A Smart Healthcare: Methods based on WBAN and Multi-engine Artificial Intelligence

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Abstract: Healthcare systems are promising solutions to improve medical services offered to patients suffering from chronic illness. The majority of the healthcare systems proposed in the literature are built to monitor and treat a single type of disease. In this paper, we propose an architecture of a Smart Healthcare System carried by a Wireless Body Area Network to supervise multiple diseases and promote the diagnosis and reactions to occurred health anomalies. We also implement a multi-engine artificial intelligence allowing the correlation between the different occurred anomalies related to multiple diseases. Forward and backward reasoning were also integrated to handle the early detection of anomalies and the provision of medical explanations of occurred health situations, respectively. A case study exemplifying our proposal were also detailed.

1 INTRODUCTION

Healthcare systems promoted great development to medicare services and brought immense benefits to human being. In particular, they have enabled the improvement of the life quality of patients suffering from chronic diseases, since they provide continuous surveillance of their health status independently of their locations. The concept of Wireless Body Area Network (WBAN) highlights efficient technologies for such systems. A WBAN is a network of wearable devices, which can be either implanted in the patient's body or placed on a fixed body position. It allows the surveillance of the patient's health status and the delivery of appropriate therapies, when required.

Multiple research works addressed the design of WBAN based healthcare systems and discussed the suitable communication technologies. An overview of these proposals will be provided in the sequel. The majority of the proposed healthcare systems exhibit a set of limits. First, the capacity of these systems in supervising and managing various parameters is reduced. This is due to the lack of suitable techniques allowing WBAN to firstly filter, merge and aggregate the sensory data it collects and then to reason and interpret aggregated data, to detect healthcare anomalies. Second, the majority of healthcare systems allow the supervision of a single type of diseases. In particular, they do not implement techniques allowing the assessment of the interdependence of the evolution of multiple physiological parameters related to different diseases. Nevertheless, sometimes it becomes crucial to monitor and treat multiple diseases, especially that a patient could suffer from multiple chronic diseases and may need the supervision of multiple physiological parameters; therefore, he/she may carry multiple medical devices. Third, the WBAN based healthcare systems exhibit the absence of communication technologies allowing the intra-nodes communication when the WBAN integrates Implantable Medical devices (IMDs), especially that such a communication improves the efficiency of IMDs in detecting occurred anomalies and delivering the suitable therapies.

We propose in this paper to design a healthcare system which allows: handling near real time[1] event diagnosis, enabling early detection of anomalies, reporting health information, and contributing to the remote reactions to occurring events. This requires the WBAN to be equipped with a certain extent of intelligence related to multiple disciplines. This can be achieved thanks to the use of a multi-engine artificial intelligence allowing the diagnosis of multiple diseases. In fact, every single-engine performs the diagnosis of a single disease. The WBAN can then

[1]Near real time means real time with a small delay which allows the achievement of the diagnosis related to occurred events and does not exceed a predefined threshold.

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infer the decisions suitable to detected anomalies by operating the inter-operation of the engines. The decisions obtained are achieved through multiple inference rules, multi-point measures, and a variety of expert knowledge about pathologies.

The paper contribution is three-fold. First, we propose an architecture of a smart healthcare system carried by a WBAN, which integrates heterogeneous wearable and implantable medical devices and sensors, to supervise multiple diseases and promote the diagnosis and reactions to occurred anomalies. Second, we implement a multi-engine artificial intelligence, to allow analyzing the interdependence between the evolution of measured parameters and the health anomalies occurrence, and correlating between the different occurred anomalies related to multiple diseases. Third, we integrate the use of a smart central node which implements the multi-engine artificial intelligence. This node integrates at least two communication interfaces to ensure the data exchange between: the IMDs and the nodes part of the WBAN, and between the WBAN and a remote supervision system.

