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Real-Time Remote Healthcare and Telemedicine Application Model using Ontology Enabled Clustering of Biomedical & Clinical Documents

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Abstract*: *Remote health monitoring has become a hot topic research due to its multi-dimensional benefits to the society. This paper is aimed at developing a novel remote health monitoring model through wireless sensor networks to ensure efficient telemedicine process. The proposed model, Real-time Remote Healthcare and Telemedicine (RRHT) utilizes the concept of model based design to provide low cost and time saving efficiency. First the low power consuming sensor nodes are placed at specified body points with facility to monitor and reduce the power consumption at each stage of the designed model. These nodes collect the patient data and transmit them in wireless medium through the gateway where the data are combined to form documents/notes. Autonomous optimized routing algorithm is employed at this stage for transmission through efficient wireless paths to the processor connected at the hospitals or health centers. At the processor, the transmitted patient data documents are clustered using ontology enabled clustering models using chicken swarm optimization (CSO) and genetic chicken swarm optimization (GCSO). The clustered results are comparatively analyzed with the previous patient database and to determine the change in health readings. Based on these findings, the suitable medication details along with advice on hospital visits are suggested by the decision module and are sent to the physicians or medical experts for approval and further diagnosis. The performance analysis shows that the proposed RRHT system with GCSO clustering is highly reliable and accurate with better speed and lower cost. These results also prove that the RRHT significantly improved the healthcare application through the utilization of better strategies in document clustering of patient data.

Keywords*: *Telemedicine, Remote Health Care, Wearable Sensors, Autonomous Optimized Routing, Ontology Enabled Clustering, Decision Support Systems.

I. INTRODUCTION

Tele-health and telemedicine concepts are being widely utilized in the fields of medicine where remote health care applications are widely regarded as the future prospects [1], [2]. These two concepts are vital components of remote healthcare system [3].

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As per the civil laws, it is compulsory to ensure basic medical facilities to each person in country. But due to various factors of financial crisis and practical difficulties, this basic medical right is just a literal guarantee to the people living in remote locations. Remote health care technologies can be a greater solution to this social issue in most developing and under developed countries [4]. Even the developed countries can utilize such technologies during the periods of natural calamities and emergency scenarios. However the major factors influencing against such systems are varied which increases the research interest in them [5]. The practical feasibility, cost, reliability and adaptability of these systems are major challenges that increase the research society to come up with more liable options. Developing such options can increase the applications of e-health systems in hospitals, clinics, nursing homes, e-health centers, rural health centers, even schools and prisons.

In recent years, wireless sensor network (WSN) has been utilized in various monitoring applications in military, banking and security services [6]. Based on these applications, researchers have utilized WSN for secured transmissions in medical fields [7]. Recently, it has been extensively utilized for the telemedicine and telecare applications due to its simplified operation and efficient throughput in improving quality of health care processes [8], [9]. Even the wireless multimedia sensor networks with efficient multi-path routing [10] can also be used. The affordable price of the personal computers and associated devices along with easy internet access has made it feasible to use WSN and other wireless networks in health care. However there are many limitations and challenges in power consumption and accuracy that need to be resolved to improve the efficiency [11]. This can significantly contribute towards the doctors to reduce their workload in analyzing the medical data of the patients. In this paper, a novel remote health care and telemedicine model has been developed using the wireless sensor networks for the transmission of patient data. Sensor nodes are placed at different points of the patient body to collect health data readings. These are combined into clinical records and transmitted through the gate-way using Autonomous optimized routing algorithm based on self-optimization concept [12] in wireless sensor networks. Transmitted data are collected and fed to the Processor containing the decision support system and clustering module where the ontology enabled clustering algorithms cluster and analyses the data with the previous patient data to determine the changes in health condition.

The clustering algorithms namely ontology based TF-IGM enriched semantic smoothing based clustering [13], chicken swarm optimization (CSO) based model and genetic-chicken swarm optimization (GCSO) based models for biomedical and clinical document clustering are utilized for this purpose. The clinical results analyzed in this stage along with suggestion for medications are forwarded to the e-health centers and/or physicians for approval before transmitting them to the patient care or medical staff attending the patients. The complete operation of this model is illustrated in this article. Section 2 provides brief discussion about the related works. Section 3 presents the methods discussed above while the proposed model is evaluated and the results are presented in section 4. Section 5 makes a conclusion about the work presented in this article.

