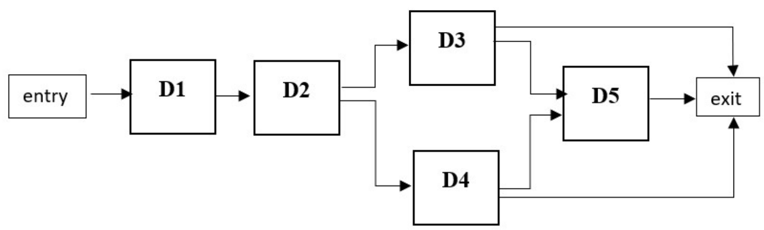

Fig. 1: Typical Workflow in a hospital

2.2 Methods

The study has two folds: One is the acquiring real time system status of all the departments and another is to optimize the pathway using the system status. The study methodology is as shown in Figure 2. After registration, the capturing process has to be initialized. The images of the patients in all the departments are captured. We develop a recognition model that recognizes the patients in the image. For this, we develop a CNN model and train it with the patient sample images. To identify the patients in the simulation, patients were made to wear the head-bands. But the sufficient dataset with headband was not available so people with masks were used to demonstrate the concept. To identify patients from the images, we train the CNN model. The dataset is divided into train set and test set. After training the model it is validated using test dataset. Once the pre-trained model is ready to detect the images (this is referred as recognition model) with accuracy, the images from the video (that is from live camera) is captured.
A database is maintained to count the number of patients in each of the department that could be used for pathway optimization. The m-ABC algorithm identifies the optimal pathway. Waiting times is estimated based on average service times and the number of patients in the departments. The optimal pathway that has minimum waiting times is selected.

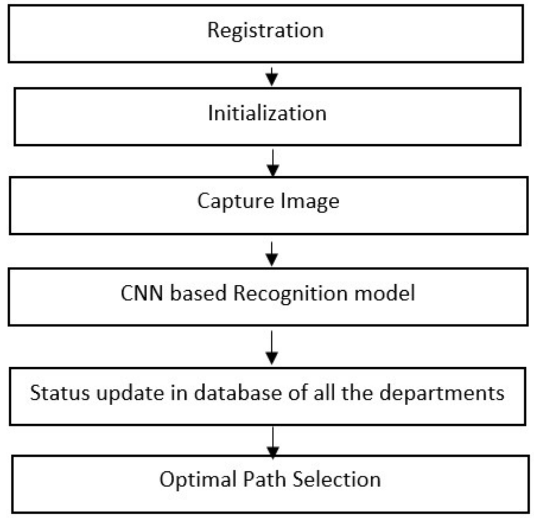

Fig. 2: Study Methodology

2.3 Model Development

The discrete process based stochastic simulation model was developed using Java programming. The progress of patients and resources was tracked throughout the OPC. The model was constructed on the predefined operations logistics such as type of patient, pathways/flow, departments, resources/staff and the distance between the departments. The processing times, arrival times (in-time) and exit times (out time) were used to build the system. Walking steps were uniformly distributed between the minimum and maximum walking steps from data collected for each department and were randomly generated. The operations managers were asked to verify the model. The simulation model was run with the empirical data and the performance measures, namely, waiting times, cycle times, utilization and load distribution, were collected. The results of the simulation model were compared with the empirical data of the OPC for validation as shown in Table 1 and there was no statistical difference between the two.

Table 1 Validation of waiting time and cycle time between simulated results and empirical data

	Empirical data		**Simulation results**		**P value**
	Mean	**S.D.**	**Mean**	**S.D.**	
Wait time in minutes	59.5	43.92	58.2	40.15	0.4
Cycle time in minutes	113.26	44.2	115.32	39.6	0.29

2.4 Patient Recognition using Image Processing

A Convolutional Neural Network (CNN) is a deep learning algorithm which takes images as input and output is the object being recognized. CNN do not need much of preprocessing of inputs. It consists

of feature learning and classification. For feature learning convolution, RELU and pooling functions are applied and flatten, fully connected softmax are applied for classification.
Recognition model first classifies the images and for this we build Convolutional Neural Network (CNN). Tensorflow framework with Keras library was used to build these layers. The hospital workflow is simulated using Java and m-ABC algorithm was used for identifying the optimal pathway.

Steps for developing the recognition model
1. Importing all the required libraries like OpenCV2, numpy
2. Adding dataset to datapath.
3. Datasets had 1995 images with masks and 1918 images without masks.
4. Images are converted to grayscale
5. Resizing and reshaping of images to 4D is carried out as neural network takes 4D input.
6. Building CNN model that consists of Two Conv2D layers, two max pooling layers, one flatten layer and one dense layer (categorical)(Figure 3).
7. Splitting dataset into train and test dataset.
8. Best epoch is saved with ModelCheckpoint.
9. Haar-cascade frontal-face is used for face detection
10. Images are capture from live camera using VideoCapture().