The remaining part of the paper is organized as follows. Section 2 provides a literature review of the developed WBAN based healthcare systems and presents the requirements of an efficient healthcare system. In Section 3, we detail the proposed architecture of the healthcare system. Section 4 illustrates the implementation of the multi-engine artificial intelligence. In Section 5, we present a case study exemplifying our proposal. Section 6 concludes the paper.

2 OVERVIEW OF HEALTHCARE SYSTEMS

This section reviews WBAN based healthcare systems and highlights the main requirements.

2.1 Literature Review

Because of the life-staining functions they can provide to patients, several research works addressed the design of WBAN based healthcare systems. For instance, a body sensor network for the detection of a cardiac arrhythmia, namely Atrial Fibrillation (AF), was proposed in (AlMusallam and Soudani, 2019). This system uses a smart electrocardiogram (ECG) sensor to detect AF episodes and to send alerts to the base station. This proposal can only detect a single type of arrhythmia, which makes it inefficient. Indeed, a patient could suffer from multiple arrhythmia. In (Sahoo et al., 2018), a healthcare system for the detection of multiple arrhythmia was proposed. This system supervises the non-invasive seismocardiogram and the ECG signals, to guarantee a reliable detection of arrhythmia. However, it does not consider the case when the patient carries an IMD (e.g., cardiac defibrillator) treating detected arrhythmia.

A healthcare system for diabetic patients was proposed in (Alfian et al., 2018). This system measures the patient's vital sign and transmits the sensed data to a remote server, which performs data processing to predict diabetes and blood glucose level, using machine learning methods. Another healthcare system to manage Bipolar disease, was proposed in (Valenza et al., 2016). This system implements a methodology allowing it to assess the patients mood status and predict mood changes based on heartbeat dynamics.

All of the presented healthcare systems provide the supervision of the patient's health status, to manage a single disease. Some of these proposals allow the prediction of anomalies, while others only provide the real time detection . Moreover, these systems exhibit the lack of proactive techniques allowing them to respond to the detected anomalies. The only reaction consists in notifying healthcare professionals. In particular, no one of these systems discusses the integration of medical devices to enable delivery of the suitable treatments when detecting anomalies.

Multiple research works reviewed the communication technologies for a WBAN based healthcare system and discussed their efficiencies. In (Teshome et al., 2018), the authors reviewed the progress of communication technologies of implants (devices which are surgically implanted, ingested, or injected in the patient's body). The authors in (Rizwan et al., 2018) reviewed the nano-sensors integrated in WBANs together with the nano-communication networks intended for healthcare applications. They highlight the need of robust solution ensuring a nano-communication in large-scale nano-networks.

2.2 Healthcare System Requirements

To provide an efficient supervision and control, the healthcare system should at least fulfill the following requirements. First, it should guarantee continuous and real-time surveillance of the patient's physiological parameters. Indeed, the suspension or the delaying of the surveillance of any parameter could lead to an erroneous evaluation of the health status. This makes the system unsafe, since an erroneous evaluation induces the absence or the inappropriate delivery of treatments, which could cause harms to the patient.

Second, the healthcare system should allow managing multiple diseases. For this, various physiological parameters need to be monitored. This could be

Table 1: Comparison between healthcare systems.

Healthcare systems	Monitored parameters	Anomalies detection	Reactions to detected anomalies	Diseases Control
(AlMusallam and Soudani, 2019)	Single	Real time detection	Absence	Single
(Sahoo et al., 2018)	Multiple	Real time detection	Alerting	Single
(Alfian et al., 2018)	Multiple	Real time and early detection	Alerting	Single
(Valenza et al., 2016)	Multiple	Real time and early detection	Absence	Single
Our system	Multiple	Real time and early detection	Alerting and therapies delivery	Multiple

achieved through the integration of multiple types of biomedical sensors and medical devices in the WBAN part of the healthcare system. Moreover, the system should also enable the analysis and the processing of collected data, to provide an accurate evaluation of the health status, whatever the supervised diseases.