II. METHODS

The proposed RRHT model of remote health care system consists of three main processes: patient data collection and processing, clustering and analyzing, and the decision approval process. Initially, the sensor nodes are placed at the patient body parts to collect the patient data which are combined into clinical records and transmitted from the gateway using Autonomous optimized routing algorithm of WSN. The clinical documents are collected and fed to the processor where the clustering is performed and decisions are made based on patient health data. The suggestions on medications are forwarded to the doctors at e-health centers for approval. This model of remote health care and telemedicine is provided in Fig. 1.

From the figure, it can be learnt that the decisions are not merely taken from the patients' health data received currently but also from the past data collected during previous medical treatments. The clustering of the documents is performed using the ontology based TF-IGM enriched semantic smoothing based clustering, CSO based model and GCSO based clustering models which were developed previously for efficient biomedical documents and clinical records clustering. Similarly, the routing of the clinical documents is performed efficiently by developing a novel Autonomous optimized routing algorithm based on the self-optimization concept.

A. Sensor nodes and data collection

The wireless medical sensor nodes are primarily utilized for monitoring and collecting various signals for the patients' body and then transmit the collected data to the destination node through the wireless radio frequency (RF). The wireless sensor nodes used in this purpose consists of Microcontroller unit (MCU), RF module, sensor module and the power supply module as described in [14].

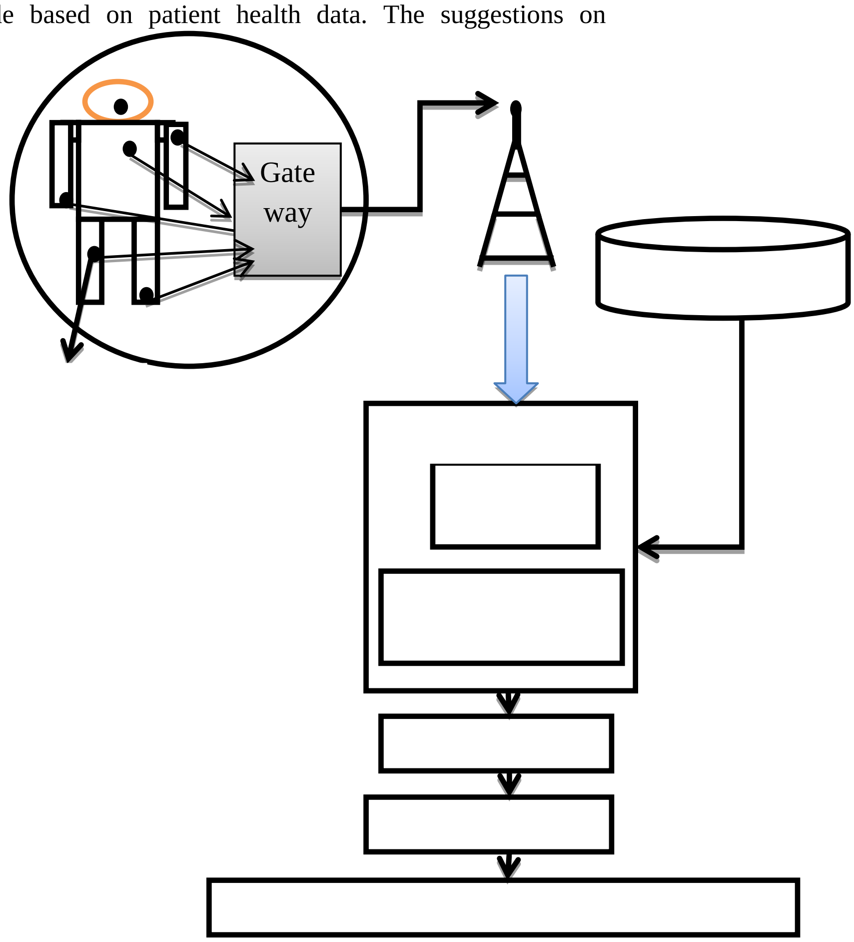

Fig.1. Ontology enabled clustering based remote health care and telemedicine model

With consideration of model cost and resource requirement, the 8bit 80C51MCU is employed as the MCU of the sensor nodes while nRF401 is used as the basic communication module. 80C51MCU has several analog-to-digital interfaces and I/O ports for easy programming and a watchdog timer for resetting the system when fault occurs. The reason for selecting nRF401 is because of its small size and low power consumption. Thus the utilized medical sensors have better performance than other sensor nodes.The sensor data are collected at the health care sink node which deals with the data from individual sensors and fuse them into clinical documents before for-warding to the central server or processing unit. The MCU of the sink node handles the data received from the patient medical sensors and also controls the functioning of the sink node. The RF module receives the data from the sensor nodes and is fused at the gateway by the sink node to form clinical documents. These documents are transmitted to the processor situated at distant location mostly in the distant health care centers in wireless medium using autonomous optimized routing algorithm.