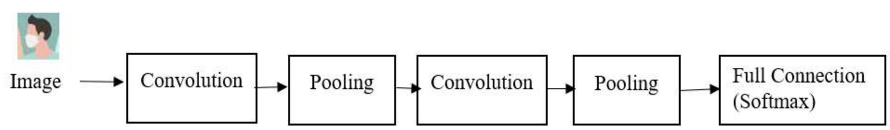

Fig. 3: CNN model for Recognition

The database gets updated in real time with the movements of the patients in various departments. Once real time department status is obtained, patients can to be scheduled to the departments on the pathways that take minimum cycle time. For identifying the optimal pathway, we propose modified Artificial Bee Colony Algorithm.

2.5 Optimal Pathway Selection through modified Artificial Bee Colony Algorithm (m-ABC)

A modified Artificial Bee Colony algorithm is a meta-heuristic algorithm inspired by honey bee swarm with addition of precedence constraints to obtain an optimal pathways for patients, intermittently.
The movement of the bees in the simulation environment is in three phases: Employed phase, Onlooker phase and Scout phase. The algorithm begins with employed bees that go in search of destination in a random fashion and ends with identifying the best optimal pathway for the patients that has minimum cycle time.

Steps of the m-ABC algorithm is given below:
1. Initialization
2. Every 10 minutes generate employed bees, onlooker bees and scout bees, depending on the number of possible patient pathways the hospital has.
3. Move the employed bees onto the food sources/departments and evaluate their nectar amounts/number of patients in the departments (real time status).

4. A trial index is a counter that keeps updating the number of departments the employed bees will visit. If this trial index is more than the maximum number of departments the bee has to visit, then the bee has lost the path and it should be discarded/not considered.
5. After the employed bees collect all the information, Place the Onlooker bees into the system. The onlooker bees will evaluate all the possible paths that the employed bees have obtained. They will compare the nectar amounts/cycle time of the patients and select the optimal patient pathway (that is the pathway with minimum cycle times).
6. After sometimes, the optimal pathway can become congested as all the patients during the selected period (10 minutes) are scheduled through the same pathways. So now send the scouts for exploring new food sources/sub optimal patient pathways.
7. Terminate if patient arrival is nil else go to step 2.

3. Results

The CNN model was trained for 20 epochs with 0.1 test size and 0.2 validation split. The trained accuracy was 99.5% and validation accuracy was 93.15 %. The time taken for recognition and allotting the pathway is 30 seconds. CNN when used on image data provides high accuracy for classification and recognition.
Initially, the patients were identified by making them wear a hand-band but its identification became difficult due to patients and attenders wearing watches. Then head bands were used. But due to non-availability of dataset to train the CNN model, we replaced head band to mask. As dataset for mask detection is available, we have used it to demonstrate the concept of identifying and count patients through images of the CCTV camera. This count is used for path optimization. The attenders were without mask. Figure 4 shows the sample image of a department and the database updation. In department D4, there are totally five people; three are patients among them.
The m-ABC algorithm is run at the backend or at the registration desk of the hospital. There are four possible pathways as per the example considered. The following parameters were randomly selected. Swarm (population) size is 30. The number of iteration is 30. The number of employed bees were equal to the number of onlooker bees. Food sources were the destination that is the last department.

The optimal path selected by onlooker bees is D1-D2-D4-D3-D5 as the waiting time at D3 is more when compared to D4. The patients can visit D3 or D4 as the sequence could be altered.

Department_id	Count
D1	4
D2	6
D3	7
D4	3
D5	6

Fig. 4: Sample images of patients in department D4 and related database

The simulation model was rerun and patients were scheduled on the selected optimal pathways by the m-ABC algorithm. Table 2 compares the waiting time and cycle time with and without patient pathway optimization. ANOVA tests (p = 0.05) show that the performance measures of the proposed 2-fold implementation are significantly better than the without optimization.

Table 2 Comparison of waiting time and cycle time between with and without m-ABC algorithm

	Without m-ABC algorithm		**With m-ABC algorithm**		**P value**
	Mean	**S.D.**	**Mean**	**S.D.**	
Wait time in minutes	58.2	40.15	42.5	32.1	0.034
Cycle time in minutes	115.32	39.6	99.2	29.6	0.042

The problem was to determine the actual status of the system and schedule patients on the optimal pathway that reduces their waiting times and the results show that method of image processing provides the information accurately and m-ABC algorithm provides the optimal pathways. In addition to patient recognition and their system status, resources like doctors, paramedics, nurses and equipment can also be identified, tracked and scheduled efficiently.

4. Conclusion

The aim of the proposed study was to accurately capture the system status of all the departments as it is important factor in real-time planning and scheduling. CNN model was used for patient recognition and a discrete event simulation model to simulate patient flow. The proposed method captures the system status more accurately and the m-ABC algorithm schedules patients on optimal pathways so that it improves the patient flow and reduces patient waiting times. As most of the clinics have live/CCTV cameras installed, this method can easily be implemented to any type of out-patient clinics. As a future work, the same could be applied in optimizing the resources of the out-patient clinics.

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