Third, for safety purposes, the healthcare system should promote the early detection of critical health status. In particular, such a functionality would allow the system to apply the suitable reactions in order to prevent the occurrence of the critical health status.

Fourth, the healthcare system should promote the delivery of proactive reactions to occurred anomalies. This could be achieved through the integration of medical devices, which guarantee the delivery of treatments, suitable to the detected anomalies. Moreover, the healthcare system should also implement proactive techniques allowing it to generate the suitable decisions to be implemented by these devices.

Table 1 provides a summary comparison of the presented healthcare systems. Based on this table, we notice that our system provides several enhancements in comparison to the other systems. First, like some healthcare systems, our system offers, not only the real time detection, but also the early detection of anomalies. Second, further the delivery of alerts, our system enables the implementation of proactive reactions by delivering therapies. Third, our healthcare system allows controlling multiple diseases. Such a function is not provided by the other systems.

3 ARCHITECTURE OF A SMART WBAN BASED HEALTHCARE SYSTEM

The purpose of this section is to present the architecture of the proposed healthcare system.

3.1 Healthcare System Architecture

The healthcare system architecture integrates two components (WBAN and remote supervision system) which interact via public communication networks.

Wireless Body Area Network (WBAN). It consists of interconnected nodes, which are carried or implanted into the patient's body. Based on their functions, we distinguish three types of WBAN nodes:

Biomedical Sensors: They measure physiological parameters and collect vital signs. The data they gather are wirelessly sent to the central node, using Bluetooth Low Energy (BLE) protocol, for example.

Medical Devices: Based on the sensed prameters, a medical device detects anomalies and treats them by delivering the suitable therapies. It also sends data describing detected anomalies and delivered therapies to the central node using the Medical Implant Communication System (MICS) band, and it implements the decisions received from the central node.

A central Node: It acts as a gateway between the WBAN nodes and the remote supervision system, to exchange data (i.e., physicians queries, health status, and sensory data). It also provides a set of features. First, it analyzes the data received from WBAN nodes. Second, it ensures the early detection of anomalies and generates the suitable decisions to them. Third, it sends the generated decisions to the RSS to be validated by physicians, then it sends them to the medical devices to be implemented through therapies delivery. Fourth, it provides medical explanations of occurred anomalies. Such features provide a certain degree of autonomy to the WBAN, since they allow it to react to occurred critical situations and rescue patients until receiving medical assistance.

A WBAN may integrate a central node and a single IMD. The selection of IMDs depends on the controlled diseases. For instance, to manage heart failure, we use an implantable cardiac device, which includes its appropriate sensors (e.g., cardiac sensors). Nevertheless, to increase visibility and ameliorate the accuracy of the detection and reaction to occurred anomalies, multiple biomedical sensors may be integrated.

Remote Supervision System (RSS). It integrates a dedicated server and a thin client interface. The dedicated server integrates: a remote database to store the patient's health status; and a data analysis and processing module to perform an advanced data processing. In this research work, we propose that the data analysis and processing module is equipped with an advanced extent of intelligence related to multiple disciplines, so that it can assist physicians in validating the decisions generated by the central node or generating new decisions. The client interface allows physicians to access to the dedicated server functionalities and exchange data with the WBAN.

In the proposed healthcare system, we distinguish two interaction scenarios between the WBAN and the RSS. The first scenario is initiated by the central node, when detecting anomalies, to send alerts (which include the health status description) to the RSS together with the generated decisions to be validated. The second interaction scenario is initiated by the RSS to: collect health status data, request medical explanations about an occurred anomaly, or to perform a regular diagnosis by requesting real time sensory data.

3.2 Artificial Intelligence (AI) for Smart WBAN

In this subsection, we detail the architecture of the healthcare system, depicted in Figure 1, together with the AI implementation within the WBAN .