B. Power consumption reduction scheme

The power consumption in a battery-operated sensor node can be reduced by setting the node to wake up once in specified duration to check the health parameter. This can satisfy the needs to consume as little power as possible in order to decrease the need for battery replacement. Many researchers have employed fuzzy approaches [15] which utilize a set of rules to find an effective solution that achieves the target while eluding complex and computationally costly solutions. In our proposed model of RRHT, network lifetime optimization can be accomplished with the reduction of packet transmission power and reduced data processing.

Energy consumption in WSN can be determined by three elements: sensing, processing and transmission of data. Energy consumption for sensing data can be computed by the specified characteristics of the node and determined by the device datasheet. Meanwhile, energy consumption for processing data for sensor node i and processing task k denoted as $E_{i,k}^{proc}$ can be computed which is directly proportional to the complexity of task k and to the average energy consumption per instruction in k of node I denoted as E_i^{ins}. It can be given as Eq. (1).

$$E_{i,k}^{proc} = I_k \times E_i^{ins} \tag{1}$$

Where I_k is the number of instructions needed to execute task k.

Similarly, the energy consumption for transmission can be computed based on the transmission and reception power consumption. Transmission power consumption and reception power consumption are given by Eq. (2), (3).

$$P_{i,j}^T = P_i^{T_0} + P_i^A(\delta_{ij}) = P_i^{T_0} + \frac{P_i^{T_x}(\delta_{ij})}{d_{ij}} \tag{2}$$

$$P_j^R = P_j^{R_0} \tag{3}$$

Where $P_{i,j}^T$ and P_j^R are power consumption values for transmitting and receiving respectively; $P_i^A(\delta_{ij})$ denotes the consumed power of Power amplifier depending on distance δ_{ij} between nodes i to j; $P_i^{T_0}$ and $P_j^{R_0}$ denotes the power consumption components of transmitter and receiver circuitries; $P_i^{T_x}$ represents the transmitting output power depending on δ_{ij} while d_{ij} denotes the drain efficiency of power antenna at node i.

Considering the channel with path loss component, the transmitted power $P_i^{T_x}(\delta_{ij})$ undergoes some modifications.

$$P_i^{T_x}(\delta_{ij}) = P_j^{R_x} \times A_{ij} \times \delta_{ij}^{\alpha PL} = \varphi_{ij} \times \delta_{ij}^{\alpha PL} \tag{4}$$

Where for reliable communication $\varphi_{ij} = P_j^{R_x} \times A_{ij}$ is the product of minimum reception power at node j with antenna parameter; αPL is the path loss component and A_{ij} is the antenna parameter defining gain and efficiency of antenna.

Substituting these modifications, the transmission energy per bit data at rate R from node i to j at transmitter ($E_{ij}^{T_x}$) and receiver ($E_j^{R_x}$) respectively, can be expressed as Eq. (5) & (6).

$$E_{ij}^{T_x} = \frac{P_{i,j}^T}{R} = \frac{1}{R}\left(P_i^{T_0} + \frac{\varphi_{ij} \times \delta_{ij}^{\alpha PL}}{d_{ij}}\right) \tag{5}$$

$$E_j^{R_x} = \frac{P_j^R}{R} = \frac{P_j^{R_0}}{R} \tag{6}$$

After computing the energy consumption values $E_{i,k}^{proc}$, $E_{ij}^{T_x}$ and $E_j^{R_x}$ for each data bit sensed, processed and transmitted, the fuzzy rules are applied to determine which command to be sent to the nodes based on input variables: throughput to workload and battery level. The main concept is to schedule the sleep of nodes that are on low energy or idle. Three membership functions (*Low*, *Medium*, *High*) are defined the input and output variables. The input variables ranges are determined with throughput to workload (0-100%) and battery level (0-1024 mWh) with smaller value to larger value (S to L). The main commands to the nodes are the sleep and wake-up. The sleep time is determined based on the above membership function and rules. In case of emergency, at the far end of network lifecycle when the number of dead nodes increases, the wake-up message is sent to wake a sleeping node to act as substitute until the dead node is recharged or replaced. This process helps in minimizing the overall power consumption and increases the network lifetime. The fuzzy inference approach requires minimal memory and energy but does not depend on batteries of the sensor nodes. These are powered through dynamic power source which generates power through the patient body heat and thus does not affect the WSN network model.