Data Processing and Analysis. Due to the limited energy resources and computational capabilities at the WBAN nodes level, the analysis and processing of health data is performed at three levels using specific data processing and analysis techniques. The *first level* is provided thanks to the data processing and analysis module, which is integrated at the biomedical sensors and medical devices levels. This module converts the large volume of data (e.g., values, signals) it receives from the sensing module into a usable information (e.g., features, states), eliminates duplicates, and stores them into its local database.

The *second level* refers to the data processing analysis module part of the central node. This module periodically collects data from sensors and medical devices and then transforms them into health status. A health status $\mathcal{S}_i = \{s_1, s_2, ..., s_n\}$ consists of heterogeneous simple medical states (e.g., hypoglycemia, hyperkalemia), where a simple medical state, say s_i, provides an overview of an event occurred in a specific organ of the body. When identifying a health status, this module records it in the health status database and notifies the multi-engine inference module.

The *third level* refers to the data processing analysis module part of RSS. This module collects health records from the central node and performs to them an advanced analysis to provide data showing the progression of the patient's health status. It also allows assisting physicians in validating received decisions.

Health Databases. Three types are distinguished:

Local Database: it is integrated in the architecture of sensors and medical devices in the form of nonvolatile memory. It only stores recent sensory and acting data, due to its limited memory space.

Health Status Database: it is part of the central node architecture allowing the storage of health status records. Each time the data processing and analysis module of the central node identifies a new health status $\mathcal{S}_i$, it records it in the health status database, together with a time stamp, say t_i, which is the instant of the identification of $\mathcal{S}_i$. Therefore, a health status record, say H_i, takes the form: $H_i = (\mathcal{S}_i, t_i)$. Due to the limited memory space of the health status database, the latter selects health records showing an old time stamp and overwrite them to store recent records.

Remote Health Database: it is integrated in the RSS architecture to store the health records processed by the data processing and analysis module part of the RSS. It ensures a long-term storage of data.

Multi-engine Inference. This module is part of the central node architecture. It ensures the execution of the forward and backward reasoning. Forward reasoning allows the early detection of critical health status. It starts from a current health status, which is identified by the data processing and analysis module, and uses the libraries of rules and hypothesizes to predict health status that could occur. Backward reasoning enables the provision of medical explanations of an occurred critical health situation. It starts from a detected critical health status and infers rules to generate plausible medical scenarios. A description of the reasoning methods will be provided in the sequel.

Knowledge Base It is integrated in the central node architecture. It includes three libraries namely, hypothesizes, medical rules, and decision rules. The hypothesizes and the inference rules of these libraries are built based on the expertise of physicians and retrieved from the RSS. They are crucial for the well functioning of the multi-engine inference module, since they allow it to execute the reasoning methods.

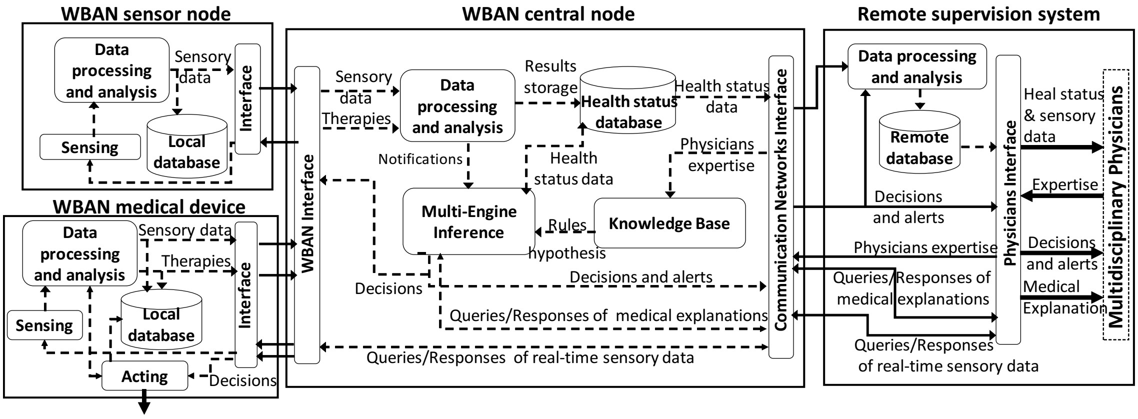

Figure 1: Healthcare system architecture.