C. Ontology enabled clinical document clustering algorithms

This module is the vital cog in the healthcare system with implications on the overall output. The patient data are combined into documents or clinical records for transmission convenience which are transmitted with higher security using the autonomous self-optimized routing strategy in WSN.

Thus received data documents are normally in the form of patient health readings like heart beat rate/pulse rate, temperature distribution, respiration rate, etc. which is standalone readings that does not provide clear indication of disease or sickness specifically. Hence these data are needed to be clustered in such a manner to utilize for detecting abnormal health condition. The concept of ontology can provide better priority based semantic similarity relationship in clustering these patient data. The ontology enabled clustering algorithms utilized in this work are TF-IGM enriched k-means & hierarchical model, CSO based clustering and GCSO based clustering models.

Ontology based semantic smoothing models have been prevalent in the field that utilizes TF-IDF for term weighting while n-gram techniques are employed for phrase detection in the documents [16]. However, this model has certain drawbacks. The n-gram technique does not perform well when the original document has been modified and also it only considers fixed length phrases and as document size grows, dimensionality increases tremendously. The TF-IDF factor is not fully effective in text document classification and affects the overall accuracy while the semantic smoothing model is effective in handling Sparsity of words but not effective in handling the density of general words. These limitations have created the opportunity to develop efficient strategies.

The first model is the ontology based TF-IGM enriched clustering model [13] which is a hybrid of concept based approach & improved semantic smoothing model. This model utilizes TF-IGM factor and improved background elimination which improves the density handling of general words while also TF-IGM incorporates a new statistical model to precisely measure the class distinguishing power of a term across different classes of text in documents. As n-gram has problems in identifying the phrases, the modified n-gram are used which detects the cases of substitution and deletion in the documents and averts them for better phrase identification. The developed clustering strategy is employed on k-means and hierarchical clustering models for biomedical documents clustering and has found to improve accuracy significantly. The second model developed based on the chicken swarm optimization algorithm also utilizes TF-IGM and modified n-grams technique. Additionally it utilizes Part-of-speech (POS) tagging and concept mapping for determining phrases and mapping of similar concept patterns in the documents. However, the dimension of these document features are considerably higher and hence a dynamic dimension reduction technique is utilized which prune the non-useful text features along with dimension reduction. Finally, the CSO based optimized clustering model clusters the documents into their suitable classes.

From this clustered results, the patient data can be analyzed more effectively. The procedures involved in CSO based biomedical document clustering algorithm are given as follows:

1. Pre-process the input documents
2. Apply semantic annotation, POS tagging and concept mapping
3. Perform modified n-grams duplication removal and TF-IGM
4. Perform dynamic dimension reduction
    a. Compute dynamic document frequency for each documents
    b. When dynamic document frequency ≤ threshold, delete the document features
    c. Form new subset of features
5. Perform CSO clustering
    a. Compute fitness for each document set
    b. Rank the documents based on fitness
    c. Establish hierarchical order and cluster them into groups
    d. Determine relationships between documents based on similarity
    e. Update each cluster of documents
6. Return clustered document sets.

The third model is based on the ontology enabled genetic-chicken swarm optimization (GCSO) based clustering in which the semantic annotation, concept mapping and modified n-grams are employed as in CSO based model. This model additionally utilizes phrase-based detection method for detecting and avoiding redundant copies documents. The term weighting is performed using Length Feature Weight (LFW) scheme as it can improve the weights based on the new factors at the level of the document. Adaptive and dynamic dimension reduction is employed in the form of Multi-level Bhattacharyya distance based Dimensionality Reduction (MBDR). MBDR discovers elliptical clusters for more effective dimensionality reduction by using only the low-dimensional subspaces. MBDR is highly scalable in terms of data size and dimension and it is also dynamic and adaptive to insertions after which the optimized clustering is performed. By theoretical comparison, it was found that this model of biomedical document cluster is highly accurate than the former two models. The major reason for this development is the use of LFW and MBDR. The steps involved in GCSO based biomedical document clustering algorithm are given as follows:

1. Pre-process the input documents
2. Apply semantic annotation, POS tagging and concept mapping
3. Modified n-gram and phrase based duplication removal
4. Term weighting using LFW
5. Perform MBDR
    a. Model documents as data stream
    b. Compute Bhattacharyya distance and error rate for each data stream
    c. Analyze and sort sub-space features based on minimum Bhattacharyya distance
    d. Set threshold for Bhattacharyya based projection distance and error rate
    e. Reduce dimension for high dimension features
    f. Form new subset of features

6. Perform GCSO clustering
    a. Compute fitness for each document set
    b. Rank the documents based on fitness
    c. Select 2N best fitness documents and apply two-parent crossover and 20-50% mutation
    d. Re-rank documents based on fitness
    e. Establish hierarchical order and cluster them into groups
    f. Determine relationships between documents based on similarity
    g. Update each cluster of documents
7. Return clustered document sets

D. Decision support module and final approval

Once the clinical documents are clustered into respective classes, it will pave way for analyzing the measured reading for specified sickness. At this stage, the patient's past data collected during the previous trial is utilized along with an ideal measurement threshold data. The present data are compared with these data to determine the change in measurements of heart beat, temperature, etc. If the data readings are greater or lesser than past data but within the ideal threshold then some precautionary medications are suggested. When the patient readings compared are beyond the ideal threshold levels then the medications are suggested for curing and also the possible hospital visits are prescribed. In worst cases, the emergency treatment are also initiated with an alert to all respective teams of health centers, ambulances and also the family members of the patient. These suggestions are subject to approval from the physicians as fully automatic health care medication systems are still not completely acceptable in the medical fields. In this research, the blood pressure is considered for evaluation and hence the data are clustered and the BP readings are compared with that of patients' past data to evaluate the changes. Table 1 shows the treatment process [17], [18] suggested by the proposed RRHT decision support system for the BP patients connected in the remote health care system.

Based on this Table-I, the decision module prescribes the treatment process and respective medications. The medications suggested for the stage-1 and stage-2 hypertension with recommended doses for selected antihypertensive agents for outpatient management of hypertension in children and adolescents [17]-[21]. These prescriptions are solely provided only based on 2004 report by American Academy of Pediatrics [22] and are verified the doctors' prescriptions of medicine and not based on the brands or companies. The medications suggested are provided only through extensive research with the help of medical professionals and hence there is high reliability in the decision support system. Thus the proposed RRHT model reduces the travel expenses and trouble faced by the unhealthy patients in reaching the hospitals without even compromising the quality of treatment.

III. PERFORMANCE EVALUATION

The proposed RRHT application is evaluated in a constrained simulation environment in MATLAB to verify the theoretical expertise. The simulation settings are utilized as in [13]. The proposed RRHT model utilized biomedical document clustering algorithms in the form of CSO based clustering and GCSO clustering. The two models are compared with existing clustering models namely MSVM [23] and ELM [24] based models. The comparisons are made in terms of accuracy, precision and recall. The experimental validation process is performed for remote patients living 10–100 km away from the hospital server in a test environment.

Table-I: Decision module Treatment process for BP patients

Systole pressure mmHg	Diastole pressure mmHg	Level	Recheck	Prescription
120	80	Normal BP	1year	Nil
120-129	<80	Elevated BP	6months	Lifestyle changes
130-139	80-89	Stage 1 hypertension	2months	Starting dose
>140	>90	Stage 2 hypertension	1-4 weeks	Maximum dose
>180	>120	Hypertensive Crisis	Emergency	Direct to hospital

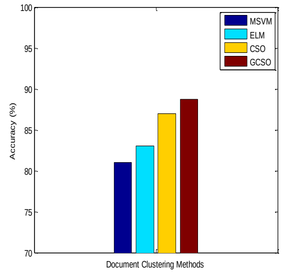

Fig.2. Clustering accuracy

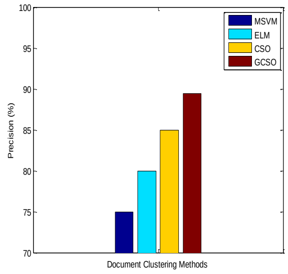

Fig.3. Clustering precision

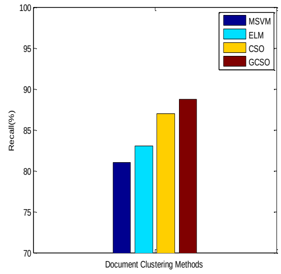

Fig.4. Clustering recall

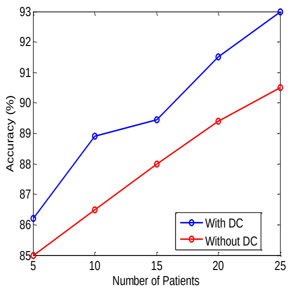

Fig.5. Accuracy with document clustering

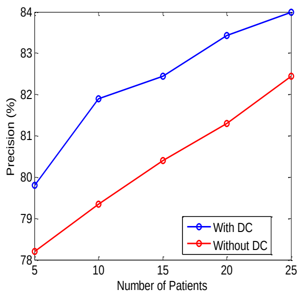

Fig.6. Precision with document clustering

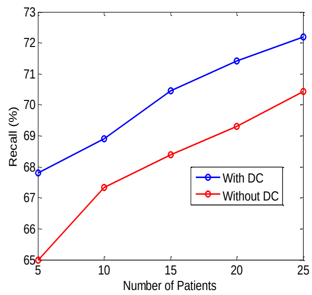

Fig.7. Recall with document clustering

Fig. 2 shows the clustering accuracy while Fig. 3 and Fig. 4 show the precision and recall of the clustering algorithms, respectively. It can be seen that the GCSO model has better performance with higher values of accuracy, precision and recall. It has around 2%, 4% and 2% higher values of accuracy, precision and recall, respectively than the CSO based model while the MSVM and ELM based clustering models have much lesser performance values.

Currently, there are many versions of remote health monitoring and telecare applications and the major difference in the proposed RRHT model is the utilization of document clustering concept. The influence of document clustering concept can be illustrated by comparing the RRHT model with and without using the document clustering algorithm in terms of accuracy, precision and recall.

Fig. 5, Fig. 6 and Fig. 7 respectively shows the accuracy, precision and recall of the RRHT with and without document clustering model. It can be seen that the use of document clustering improves the accuracy, precision and recall of the proposed RRHT application system. RRHT with document clustering achieves 3%, 2% and 2% greater accuracy, precision and recall than that without document clustering. In addition to the validation parameters, the RRHT has been evaluated in terms of time consumed for sending the collected patient data to the hospital and the time for sending and receiving alarm messages over WSN. Table 2 shows the average time taken for different processes in RRHT. Time for each process in the table is the average of 20 iterations.

The evaluation results prove that the RRHT can significantly improve remote healthcare application with the use of document clustering while the GCSO based document clustering has better performance among the clustering algorithms. From the experiments, it has also been found that one physician can observe 15–20 patients if exclusively appointed on proposed system; however, this number reduces to 5–12 patients if a physician is requested to monitor patients through recommended scheme along with regular patient treatment in hospital. Moreover, it is important to state that the number of patients depends on the condition of the patients in hospital as well as patients monitored by the recommended RRHT scheme.

Table-II: Average time for RRHT processes over WSN

Process	**Time (HH:MM:SS)**
Patient data into clinical documents	00:02:32
Clinical documents transmission over WSN	00:00:56
Document clustering and related processes	00:00:51
Decision support module analysis	00:00:23
Final verification by doctors	00:00:48
Description details to patients from hospital server	**00:00:21**
Emergency alarm message to patient location	**00:00:13**

IV. CONCLUSION

This paper proposed the development of RRHT for the telecare and telemedicine application for remote patients. This model employed the wearable sensors to collect data while WSN for transmission through autonomous optimized routing algorithm. The model employed ontology enabled document clustering algorithms for improving the detection of patient health data through efficient clustering of clinical records and subsequent comparison with past data.

The decision module detects the consistencies in the patient health data readings and suggested the suitable treatment process and/or medications. This model has been evaluated to determine its efficiency and the valid performance results proved that this model is highly efficient than most existing models in the lines of remote health monitoring and telemedicine. In future, this model is intended to include more disease detecting capabilities through high intelligent systems. It is also planned to build this model by tackling practical difficulties and increasing the accuracy of diagnosis.

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