4 MULTI-ENGINE ARTIFICIAL INTELLIGENCE

In this section, we detail the AI implementation in the proposed WBAN based healthcare system.

4.1 Hypothesis and Inference Rules

In this subsection, we model hypothesizes and inference rules (medical and decision rules) through the use of heterogeneous simple medical states. Two types of simple medical states can be distinguished: a) observable state (e.g., ventricular arrhythmia), which refers to a state that can be evaluated by senors or by medical devices; and b) unobservable state (e.g., intracellular Ca^{2+}), which cannot be measured neither by senors nor medical devices. Unobservable states are identified based on the physicians expertise.

***Hypothesizes*:** Some diseases could contribute to the occurrence of specific medical states. This information can be modeled through hypothesizes. An hypothesis (Ht) takes the following form: $CD \overset{High risk of}{\rightarrow} S$, where CD refers to a Chronic Disease and S is a conjunction and/or disjunction of simple medical states. Such hypothesis means that a patient who exhibits CD is highly vulnerable to the occurrence of S.

***Medical Rules*:** A Medical Rule (MR) is modeled as follows: $S \rightarrow_T S'$, where S (as well as S') represents a conjunction and/or disjunction of simple medical states. Such a rule means that the occurrence of S leads to the occurrence of S', within a time period T.

***Decision Rules*:** As discussed previously, our healthcare system allows generating decisive decisions to rescue a patient when detecting a critical health status. To do so, a set of decisions rules are used. A Decision Rule (DR) is modeled as: $S \rightarrow D$, where S represents a conjunction and/or disjunction of medical states and D represents a conjunction and/or disjunction of simple decisions. The meaning of such a decision rule is when detecting S applies D. Two types of simple decisions can be distinguished: a) decisions sent to medical devices after being validating to be implemented in the form of therapies; and b) decisions sent to the RSS in the form of alerts.

4.2 Forward Chaining

Forward reasonning is implemeneted, to provide early detection of anomalies. It starts from: a) a current patient's health status, which is identified by the data processing and analysis module part of the central node; and b) a set of rules retrieved from the knowledge base. When applying forward chaining, multiple conclusions describing the subsequent health status can be generated. The output of such a reasoning is a tree, which includes: a root node representing the current health status of the patient, say $\mathcal{S}_0$, and a set of nodes representing the generated conclusions, which refer to the predicted health status. Assuming that $\mathcal{S}_i$ is a health status represented by a node in the tree under construction. Starting from $\mathcal{S}_i$, rules are executed in forward chaining as follows. For every inference rule, which can be in the form $S \rightarrow_T S'$ (or $S \rightarrow D$) within the knowledge base: if its premise S is part of $\mathcal{S}_i$ (i.e., $S \sqsubseteq \mathcal{S}_i$), then a node, say $\mathcal{S}_j$ (or D_j, respectively), which represents the consequence of the rule S', is appended to the tree (if it does not exist), and then linked to the node $\mathcal{S}_i$. Such a process is repeated until: none of the inference rules within the knowledge base can be executed; or a new current health status is identified. In this case, forward chaining is restarted, to begin its reasoning from the new status.

Each time, a node representing decisions is created, the central node reacts by alerting the RSS. The physicians can then validate received decisions, adjust them or generated new ones through the RSS. According to the received RSS response, the central nodes applies the decisions. These decisions allow the WBAN to react by even preventing the anomaly occurrence or by treating it when it occurs.

4.3 Backward Chaining

To provide a medical explanation of an occurred health status, a backward reasoning is implemented. Such a reasoning starts from a detected critical health status, say $\mathcal{S}_c$, and executes inference rules in backward chaining, to generate a set of plausible medical scenarios. The generated scenarios satisfy the health status progression over time, and take the form of a tree, whose root node represents $\mathcal{S}_c$. We denote by $\mathcal{H} = \{H_1, H_2, ..., H_i, ..., H_c\}$ the health records showing the health status progression, which are retrieved from the health status database, where H_c is the record describing $\mathcal{S}_c$, and H_1 is the oldest record in the database. The construction process of medical scenarios is detailed as follows. Assuming that $\mathcal{S}_i$ is a node representing a health status in the tree under construction. Starting from $\mathcal{S}_i$, a medical inference rule ($S \rightarrow_T S'$) retrieved from the knowledge base can be executed in backward only after verifying whether the two following conditions are met: a) The consequence S' in the rule is part of $\mathcal{S}_i$ ($S' \sqsubseteq \mathcal{S}_i$); and b) If the premise S is observable (i.e., S is a conjunction and/or disjunction of observable medical states), then S should be part of the health status $\mathcal{S}_{i-1}$ immediately preceding the health status $\mathcal{S}_i$ in the health records $\mathcal{H}$ and occurring no earlier than the time period T (i.e., $S \sqsubseteq \mathcal{S}_{i-1} \wedge t_i - t_{i-1} \geq T$). If a rule is executed, a node representing $\mathcal{S}_{i-1}$ (if S is observable) or S (if S is unobservable) is appended to the tree and linked to $\mathcal{S}_i$.

Inferring rules in backward is repeated until one of these two conditions is met: none of the inference rules within the knowledge base can be executed; or the oldest record H_1 in $\mathcal{H}$ has been included in the tree. These two conditions allow ensuring the termination of the chaining process. Indeed, backward chaining is a finite process whose iteration numbers depend on the number of the inference rules in the knowledge database and the number of collected health records. Moreover, to prevent the occurrence of loops, we propose to limit the execution of inference rules, whose conditions and premises only include unobservable medical states, to a threshold.

When the inferring process terminates, some hypothesizes can be retrieved from the knowledge base to explain the occurrence of some health status.

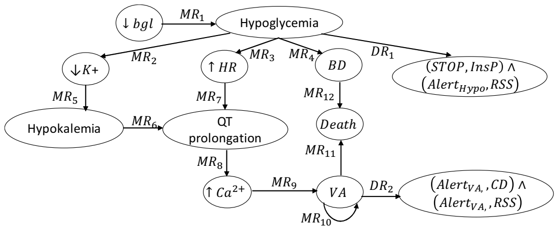

Figure 2: Tree of predicted health states.

5 CASE STUDY

In this section, we present a case study to exemplify the functioning of the proposed system.

Architecture Description. We assume that the supervised patient suffers from heart failure and diabetes. To this end, the WBAN should at least include: a) *Two medical devices*: an Insulin Pump (*InsP*) to supervise and control diabetes by regulating the blood glucose level (bgl); and an Implantable Cardiac Defibrillator (*ICD*) to treat the heart failure disease by reacting to the occurred arrhythmia. These two devices are currently available in the market; b) *A set of biomedical* sensors, which are available in the market, including glucose, heart rate, ECG, and potassium sensors; and c) *A central node* which integrates in its knowledge base a set of hypothesis and inference rules to control diabetes and heart failure. We assume that knowledge base includes at least: hypothesis, medical rules and decision rules detailed in Tables 2, 3 and 4, respectively. Some of the medical rules presented in Table 3 were inspired from the research work developed in (Ellouze et al., 2017).

Forward Chaining for the Early Detection of Critical Health Status. At the instant t_i, the data processing and analysis module generates and stores a health record H_i (Table 5) in the health status database, and notifies the multi-engine inference module . Then, the latter executes the forward reasoning starting from H_i.

Starting from H_i, which showed the decreased blood glucose level, the multi-engine inference module retrieves the rule MR_1 and executes it in forward, since its premises corresponds to s_4 part of H_i. After that, it retrieves the rules MR_2, MR_3, MR_4 and DR_1, and then executes them. By executing DR_1, the multi-engine inference module sends an alert to the RSS to notify it about predicted anomaly and the decisions it generates. After receiving decisions validation, it orders the Insulin Pump to stop insulin injection. Later,

Table 2: Example of Hypothesizes.

Hypothesizes	Descriptions
$(Ht_1) : DM \overset{High risk of}{\rightarrow} Hypo$	(Ht_1) and (Ht_2) state that a patient suffering from Diabetes Mellitus (DM) or Type 1 Diabetes ($T1D$) has a high risk of Hypoglycemia ($Hypo$).
$(Ht_2) : T1D \overset{High risk of}{\rightarrow} Hypo$	

Table 3: Examples of heterogeneous medical rules.

Medical Rules	Descriptions
$(MR_1) : \searrow bgl \rightarrow_T Hypo$	(MR_1) states that the decrease of the blood glucose level ($\searrow bgl$), leads to Hypoglycemia ($Hypo$), within avperiod T.
$(MR_2) : Hypo \rightarrow_T \searrow K^+$	(MR_2), (MR_3) and (MR_4) state that $Hypo$ leads to the decrease of the serum potassium concentration ($\searrow K^+$), the increase of Heart Rate ($\nearrow HR$), or Brain Death (BD), respectively, within a period T.
$(MR_3) : Hypo \rightarrow_T \nearrow HR$	
$(MR_4) : Hypo \rightarrow_T BD$	
$(MR_5) : \searrow K^+ \rightarrow_T Hypokalemia$	(MR_5) states that $\searrow K^+$ leads to Hypokalemia, within a period T.
$(MR_6) : Hypokalemia \rightarrow_T QT prolong$	(MR_6) states that the occurrence of Hypokalemia leads to the prolongation of the QT interval ($QT prolong$) within a time period T.
$(MR_7) : \nearrow HR \rightarrow_T QT prolong$	(MR_7) states that an increased heart rate leads to the prolongation of the QT interval within a given period of time T.
$(MR_8) : QT prolong \rightarrow_T \nearrow Ca^{2+}$	(MR_8) states that the occurrence of a QT prolongation induces the increase of the intracellular Ca^{2+} within a period of time of length T.
$(MR_9) : \nearrow Ca^{2+} \rightarrow_T VA$	(MR_9) states that an increased intracellular Ca^{2+} leads to the occurrence of Ventricular Arrhythmia (VA), within a period T.
$(MR_{10}) : VA \rightarrow_T VA$	(MR_{10}) states that the occurrence of a VA leads to the occurrence of another VA within a period of time of length T.
$(MR_{11}) : VA \rightarrow_T Death$	(MR_{11}) and (MR_{12}) state that the occurrence of a fatal VA or BD, respectively, induces the patient's death within a time period T.
$(MR_{12}) : BD \rightarrow_T Death$	

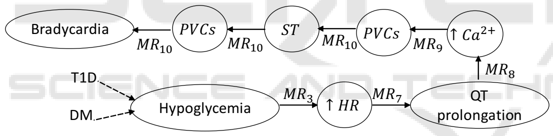

Figure 3: Medical explanation of Bradycardia occurrence.

it retrieves the rules MR_5, MR_7, and MR_{12} and executes them, since their premises corresponds to the consequences of the rules MR_2, MR_3 and MR_4, receptively. After the execution of MR_6, MR_8 and MR_9, the rules MR_{10}, MR_{11}, and DR_2 are executed. To apply the decisions of DR_2, the multi-engine inference module sends a notification to the ICD and the RSS to notify them about the occurrence of VA. The forward reasoning results is depicted in Figure 2.

Medical Explanations of an Occurred Health Anomaly. To exemplify the reasoning allowing the provision of medical explanations of an occurred anomaly, we use an example of health status progression from hypoglycemia to Bradycardia, which was showed in (Reno et al., 2013). We assume that this health progression occured within a supervised patient. When receiving an alert related to Bradycardia detection from the central node (more precisely from the multi-engine inference module), the physicians request medical explanations through the delivery of a specific request. Upon request reception, the multi-engine inference module collects health records $\mathcal{H} = \{H_1, H_2, H_3, H_4, H_5, H_6, H_7\}$ from the health status database, where H_7 is the record showing Bradycardia, and H_1 is the oldest record in the database. Table 2 details the contents of collectd records. After that, the multi-engine inference module executes the backward reasoning. Starting from H_7, it retrieves the rule MR_{10} from the knowledge database and executes it in backward three times, since the consequences and the premises of this rule correspond to Bradycardia, PVCs, and ST, which are three types of VA occurred in H_7, H_6,H_5, and H_4. Since $\uparrow Ca^{2+}$ is an unobservable state that cannot observed in health records, the inference module executes MR_9 in backward. After that, it retrieves and executes MR_8, as its premises corresponds to a QT prolongation which occurred in H_3. Later, since an increased heart rate was occurred in H_2, the rule MR_7 is executed. Finally, the multi-engine inference module executes MR_3, since hypoglycemia, which is its premises, occurred in H_1. To explain hypoglycemia occurrence, hypothesizes Ht_1 and Ht_2 are used. Upon completing the construction of the medical explanations (Figure 3), the multi-engine inference module sends it to the physicians as a response to the received request.

Table 4: Examples of decision rules.

Decision rules	Descriptions
$DR_1 : Hypo \rightarrow (Alert_{Hypo}, RSS) \wedge (STOP, InsP)$	When Hypoglycemia occurs, sends an alert to the *RSS* and then orders Insulin Pump to stop insulin injection.
$DR_2 : VA \rightarrow (Alert_{VA}, ICD) \wedge (Alert_{VA}, RSS)$	When *VA* occurs, sends an alert to the *ICD* and to the *RSS* to notify them about *VA* occurrence.

Table 5: Part of health records collected at the instant t_i.

	Time stamps	s_1 (ECG)	s_2 (HR)	s_3 (QT)	s_4 (bgl)
H_i	t_i	Normal sinus rhythm	Normal	Normal	Decreased

Table 6: Part of health records collected after the instant t_7.

	Time stamps	s_1 (ECG)	s_2 (HR)	s_3 (QT)	s_4 (bgl)
H_1	t_1	Normal sinus rhythm	Normal	Normal	Hypoglycemia
H_2	t_2	Normal sinus rhythm	Increased	Normal	Hypoglycemia
H_3	t_3	Premature Atrial Contractions (PACs)	Increased	Prolongation	Hypoglycemia
H_4	t_4	Premature Ventricular Contractions (PVCs)	Increased	Prolongation	Hypoglycemia
H_5	t_5	Sinus Tachycardia (ST)	Increased	Prolongation	Hypoglycemia
H_6	t_6	PVCs	Increased	Prolongation	Hypoglycemia
H_7	t_7	Bradycardia	Increased	Prolongation	Hypoglycemia

6 CONCLUSION

In this paper, we focused on the design of a Smart Healthcare System carried by a WBAN which allows managing multiple types of chronic diseases. The proposed architecture of the healthcare system integrates heterogeneous components to promote the supervision of multiple types of diseases. It is also equipped by a certain extent of intelligence related to multiple discipline allowing it to appropriately diagnosis anomalies and react to them. In particular, a set of inference rules and hypothesizes together with two reasoning methods are used. A case study to exemplify the functioning of the proposed healthcare system were also detailed.

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